Institute of Sound
and Vibration Research

UNIVERSITY OF
Southampton

MoViC 2016: Motion and Vibration Control
RASD 2016: Recent Advances in Structural Dynamics

3-6 July 2016
Southampton, UK

MoViC
RASD
2016

Proceedings of the

XIII International Conference on Motion and Vibration Control

XII International Conference on Recent Advances in Structural Dynamics

Edited by

E Bonisoli, Politecnico di Torino, Italy
M J Brennan, Universidade Estadual Paulista, Brazil
N S Ferguson, University of Southampton, UK
P Forte, University of Pisa, Italy
M Ghandchi Tehrani, University of Southampton, UK
M Hirata, Utsunomiya University, Japan
B R Mace, University of Auckland, New Zealand
J M Muggleton, University of Southampton, UK
K Nakano, University of Tokyo, Japan
A R Plummer, University of Bath, UK
P Rapisarda, University of Southampton, UK
E Rustighi, University of Southampton, UK
D Stoten, University of Bristol, UK
K Sweitzer, Booz Allen Hamilton, USA
J Tang, University of Connecticut, USA
D J Thompson, University of Southampton, UK
L N Virgin, Duke University, USA
T P Waters, University of Southampton, UK
C Zang, Nanjing University of Aeronautics and Astronautics, China
Z Zhang, Shanghai Jiao Tong University, China

Southampton, United Kingdom
3-6 July 2016

SALE OF PROCEEDINGS

Copies of the proceedings can be purchased from:

Dynamics Group
Institute of Sound and Vibration Research
University of Southampton
Highfield
Southampton
SO17 1BJ
United Kingdom

E-mail: isvr@southampton.ac.uk

NOTICE

The contents of these proceedings have been produced from author-typed manuscripts. The authors are solely responsible for the technical content and opinions expressed therein. The opinions are not necessarily those of the conference organisers.

International Standard Book Number 9780854329939

Printed by The Print Centre, University of Southampton, Southampton, United Kingdom.

Organisation

Chair

Emiliano Rustighi and Neil Ferguson

Organising Committee and Proceedings Editors

Elvio Bonisoli
Michael Brennan
Paola Forte
Maryam Ghandchi Tehrani
Mitsuo Hirata
Brian Mace
Jennifer Muggleton
Kimihiko Nakano
Andrew Plummer
Paolo Rapisarda
David Stoten
Karl Sweitzer
Jiong Tang
David Thompson
Lawrie Virgin
Timothy Waters
Chaoping Zang
Zhiyi Zhang

Conference Secretariat

Glen Martin

Institute of Sound and Vibration Research, University of Southampton,
Southampton, UK

PREFACE

On behalf of the Organising Committee, it is a pleasure to welcome you to Southampton for the Thirteenth International Conference on Motion and Vibration Control (MoViC), together with the Twelfth International Conference on Recent Advances in Structural Dynamics (RASD). MoViC is an event that started in Yokohama, Japan in 1992 and has been organised every two years alternating between Japan, USA and Europe. The eleven previous RASD conferences have been held every three years or so since 1980 primarily in Southampton, UK. The idea of joining the two conferences came quite naturally because of the common ground of the two conferences and the chances of cross-pollination between two otherwise separate research groups.

This joint conference is then devoted to theoretical, numerical and experimental developments in motion/vibration/structural dynamics, their control and application to all types of structures and dynamical systems. The conference will reflect the state-of-the-art in these topics, and is an excellent opportunity to exchange scientific, technical and experimental ideas.

The Conference Proceedings include over 250 papers by authors from over 20 countries and are contained on a USB memory stick attached to your lanyard. You will find this inside the conference folder together with the book of abstracts which may help you in planning your conference. There is a full programme over the three days with forty sessions covering several topic areas, so there should be something of interest for everyone. All submitted papers have been carefully peer-reviewed and the level of this conference edition is of extremely high quality. The proceedings will be published in the Journal of Physics: Conference Series.

The presentations will take place in Building 46 (Physics) and Building 44 (Shackleton) on the University of Southampton Highfield Campus. Registration will take place from 17:00 to 19:00 on Sunday 3 July in Garden Court of Building 40 (Staff Social Club). Further registration will take place from 08:00 on Monday 4 July. The five lecture theatres being used are lecture theatres A, B and C in the Physics Building and lecture theatres A and B in the Shackleton Building. There will be exhibition stands in the Physics Building Foyer. Tea and coffee will be served in the Physics Building Foyer and in the Shackleton Building outside Lecture Theatre A. Lunch will be served in Garden Court of Building 40. Please refer to page 137 for a map of all these locations.

Following the afternoon session on Monday, there will be a reception and barbecue in Building 38 (Staff Social Club). The reception is for all delegates and accompanying persons. Please ensure you wear your name badge during the conference sessions and social events. On Tuesday evening there will be a conference dinner at Beaulieu National Motor Museum. Coaches will depart from the coach bays at the Highfield Campus Interchange from 18:00.

I would like to thank members of the Organising Committee for their help, over the last year or so, in shaping the conference and for their invaluable assistance in the paper review process. I would also like to thank the conference secretary, Glen Martin, without whom there would be no conference. Lastly, I would like to thank all delegates for supporting the conference – I hope that it will be a success.

On behalf of the Organising Committee, I would like to wish everyone an enjoyable conference and a pleasant stay in Southampton.

Emiliano Rustighi

CONTENTS

PLENARY PAPERS **Page No.**

Contents

Active Vibration Control

Contents

Analytical Methods

Contents

ANTARES-EMVEM

Biomechanics and Human-Machine Interface

Contents

Civil Engineering Structures

Control of Civil Infrastructures

Contents

Control Theory

Damage Detection and Structural Health Monitoring

Contents

Contents

Energy Harvesting

Experimental Techniques

Fluid-Structure Interaction

Contents

Modal Analysis and Structural Modification

Nonlinear Vibrations

Contents

Contents

Numerical Methods

Railway Induced Noise and Vibration

Contents

Rotor Dynamics and Control

Sensors and Actuators

Contents

Contents

Structural Acoustics and Noise Control

Contents

System Identification and Inverse Problems

Uncertain Dynamical Systems

Contents

Contents

Vibration Control Devices

Contents

Vibroacoustics

XIII International Conference on Motion and Vibration Control

XII International Conference on Recent Advances in Structural Dynamics

TECHNICAL PROGRAMME

Conference Outline

Sunday 3 July

17:00 – 19:00	Early Registration

Monday 4 July

08:00 – 10:00	Registration
08:45 – 09:00	Opening Ceremony
09:00 – 10:00	Plenary Session 1
10:00 – 10:30	*Morning Refreshments*
10:30 – 12:30	Technical Sessions
12:30 – 13:30	*Lunch*
13:30 – 14:30	Plenary Session 2
14:30 – 15:30	Technical Sessions
15:30 – 16:00	*Afternoon Refreshments*
16:00 – 18:00	Technical Sessions
19:00 – 20:00	*Reception and Barbecue*

Tuesday 5 July

09:00 – 10:00	Plenary Session 3
10:00 – 10:30	*Morning Refreshments*
10:30 – 12:30	Technical Sessions
12:30 – 14:00	*Lunch and Poster Exhibition*
14:00 – 15:00	Plenary Session 4
15:00 – 16:00	Technical Sessions
16:00 – 16:30	*Afternoon Refreshments*
16:30 – 18:00	Technical Sessions
18:00	*Coaches depart from the Highfield Interchange*
19:00 – 23:00	*Dinner at Beaulieu National Motor Museum*

Wednesday 6 July

09:00 – 10:00	Plenary Session 5
10:00 – 10:30	*Morning Refreshments*
10:30 – 12:30	Technical Sessions
12:30 – 13:30	*Lunch*
13:30 – 15:00	Technical Sessions
15:00 – 15:15	Closure Session and Best Presentation Award
15:15 – 15:45	*Afternoon Refreshments*

MONDAY 4 JULY 2016

08:45	**Opening Ceremony** Physics Lecture Theatre A (46/3001)	**Professor P R White**, *Director of the Institute of Sound and Vibration Research, University of Southampton*
09:00	**Plenary Session 1** Physics Lecture Theatre A (46/3001)	**Professor K W Wang**, "From Muscles to Plants – Nature-Inspired Adaptive Metastructures for Structural Dynamics Enhancement", *University of Michigan, USA*
10:00	**Morning Refreshments**	

	Physics Lecture Theatre A (46/3001)	Physics Lecture Theatre B (46/2003)	Physics Lecture Theatre C (46/2005)	Shackleton Lecture Theatre A (44/1041)	Shackleton Lecture Theatre B (44/1057)
	Active Vibration Control I	**Vehicle Dynamics and Control I**	**Vibroacoustics**	**Damage Detection and Structural Health Monitoring I**	**Biomechanics and Human-Machine Interface**
10:30	Model-based active control of a continuous structure subjected to moving loads (2204) D Stancioiu	Dynamically Substructured System Testing for Railway Vehicle Pantographs (2119) D P Stoten	Prediction of noise transmission through infinite panels using a wave and finite element method (2126) Y Yang	The Parameter Identification Method of Blade Asynchronous Vibration under Sweep Speed Excitation (2198) L Yue	Frontal Plane Modelling of Human Dynamics during Standing in Narrow-Stance (2304) M Sonobe
10:45	Comparison of adaptive algorithms for the control of tonal disturbances in mechanical systems (2215) M Zilletti	Synthesised H_∞/μ Control Design for Dynamically Substructured Systems (2124) T Yamaguchi	Dynamic response analysis of an aircraft structure under thermal-acoustic loads (2491) H Cheng	The influences of soil and nearby structures on dispersion characteristics of wave propagating along buried plastic pipes (2221) S Liu	Reduced-order models for vertical human-structure interaction (2440) K Van Nimmen
11:00	Active vibration control of a plate using vibration gradients (2247) T Kaizuka	Fundamental study of subharmonic vibration of order 1/2 in automatic transmissions for cars (2151) T Ryu	Modelling of high-frequency structure-borne sound transmission on FEM grids using the Discrete Flow Mapping technique (2497) G Tanner	Application of the wave finite element method to reinforced concrete structures with damage (2252) E E Masri	Human-structure interaction effects on the maximum dynamic response based on an equivalent spectral model for pedestrian-induced loading (2494) E Bassoli
11:15	Ground test for vibration control demonstrator (2270) C Meyer	A New Approach for NOx Soft Sensors for the Aftertreatment of Diesel Engines (2153) S Ishizuka	Application of FE-SEA hybrid method in vibro-acoustic environment prediction of complex structure (2554) Z H Qi	Damage Identification Dependence on Number of Vibration Modes Using Mode Shape Curvature Squares (2269) R Janeliukstis	A study of a steering system algorithm for pleasure boats based on stability analysis of a human-machine system model (2349) F Ikeda
11:30	Lateral Vibration Attenuation by the Dynamic Adjustment of Bias Currents in Magnetic Suspension System (2275) T Mizuno	Optimal Design of Spring Characteristics of Damper for Subharmonic Vibration in Automatic Transmission Powertrain (2154) T Nakae		Remote pipeline assessment and condition monitoring using low-frequency axisymmetric waves: a theoretical study of torsional wave motion (2416) J M Muggleton	Sports Training Support Method by Self-Coaching with Humanoid Robot (2366) S Toyama
11:45	Active vibration isolation through a Stewart platform with piezoelectric actuators (2295) C Wang	Optimization of vehicle-trailer connection systems (2159) F Sorge		A novel method for the remote condition assessment of buried pipelines using low-frequency axisymmetric waves (2418) J M Muggleton	
12:00	Vibration attenuation of conductive beams by inducing eddy currents (2317) L Irazu	Multibody simulation of vehicles equipped with an automatic transmission (2219) B Olivier			
12:15	Active partial eigenvalue assignment for friction-induced vibration using receptance method (2664) Y Liang	Design and implementation of a personal mobility of single spherical drive (2356) T Hoshino			
12:30	**Lunch** (B40 Garden Court)				

MONDAY 4 JULY 2016

13:30	**Plenary Session 2** Physics Lecture Theatre A (46/3001)	**Professor K Murphy**, "Dynamics of Passive Balancing Rings for Rotating Systems", *University of Louisville, USA*			
	Physics Lecture Theatre A (46/3001)	Physics Lecture Theatre B (46/2003)	Physics Lecture Theatre C (46/2005)	Shackleton Lecture Theatre A (44/1041)	Shackleton Lecture Theatre B (44/1057)
	Active Vibration Control II	**Vehicle Dynamics and Control II**	**Structural Acoustics and Noise Control I**	**Damage Detection and Structural Health Monitoring II**	**Impulse Loading and Impact Dynamics**
14:30	Passive Micro Vibration Isolator Utilizing Flux Pinning Effect for Satellites (2330) T Shibata	Study on Vibration Reduction Design of Suspended Equipment of High Speed Railway Vehicles (2397) Y Sun	Target spectrum matrix definition for multiple-input-multiple-output control strategies applied on direct-field-acoustic-excitation tests (2232) M A Blanco	Dynamic behaviour of a rotating cracked beam (2480) A Yashar	Rebound Vibration of Two-Plates Bonded Model for an Internal Mirror of SLR Camera (2314) H Matsumoto
14:45	Test rig with active damping control for the simultaneous evaluation of vibration control and energy harvesting via piezoelectric transducers (2342) S Perfetto	Pneumatic tyres interacting with deformable terrains (2442) C A Bekakos	Optimization of natural frequencies of large-scale two-stage raft system (2260) L V Zhiqiang	Structural Dynamic Response Compressing Technique in Bridges using a Cochlea-inspired Artificial Filter Bank (CAFB) (2611) G Heo	Impact analyses for negative flexural responses (hogging) in railway prestressed concrete sleepers (2548) S Kaewunruen
15:00	Suppressing self-excited vibrations of mechanical systems by impulsive force excitation (2348) T Pumhössel	Characterisation of vibration input to flywheel used on urban bus (2454) L Wang	A study on calculation method for mechanical impedance of air spring (2283) S Changgeng	The Detection of Vertical Cracks in Asphalt Using Seismic Surface Wave Methods (2434) M Iodice	Research of hail impact on aircraft wheel door with lattice hybrid structure (2630) S Li
15:15	Time-varying shunted electro-magnetic tuneable vibration absorber (2362) E Turco	Study on the precision of the guide control system of independent wheel (2463) Y Ji	A numerical method for seeking the relationship between structural modes and acoustic radiation modes of complicated structures (2213) C W Su		
15:30	**Afternoon Refreshments**				

MONDAY 4 JULY 2016

	Physics Lecture Theatre A (46/3001)	Physics Lecture Theatre B (46/2003)	Physics Lecture Theatre C (46/2005)	Shackleton Lecture Theatre A (44/1041)	Shackleton Lecture Theatre B (44/1057)
	Active Vibration Control III	**Vehicle Dynamics and Control III**	**Structural Acoustics and Noise Control II**	**Rotor Dynamics and Control**	**Fluid-Structure Interaction**
16:00	Vibration Control by a Shear Type Semi-active Damper Using Magnetorheological Grease (2377) T Shiraishi	A Study on Automatic Passenger Mover Envelope Gauge (2474) Y Ji	Noise Control for a Moving Evaluation Point Using Neural Networks (2395) T Maeda	Enhancing stability of industrial turbines using adjustable partial arc bearings (2515) A Chasalevris	Dynamic strain measurements of marine propellers under non-uniform inflow (2155) J Tian
16:15	Wave absorption of an orthotropic rectangular panel based on direct feedback (2378) H Iwamoto	Study on coupled shock absorber system using four electromagnetic dampers (2510) H Okano	Active structural acoustic control using the remote sensor method (2447) J Cheer	Preventing the oil film instability in rotor-dynamics (2161) F Sorge	Vibro-acoustics of porous materials – waveguide modelling approach (2162) R Darula
16:30	Experimental investigation on a colloidal damper rendered controllable under the variable magnetic field generated by moving permanent magnets (2410) B Suciu	Steering Dynamics of Tilting Narrow Track Vehicle with Passive Front Wheel Design (2514) J T C Tan	Active Structural Acoustic Control in an Original A400M Aircraft Structure (2483) C Koehne	Vibration attenuation of rotating machines by application of magnetorheological dampers to minimize energy losses in the rotor support (2185) J Zapoměl	Development of Overflow-Prevention Valve with Trigger Mechanism (2325) Y Ishino
16:45	Development of simple operation crane system for the real application (2472) M Wada	Integrated navigation of aerial robot for GPS and GPS-denied environment (2556) S Suzuki	Theoretical investigation into tunable band gaps of an Euler-Bernoulli beam with 2DOF LR structures (2579) Z Xingqian	Predicting Critical Speeds in Rotordynamics: A New Method (2094) J D Knight	Discrete Flow Mapping in coupled two and three dimensional domains: a global interface problem (2529) J Bajars
17:00	Hybrid Fluid-borne Noise Control in Fluid-filled Pipelines (2481) M Pan	Model Predictive Control considering Reachable Range of Wheels for Leg / Wheel Mobile Robots (2564) N Suzuki	Response of a shell structure subject to distributed harmonic excitation (2599) R Cao	Modal interaction and vibration suppression in industrial turbines using adjustable journal bearings (2516) A Chasalevris	Suppression of two-dimensional vortex-induced vibration with active velocity feedback controller (2202) B Ma
17:15	Development of sensorless easy-to-use overhead crane system via simulation based control (2487) Y Tagawa	Design and Experimental Verification of Vibration Suppression Device on the Lift of Wheelchair-accessible Vehicles (2577) Y Hatano	Enhanced acoustic transmission into dissipative solid materials through the use of inhomogeneous plane waves (2600) D C Woods	Mathematic study of the rotor motion with a pendulum self-balancing device (2627) O P Ivkina	Hydrodynamic and hydrostatic modelling of hydraulic journal bearings considering small displacement condition (2359) C Y Chen
17:30	Application of a load-bearing passive and active vibration isolation system in hydraulic drives (2527) O Unruh	A Hierarchical Model Predictive Tracking Control for Independent Four-Wheel Driving/Steering Vehicles with Coaxial Steering Mechanism (2582) M Itoh	Active Noise Control for Dishwasher noise (2643) N Lee	Dynamic analysis on rotor-bearing system with coupling faults of crack and rub-impact (2631) Z Huang	Methodology for Dynamic Analysis of Nuclear Reactor Vessel and Reactor Internals (2748) J B Park
17:45	Acceleration control system for semi-active in-car crib with joint application of regular and inverted pendulum mechanisms (2288) T Kawashima	Automated Driving System Architecture to Ensure Safe Delegation of Driving Authority (2587) S Yun	Nonlinear Microstructured Material to Reduce Noise and Vibrations at Low Frequencies (2263) D Lavazec		
19:00	**Reception and Barbecue** (B38 Arlott)				

Technical Programme

	Session Title	Session Chair
09:00 - 10:00	Plenary Session 1	Michael Brennan
10:30 - 12:30	Active Vibration Control I	Michael Brennan Zhiyi Zhang
	Vehicle Dynamics and Control I	Kimihiko Nakano Dao Gong
	Vibroacoustics	Radoslav Darula Gregor Tanner
	Damage Detection and Structural Health Monitoring I	Chaoping Zang Timothy Waters
	Biomechanics and Human-Machine Interface	Paola Forte Stephen Elliott
13:30 - 14:30	Plenary Session 2	Lawrie Virgin
14:30 - 15:30	Active Vibration Control II	Michele Zilletti
	Vehicle Dynamics and Control II	Teruya Yamaguchi
	Structural Acoustics and Noise Control I	Stuart Bolton
	Damage Detection and Structural Health Monitoring II	Timothy Waters
	Impulse Loading and Impact Dynamics	Sakdirat Kaewunruen
16:00 - 18:00	Active Vibration Control III	Stephen Elliott Jordan Cheer
	Vehicle Dynamics and Control III	Kimihiko Nakano Satoshi Suzuki
	Structural Acoustics and Noise Control II	Changgeng Shuai Michael Kingan
	Rotor Dynamics and Control	Jaroslav Zapomel Athanasios Chasalevris
	Fluid-Structure Interaction	Zhiyi Zhang No-Cheol Park

TUESDAY 5 JULY 2016

09:00	**Plenary Session 3** Physics Lecture Theatre A (46/3001)	**Professor T Mizuno**, "Recent advances in magnetic suspension technology", *Saitama University, Japan*
10:00	**Morning Refreshments**	

	Physics Lecture Theatre A (46/3001) **Nonlinear Vibrations I**	Physics Lecture Theatre B (46/2003) **Railway Induced Noise and Vibration I**	Physics Lecture Theatre C (46/2005) **Stochastic Dynamics and Random Vibrations**	Shackleton Lecture Theatre A (44/1041) **Vibration Control Devices I**	Shackleton Lecture Theatre B (44/1057) **Control of Civil Infrastructures**
10:30	The Characteristics of Vibration Isolation System with Damping and Stiffness Geometrically Nonlinear (2131) Z Q Lu	Vibration analysis of concrete bridges during a train pass-by using various models (2167) Q Li	Multiaxis Rainflow Fatigue Methods for Nonstationary Vibration (2136) T Irvine	Analysis of a vibration isolation table comprising post-buckled Γ-shaped beam isolators (2196) T Sasaki	Application of the nonlinear substructuring control method to nonlinear 2-degree-of-freedom systems (2272) R Enokida
10:45	Chaotic motions of a tethered satellite system in circular orbit (2150) D P Jin	Sound transmission loss of windows on high speed trains (2191) Y Zhang	Response moments of dynamic systems under non-Gaussian random excitation by the equivalent non-Gaussian excitation method (2168) T Tsuchida	On the undamped vibration absorber with cubic stiffness characteristics (2331) G Gatti	Experimental evaluation of a control system for active mass dampers consisting of a position controller and neural oscillator (2301) T Sasaki
11:00	Periodic response of an axially high-speed moving beam under 3:1 internal resonance (2192) H Ding	Experimental investigation on the dissipative and elastic characteristics of a yaw colloidal damper destined to carbody suspension of a bullet train (2409) B Suciu	Stability of a nonlinear second order equation under parametric bounded noise excitation (2177) R Wiebe	Dynamics of a passive micro-vibration isolator based on a pretensioned plane cable net structure and fluid damper (2337) Y Chen	Accelerometer-based estimation and modal velocity feedback vibration control of a stress-ribbon bridge with pneumatic muscles (2444) X Liu
11:15	Robust simulation of buckled structures using reduced order modeling (2176) R Perez	Study of the shadow effect caused by a railway tunnel (2256) Q Jin	A simplified method for random vibration analysis of structures with random parameters (2200) M Ghienne	Prediction of peak response values of structures with and without TMD subjected to random pedestrian flows (2443) K Lievens	Seismic Vibration Control of Elevated Water Tank by TLD and Validation of Full-Scale TLD Model through Real-Time-Hybrid-Testing (2594) A Roy
11:30	A Method for Stable Deployment of an Electrodynamic Tethered Satellite in Three-Dimensional Space (2183) B S Yu	Prediction of radiation ratio and sound transmission of complex extruded panel using wavenumber domain FE and BE methods (2360) H Kim	CR-Calculus and adaptive array theory applied to MIMO random vibration control tests (2249) U Musella	Design of an Active Bumper with a Series Elastic Actuator for Pedestrian Protection of Small Unmanned Vehicles (2504) N Terumasa	Research on Hybrid Seismic Response Control System for Motion Control of Two Span Bridge (2610) G Heo
11:45	Exploration of nonlinearly shunted piezoelectrics as vibration absorbers (2253) B Zhou	The response of a high-speed train wheel to a harmonic wheelrail force (2408) X Sheng	Dynamic Modeling and Very Short-term Prediction of Wind Power Output Using Box-Cox Transformation (2299) K Urata	The effect of beam inclination on the performance of a passive vibration isolator using buckled beams (2165) H Mori	Passive vibration suppression using inerters for a multi-storey building structure (2233) S Y Zhang
12:00	Effect of asymmetry in the restoring force of the "click" mechanism in insect flight (2255) A Abolfathi	Effects of rail dynamics and friction characteristics on curve squeal (2415) B Ding	Exact statistical energy analysis of systems excited by time correlated random excitations (2603) C Lecomte	An energy approach for the active vibration control of an oscillator with two translational degrees of freedom using two auxiliary rotating masses (2403) R Bäumer	Experimental Study on a Tuned-Mass Damper of Offshore for Vibration Reduction (2452) Q Wu
12:15		Rail roughness and rolling noise in tramways (2417) L Chiacchiari	Multi-dimensional Fokker-Planck equation analysis using the modified finite element method (2171) J Náprstek	Development of optimal design theory for series multiple tuned mass dampers considering stroke and multiple structural modes (2406) J F Wang	Damping Performance of Taut Cables with Passive Absorbers Incorporating Inerters (2399) J Luo

TUESDAY 5 JULY 2016

<table>
<tr><td>12:30</td><td>Lunch with Poster Exhibition
(B40 Garden Court)</td><td colspan="4">A novel test rig for the dynamic characterization of large size tilting pad journal bearings (2186) P Forte
Finite element parametric study of the influence of friction pad material and morphological characteristics on disc brake vibration phenomena (2188) P Forte
Experimental and numerical investigations on the dynamic response of turbine blades with tip pin dampers (2324) S Zucca
Modeling and feedforward controller design in 2-dimensional shaking table systems (2344) K Seki
Study on Walking Training System using High-Performance Shoes constructed with Rubber Elements (2428) Y Hayakawa
Vibration Reduction of Wind Turbines Using Tuned Liquid Column Damper Using Stochastic Analysis (2502) M H Alkmim
Research on damping properties optimization of variable-stiffness plate (2566) Q W Kai
Model updating in flexible-link multibody systems (2589) R Belotti
Vibration control using nonlinear damped coupling (2618) M G Tehrani
Application of the Wave and Finite Element Method to Calculate Sound Transmission Through Cylindrical Structures (2128) M J Kingan
On the synchronization of two metronomes and their related dynamics (2404) J C Carranza</td></tr>
<tr><td>14:00</td><td>Plenary Session 4
Physics Lecture Theatre A (46/3001)</td><td colspan="4">Professor R Goodall, “Motion and vibration control for railway vehicles”, Loughborough University, UK</td></tr>
<tr><td></td><td>Physics Lecture Theatre A (46/3001)</td><td>Physics Lecture Theatre B (46/2003)</td><td>Physics Lecture Theatre C (46/2005)</td><td>Shackleton Lecture Theatre A (44/1041)</td><td>Shackleton Lecture Theatre B (44/1057)</td></tr>
<tr><td></td><td>Nonlinear Vibrations II</td><td>Railway Induced Noise and Vibration II</td><td>Control Theory</td><td>Vibration Control Devices II</td><td>Civil Engineering Structures</td></tr>
<tr><td>15:00</td><td>Insight into the dynamic behaviour of the Van der Pol/Raleigh oscillator using the internal stiffness and damping forces (2388)
M J Brennan</td><td>Development of a model to assess acoustic treatments to reduce railway noise (2426)
H Jeong</td><td>Linear Matrix Inequality Method for a Quadratic Performance Index Minimization Problem with a class of Bilinear Matrix Inequality Conditions (2277)
M Tanemura</td><td>Characterization and performance evaluation of a vertical seismic isolator using link and crank mechanism (2511)
N Tsujiuchi</td><td>Bidirectional Connected Control Method Applied to an Experimental Structural Model Split into Four Substructures (2334)
T Watanabe</td></tr>
<tr><td>15:15</td><td>Nonlinear Dynamics of Structures with Material Degradation (2607)
P Soltani</td><td>Analysis of dynamic stiffness effect of primary suspension helical springs on railway vehicle vibration (2453)
W Sun</td><td>Experimental Verification of a Vehicle Localization based on Moving Horizon Estimation Integrating LRS and Odometry (2522)
K Sakaeta</td><td>A simple levitation system using wireless power supply system and Lorentz force (2624)
K Oka</td><td>Wave propagation in rods with an exponentially varying cross-section - modelling and experiments (2547)
M K Kalkowski</td></tr>
<tr><td>15:30</td><td>A model identification technique to characterize the low frequency behaviour of surrogate explosive materials (2619)
J Paripovic</td><td>Transient wave propagation analysis of a pantograph-catenary system (2596)
K Nagao</td><td>Moving Horizon Estimation for Vehicle Robots using Partial Marker Information of Motion Capture System (2576)
M Takahashi</td><td>Force transmissibility and vibration power flow behaviour of inerter-based vibration isolators (2650)
J Yang</td><td>Ambient modal testing of a double-arch dam: the experimental campaign and model updating (2622)
J H G Palacios</td></tr>
<tr><td>15:45</td><td></td><td>Contact force control of an active pantograph for high speed trains (2557)
M T Ko</td><td>Improving active eigenvector assignment through passive modifications (2588)
R Belotti</td><td></td><td>Numerical and experimental investigation on the effects of non-structural components on the elastic fundamental period of buildings (2625)
R Ditommaso</td></tr>
<tr><td>16:00</td><td colspan="5">Afternoon Refreshments</td></tr>
</table>

TUESDAY 5 JULY 2016

	Physics Lecture Theatre A (46/3001)	Physics Lecture Theatre B (46/2003)	Physics Lecture Theatre C (46/2005)	Shackleton Lecture Theatre A (44/1041)	Shackleton Lecture Theatre B (44/1057)
	Nonlinear Vibrations III	**ANTARES-EMVEM**	**Innovative Combustion Technology**	**Modal Analysis and Structural Modification**	**Sensors and Actuators**
16:30	Dynamic response of a nonlinear parametrically excited system subject to harmonic base excitation (2412) B Zaghari	Flywheel proof mass actuator for velocity feedback control (2218) A Kras	Study on Model Based Combustion Control of Diesel Engine with Multi Fuel Injection (2567) R Ikemura	A Structured Model Reduction Method for Linear Interconnected Systems (2250) R Sato	The Development of an Intelligent Hybrid Active-passive Vibration Isolator (2264) C Shuai
16:45	Studies of parametrically excited non-linear MDOF systems at parametric resonances (2424) T J Kniffka	Sweeping piezoelectric patch vibration absorbers (2363) D Casagrande	Combustion Control System Design of Diesel Engine via ASPR based Output Feedback Control Strategy with a PFC (2461) I Mizumoto,	Dynamic similarity design method for an aero-engine dual-rotor test rig (2286) H Miao	Steering Law Controlling the Constant Speeds of Control Moment Gyros (2291) Y Koyasako
17:00	Vibration suppression of a flywheel system using a novel nonlinear vibration absorber with an Euler buckled beam (2496) L Haiping	Active control of turbulent boundary layer sound transmission into a vehicle interior (2433) A Caiazzo	$\boldsymbol{H}_\infty$ control of combustion in diesel engines using a discrete dynamics model (2460) M Hirata	Understanding the effect of hammering process on the vibration characteristics of cymbals (2290) F Kuratani	An application review of dielectric electroactive polymer actuators in acoustics and vibration control (2323) Z Zhao
17:15	Exploiting modal interaction during run-up of a magnetically supported Jeffcott rotor (2545) F Dohnal	Dynamic analysis of nonlinear behaviour in inertial actuators (2467) M Dal Borgo	Control of the low-load region in partially premixed combustion (2568) G Ingesson	Optimization of a tuned vibration absorber in a multibody system by operational analysis (2347) F Infante	
17:30	Complex Dynamics of Delay-Coupled Neural Networks (2281) X Mao	Active vibration control of an inertial actuator subject to broadband excitation (2492) S Camperi	Combustion Control of Diesel Engine using Feedback Error Learning with Kernel Online Learning Approach (2456) E S Widayaka	Static and dynamic behaviours of helical spring in MR fluid (2549) S Kaewunruen	
17:45	Force, displacement and strain nonlinear transfer function estimation (2451) K A Sweitzer	Plate Metamaterial for broad-band vibration control (2693) M. Zientek		Error localization of finite element updating model based on element strain energy (2375) Z Huang	
18:00	Coaches depart from the Highfield Interchange				
19:00	**Conference Dinner at National Motor Museum**				

Technical Programme

	Session Title	Session Chair
09:00 - 10:00	Plenary Session 3	Timothy Waters
10:30 - 12:30	Nonlinear Vibrations I	Lawrie Virgin Horst Ecker
	Railway Induced Noise and Vibration I	David Thompson Xiaozhen Sheng
	Stochastic Dynamics and Random Vibrations	Karl Sweitzer Tom Irvine
	Vibration Control Devices I	Jiong Tang Paola Forte
	Control of Civil Infrastructures	Jennifer Muggleton Ryuta Enokida
14:00 - 15:00	Plenary Session 4	David Thompson
15:00 - 16:00	Nonlinear Vibrations II	Giabluca Gatti
	Sensors and Actuators	Andrew Plummer
	Control Theory	Maryam Ghandchi Tehrani
	Vibration Control Devices II	Brian Mace
	Civil Engineering Structures	Jennifer Muggleton
16:30 - 18:00	Nonlinear Vibrations III	Thomas Pumhossel
	Railway Induced Noise and Vibration II	Giacomo Squicciarini
	Innovative Combustion Technology	Ikuro Mizumoto
	Modal Analysis and Structural Modification	Brian Mace Christophe Lecomte
	ANTARES-EMVEM	Maryam Ghandchi Tehrani

WEDNESDAY 6 JULY 2016

09:00	**Plenary Session 5** Physics Lecture Theatre A (46/3001)	**Professor D J Wagg**, "Reducing vibrations in structures using structural control", *University of Sheffield, UK*			
10:00	**Morning Refreshments**				
	Physics Lecture Theatre A (46/3001)	Physics Lecture Theatre B (46/2003)	Physics Lecture Theatre C (46/2005)	Shackleton Lecture Theatre A (44/1041)	Shackleton Lecture Theatre B (44/1057)
	Energy Harvesting I	**Smart Structures**	**Dynamics and Control of Multibody Systems I**	**Uncertain Dynamical Systems**	**Experimental techniques**
10:30	On The Dynamics and Design of a Two-body Wave Energy Converter (2405) C Liang	Advanced design of integrated vibration control systems for adjacent buildings under seismic excit. (2230) F P Quiñonero	Dynamics and control of robotic spacecrafts for the transportation of flexible elements (2148) H Wen	A framework for the analysis of vibrations of structures with uncertain attachments (2152) S Li	A pseudodynamic testing algorithm for obtaining seismic responses of structures (2174) S Y Chang
10:45	Inverse design of nonlinearity in energy harvesters for optimum damping (2170) M G Tehrani	Vibration reduction of a woven composite fan blade by piezoelectric shunted devices (2538) O Thierry	Stochastic stability assessment of a semi-free piston engine generator concept (2310) T N Kigezi	Quantifying the variability in stiffness and damping of an automotive vehicle's trim-structure mounts (2169) A Abolfathi	Vibration Prediction Method of Electric Machines by using Experimental Transfer Function and Magnetostatic FEA (2254) A Saito
11:00	Broadband vibratory energy harvesting via bubble shaped response curves (2237) Z Q Lu	Active buckling control of an imperfect beam-column with circular cross-section using piezo-elastic supports and integral LQR control (2265) M Schaeffner	Active control of multi-input hydraulic journal bearing system (2365) J Chuang	Flexural Wave Propagation in Slowly Varying Random Waveguides Using a Finite Element Approach (2401) A T Fabro	Fatigue Damage Spectrum calculation in a Mission Synthesis procedure for Sine-on-Random excitations (2379) A Angeli
11:15	Application review of dielectric electroactive polymers (DEAPs) and piezoelectric materials for vibration energy harvesting (2280) X Yuan	Parameter identification for active mass damper controlled systems (2313) C C Chang	Design of passive interconnections in tall buildings subject to earthquake disturbances to suppress inter-storey drifts (2429) K Yamamoto	Random seismic response and sensitivity analysis of uncertain multi-span continuous beams subjected to spatially varying ground motions (2336) Y Y Li	Inferring unstable equilibrium configurations from experimental data (2385) L N Virgin
11:30	On the influence of nonlinearities on vibrational energy transduction under band-limited noise excitations (2320) K Nakano	A broadband frequency-tunable dynamic absorber for the vibration control of structures (2319) T Komatsuzaki	Numerical and experimental comparison of the energy transfer in a parametrically excited system (2446) A Fichtinger	Experimental investigation of the variability in the dynamics of connected structures (2352) M R Souza	Sound power and vibration levels for two different piano soundboards (2414) G Squicciarini
11:45	Adjustable Nonlinear Mechanism System for Wideband Energy Harvesting in Rotational Circumstances (2345) Y Zhang	Active load path adaption in a simple kinematic load-bearing structure due to stiffness change in the structure's supports (2384) C M Gehb	Stabilization and set-point regulation of underactuated mechanical systems (2533) M Loccufier	Uncertainties Quantification and Propagation of Multiple Correlated Variables with Limited Samples (2382) Z Shen	Experimental investigation on dynamic response of aircraft panels excited by high-intensity acoustic loads in thermal environment (2575) Z Q Wu
12:00	Energy harvesting from the vibrations of a passing train: effect of speed variability (2357) M Brennan	Parallel kinematic mechanisms for distributed actuation of future structures (2551) G Lai	Optimisation of shimmy suppression device in an aircraft main landing gear (2535) Y Li	Vibration analysis of structure with uncertainty using two-level Gaussian processes and Bayesian inference (2389) K Zhou	Synchronization of dynamic response measurements for the purpose of structural health monitoring (2422) K Maes
12:15	A numerical analysis of the electrical output response of a nonlinear piezoelectric oscillator subjected to a harmonic and random excitation (2141) T L Pereira	Exploring vibration control strategies for a footbridge with time-varying modal parameters (2621) J M Soria		Variability analysis on the structural elastic properties of adhesively joined cylinders (2326) K Van Massenhove	

WEDNESDAY 6 JULY 2016

12:30	**Lunch** (B40 Garden Court)				
	Physics Lecture Theatre A (46/3001)	Physics Lecture Theatre B (46/2003)	Physics Lecture Theatre C (46/2005)	Shackleton Lecture Theatre A (44/1041)	Shackleton Lecture Theatre B (44/1057)
	Energy Harvesting II	**Numerical methods**	**Dynamics and Control of Multibody Systems II**	**System Identification and Inverse Problems**	**Analytical methods**
13:30	Impulsive parametric damping in energy harvesting (2466) M G Tehrani	Reduced Order Models for Dynamic Behavior of Elastomer Damping Devices (2231) B Morin	Digging Soil Experiments for Micro Hydraulic Excavators based on Model Predictive Tracking Control (2580) T Tomatsu	On a space-frequency regularization for source reconstruction (2087) M Aucejo	Vibration analysis and optimization of sandwich composite with curvilinear fibers (2289) S Honda
13:45	Concept study of a novel energy harvesting-enabled tuned mass-damper-inerter (EH-TMDI) device for vibration control of harmonically-excited structures (2495) J Salvi	Optimization of an installation angle of a root-cutting blade for an automatic spinach harvester (2338) A Fujisawa	The dynamic research and position estimation of the towed array during the U-turn process (2581) J X Yang	Wind load Identification of a guyed mast inversely from full-scale response measurement (2229) A K Amiri	Governing equations of multi-component rigid body-spring discrete element models of reinforced concrete columns (2593) P B Guan
14:00	A simulation of the performance of a self-tuning energy harvesting cantilever beam (2543) J L Kaplan	A hybrid approach for modelling dynamic behaviours of a rotor-foundation system (2350) Z G Zhang	Control of vibrations for a parallel manipulator with flexible links - concepts and experimental results (2591) M Morlock	Inverse characterisation of frequency-dependent properties of adhesives (2259) L Rouleau	Integration simulation method concerning speed control of ultrasonic motor (2340) R Miyauchi
14:15	Design of an electromagnetic-transducer energy harvester (2697) L Simeone	FEM Techniques for High Stress Detection in Accelerated Fatigue Simulation (2394) M Veltri	Fast trajectory planning by design of initial trajectory in overhead traveling crane with considering obstacle avoidance and load vibration suppression (2146) A Inomata	Vibration characteristics and optimization for panel elastically supported in mobile phone (2341) Y Kaito	A multiple-scales asymptotic approach for dynamic response analysis of piezoelectric laminated composites (2398) G Kondagunta
14:30	Global stabilization of high-energy response of a nonlinear wideband electromagnetic energy harvester (2609) T Sato	Local modes analysis of a rotating marine ship propeller with higher order harmonic elements (2670) C Feng	Modeling and control of a cable-suspended robot for inspection of vertical structures (2605) N Barry	A new method for the identification of the parameters of the Dahl model (2309) I G Baños	Milling Stability Analysis Based on Chebyshev Segmentation (2311) J Huang
14:45	Design, modelling and experimental characterization of a novel regenerative shock absorber with a ball-screw-based mechanical motion rectifier (2592) Y Liu	Dynamic finite element model validation of an assembled aero-engine casing (2729) Z Huang			A nonlinear cointegration approach with applications to structural health monitoring (2537) H Shi
15:00	**Closure Session and Best Presentation Award** Physics Lecture Theatre A (46/3001)				
15:15	**Afternoon Refreshments**				

Technical Programme

	Session Title	Session Chair
09:00 - 10:00	Plenary Session 5	Neil Ferguson
10:30 - 12:30	Energy Harvesting I	Philip Bonello Elvio Bonisoli
	Smart Structures	Michele Zilletti Jordan Cheer
	Dynamics and Control of Multibody Systems I	Jiong Tang Teresa Maria Berruti
	Uncertain Dynamical systems	Adriano Fabro Christophe Lecomte
	Experimental Techniques	Iván Munoz Díaz Michał Kalkowski
13:30 - 15:00	Energy Harvesting II	Jonathan Salvi
	Numerical Methods	Michał Kalkowski
	Dynamics and Control of Multibody Systems II	Giacomo Squicciarini
	System Identification and Inverse Problems	Evangelos Ntotsios
	Analytical Methods	Keith Worden

XIII International Conference on Motion and Vibration Control

XII International Conference on Recent Advances in Structural Dynamics

ABSTRACTS

09:00 PLENARY SESSION

From Muscles to Plants – Nature-Inspired Adaptive Metastructures for Structural Dynamics Enhancement

K W Wang

Stephen P. Timoshenko Professor and Tim Manganello/BorgWarner Department Chair, Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI

During the past few decades, due to the advances in materials, electronics, and system integration technologies, structural dynamics and controls researchers in various engineering disciplines (e.g., aerospace, civil, mechanical) have been investigating the feasibility of creating adaptive structures. The vision is to develop multifunctional structural systems that have various embedded and distributed autonomous functionalities, such as shape reconfiguration and morphing, materials and mechanical property variations, energy harvesting, vibration and stability controls, and health monitoring and healing. From a structural system point of view, one of the major challenges is on how to best synthesize the cross-field and local-global coupling characteristics of the various adaptive materials and elements to optimize the overall structure performance. It has been recognized that to achieve significant new advances in adaptive structures, researchers have to conduct even more cross talks among various fields and disciplines. In recent years, interesting approaches have been explored to develop mechanical metastructures based on synergistic modular architectures, often observed in nature, such as in biological or atomistic systems. This presentation will discuss some of the recent interdisciplinary research efforts in synthesizing nature-inspired adaptive metastructures for structural dynamics enhancement and applications.

13:30 PLENARY SESSION

Dynamics of Passive Balancing Rings for Rotating Systems

K Murphy

Professor and Chairman, Department of Mechanical Engineering, University of Louisville, USA

Rotating components appear in a vast array of applications, ranging from large-scale industrial systems to small-scale consumer products. In all of these systems, out-of-balance situations invariably arise causing unwanted vibrations. And, though transient vibrations can be pronounced (as the system spins-up through resonance), the steady-state responses tend to be the most detrimental. The present work looks at the efficacy of a simple balance ring device; these have been used in a number of applications, most notably washing machines. These rings are simple, dynamic devices that consist of an enclosed circular track - or ring - that contains metal balls and a fluid. This ring is mounted on the rotating, out-of-balance component. The intent is that, as the system spins, the balls migrate to the side opposite the out-of-balance. This moves the effective center of mass back toward the geometric center of rotation and diminishes the vibration amplitude.

The present discussion begins with a historical look at these dynamic balancers - and the models used to describe/design them. A new model is also proposed; this permits ball-to-ball impacts, formation of ball-trains, and separation of ball-trains. Some of the technical challenges of this model are discussed, as are some features of the dynamic response. Suggestions for future directions are also proposed.

Notes

10:30 Active Vibration Control I

Model-based active control of a continuous structure subjected to moving loads (2204)

D Stancioiu, H Ouyang

Modelling of a structure is an important preliminary step of structural control. The main objectives of the modelling, which are almost always antagonistic are accuracy and simplicity of the model. The first part of this study focuses on the experimental and theoretical modelling of a structure subjected to the action of one or two decelerating moving carriages modelled as masses. The aim of this part is to obtain a simple but accurate model which will include not only the structure-moving load interaction but also the actuators dynamics. A small scale rig is designed to represent a four-span continuous metallic bridge structure with miniature guiding rails. A series of tests are run subjecting the structure to the action of one or two mini-carriages with different loads that were launched along the structure at different initial speeds. The second part is dedicated to model based control design where a feedback controller is designed and tested against the validated model. The study shows that a positive position feedback is able to improve system dynamics but also shows some of the limitations of state-space methods for this type of system.

10:30 Vehicle Dynamics and Control I

Dynamically Substructured System Testing for Railway Vehicle Pantographs (2119)

D P Stoten, T Yamaguchi, Y Yamashita

The overall objective of this paper is to establish a dynamically substructured system (DSS) testing approach for railway vehicle pantographs. In this approach a pilot study quasi-pantograph (QP) is tested within a laboratory environment, where the catenary wire, contact wire and catenary support (abbreviated as 'catenary' in this paper) are modelled as a numerical substructure. This is simulated in real time and in parallel with the operation of the physical substructure, i.e. the QP rig itself. The entire DSS is driven by parametric excitation within the catenary model, whilst the numerical and physical substructures are synchronised at their interface via the DSS control technique of [1]. Simulation and physical experimental investigations of the pilot QP rig, constructed within the Advanced Control and Test Laboratory at the University of Bristol, UK, demonstrate the efficacy of the method when subjected to parametric variations, unknown parameter values and parametric excitation.

10:30 Vibroacoustics

Prediction of noise transmission through infinite panels using a wave and finite element method (2126)

Y Yang, B R Mace, M Kingan

The transmission of sound through simple infinite isotropic panels can be predicted in a straightforward manner using well-established analytical models. However, such models become difficult to implement for more complicated structures such as laminates etc. In these cases, numerical approaches such as the finite element method are viable alternatives. However, these methods can be computationally intensive as the entire structure must usually be meshed with the surrounding fluid being modelled using finite, infinite or boundary element methods. This paper describes the extension of a Wave and Finite Element (WFE) method for the prediction of sound transmission through infinite, two-dimensional panels. Excitation of the structure by oblique plane waves, a diffuse sound field and a point force are all considered. The WFE method involves a finite element model of a small segment of the panel from which the wave properties and the response to external excitation can be found. Because the WFE method only involves meshing a small segment of the panel, computational times are significantly less than a full finite element simulation. Two example applications of the method are described, namely a thin isotropic panel and a laminated panel.

10:30 Damage Detection and Structural Health Monitoring I

The Parameter Identification Method of Blade Asynchronous Vibration under Sweep Speed Excitation (2198)

L Yue, H Liu, C Zang, D Wang, W Hu, L Wang

The non-contact blade tip timing (BTT) measurement, with the advantage of measuring all the disk blades, has obtained widespread applications in industries. The measured data is under-sampled. Generally asynchronous vibrations will appear with the rotating speed sweeping under the excitation of the flow field, which can create a great increase of the blade vibration amplitude that is potentially harmful to the operation reliability of the turbine. In this paper, the investigation on the parameter identification method of blade asynchronous vibration under variable speed excitations was deeply explored. A novel method of parameter identification has been developed, based on the two sensors data interpolation in order to increase the frequency that can be identified. The spectral analysis with all phases Fast Fourier Transform (apFFT) was performed to extract the accuracy amplitude and phase of the blade. The order tracking calculation was carried out based on the minimum angle error. A mathematical model with four blades was developed to simulate the BTT testing data which can produce the simulation of speed sweep asynchronous vibration signal of the four blades. The correctness and accuracy of the algorithm was verified with the parameters identification of blade asynchronous vibration using the simulation model.

10:30 Biomechanics and Human-Machine Interface

Frontal Plane Modelling of Human Dynamics during Standing in Narrow-Stance (2304)

M Sonobe, H Yamaguchi, J Hino

Standing ride type vehicles like electric skateboards have been developed in recent years. Although these vehicles have advantages as being compact and low cost due to their simple structure, it is necessary to improve the riding quality. Therefore, the system aiding riders to keep their balance on a skateboard by feedback control or feedforward control has been required. To achieve it, a human balance model should be built as simple as possible. In this study, we focus on the human balance modelling during standing when the support surface moves largely. We restricted the model on frontal plane and narrow stance because the restrictions allow us to assume single-degree-of-freedom model. The balance control system is generally assumed as a delayed feedback control system. The model was identified through impulse response test and frequency response test. As a result, we found the phase between acceleration of the skateboard and posture angle become opposite phase in low frequency range.

Notes

10:45 Active Vibration Control I

Comparison of adaptive algorithms for the control of tonal disturbances in mechanical systems (2215)

M Zilletti, S J Elliott, J Cheer

This paper presents a study on the performance of adaptive control algorithms designed to reduce the vibration of mechanical systems excited by a harmonic disturbance. The mechanical system consists of a mass suspended on a spring and a damper. The system is equipped with a force actuator in parallel with the suspension. The control signal driving the actuator is generated by adjusting the amplitude and phase of a sinusoidal reference signal at the same frequency as the excitation. An adaptive feedforward control algorithm is used to adapt the amplitude and phase of the control signal, to minimise the mean square velocity of the mass. Two adaptation strategies are considered in which the control signal is either updated after each period of the oscillation or at every time sample. The first strategy is traditionally used in vibration control in helicopters for example; the second strategy is normally referred to as the filtered-x least mean square algorithm and is often used to control engine noise in cars. The two adaptation strategies are compared through a parametric study, which investigates the influence of the properties of both the mechanical system and the control system on the convergence speed of the two algorithms.

10:45 Vehicle Dynamics and Control I

Synthesised H_∞/μ Control Design for Dynamically Substructured Systems (2124)

T Yamaguchi, D P Stoten

In the dynamically substructured system (DSS) testing technique, a controller that synchronises the responses of physical and numerical substructures is an essential part of the testing scheme to ensure synchronisation fidelity. This paper discusses a novel approach that generates a two-degree-of-freedom (2-DOF) output feedback controller for multi-input, multioutput (MIMO) DSS via control synthesis. This 2-DOF output feedback controller yields robust stability and robust performance of the physical/numerical substructure synchronisation and enables controller tuning in the frequency domain. Simulation and experimental results have been shown to validate the efficacy of the method.

10:45 Vibroacoustics

Dynamic response analysis of an aircraft structure under thermal-acoustic loads (2491)

H Cheng, H B Li, W Zhang, Z Q Wu, B R Liu

Future hypersonic aircraft will be exposed to extreme combined environments includes large magnitude thermal and acoustic loads. It presents a significant challenge for the integrity of these vehicles. Thermal-acoustic test is used to test structures for dynamic response and sonic fatigue due to combined loads. In this research, the numerical simulation process for the thermal acoustic test is presented, and the effects of thermal loads on vibro-acoustic response are investigated. To simulate the radiation heating system, Monte Carlo theory and thermal network theory was used to calculate the temperature distribution. Considering the thermal stress, the high temperature modal parameters are obtained with structural finite element methods. Based on acoustic finite element, modal-based vibro-acoustic analysis is carried out to compute structural responses. These researches are very vital to optimum thermal-acoustic test and structure designs for future hypersonic vehicles structure

10:45 Damage Detection and Structural Health Monitoring I

The influences of soil and nearby structures on dispersion characteristics of wave propagating along buried plastic pipes (2221)

S Liu, J Jiang, N Parr

Water loss in distribution systems is a global problem for the water industry and governments. According to the international water supply association (IWSA), as a result of leaks from distribution pipes, 20% to 30% of water is lost while in transit from treatment plants to consumers. Although governments have tried to push the water industry to reduce the water leaks, a lot of experts have pointed out that a wide use of plastic pipes instead of metal pipes in recent years has caused difficulties in the detection of leaks using current acoustic technology. Leaks from plastic pipes are much quieter than traditional metal pipes and comparing to metal pipes the plastic pipes have very different coupling characteristics with soil, water and surrounding structures, such as other pipes, road surface and building foundations. The dispersion characteristics of wave propagating along buried plastic pipes are investigated in this paper using finite element and boundary element based models. Both empty and water-filled pipes were considered. Influences from nearby pipes and building foundations were carefully studied. The results showed that soil condition and nearby structures have significant influences on the dispersion characteristics of wave propagating along buried plastic pipes.

10:45 Biomechanics and Human-Machine Interface

Reduced-order models for vertical human-structure interaction (2440)

K Van Nimmen, G Lombaert, G De Roeck, P Van den Broeck

For slender and lightweight structures, the vibration serviceability under crowd-induced loading is often critical in design. Currently, designers rely on equivalent load models, upscaled from single-person force measurements. Furthermore, it is important to consider the mechanical interaction with the human body as this can significantly reduce the structural response. To account for these interaction effects, the contact force between the pedestrian and the structure can be modelled as the superposition of the force induced by the pedestrian on a rigid floor and the force resulting from the mechanical interaction between the structure and the human body. For the case of large crowds, however, this approach leads to models with a very high system order. In the present contribution, two equivalent reduced-order models are proposed to approximate the dynamic behaviour of the full-order coupled crowd-structure system. A numerical study is performed to evaluate the impact of the modelling assumptions on the structural response to pedestrian excitation. The results show that the full-order moving crowd model can be well approximated by a reduced-order model whereby the interaction with the pedestrians in the crowd is modelled using a single (equivalent) SDOF system.

Notes

11:00 Active Vibration Control I

Active vibration control of a plate using vibration gradients (2247)

T Kaizuka, K Nakano

Minimization of the squared transverse velocity at a measurement point does not guarantee the global vibration reduction for the whole structure, and the control result is dependent on the measurement point. Flexibility of the sensor placement is usually limited in practice. If the measurement point is near the nodal line of the mode, this mode cannot be decreased effectively and even increased by the control force. This study investigates the control method with the error criterion being the sum of the squared vibration velocity and the squared vibration gradients (spatial gradients) at a measurement point. Since the spatial distributions of the vibration velocity and its gradients are different, the aforementioned problem caused by the nodal line are mitigated. The numerical examples indicate that the performance of the control including the vibration gradients is less dependent on the measurement point, and this method achieves a better global vibration reduction, than the conventional method, i.e., minimization of the squared vibration velocity.

11:00 Vehicle Dynamics and Control I

Fundamental study of subharmonic vibration of order 1/2 in automatic transmissions for cars (2151)

T Ryu, T Nakae, K Matsuzaki, A Nanba, Y Takikawa, Y Ooi, A Sueoka

A torque converter is an element that transfers torque from the engine to the gear train in the automatic transmission of an automobile. The damper spring of the lock-up clutch in the torque converter is used to effectively absorb the torsional vibration caused by engine combustion. A damper with low stiffness reduces fluctuations in rotational speed but is difficult to use because of space limitations. In order to address this problem, the damper is designed using a piecewise-linear spring with three stiffness stages. However, the damper causes a nonlinear vibration referred to as a subharmonic vibration of order 1/2. In the subharmonic vibration, the frequency is half that of the vibrations from the engine. In order to clarify the mechanism of the subharmonic vibration, in the present study, experiments are conducted using the fundamental experimental apparatus of a single-degree-of-freedom system with two stiffness stages. In the experiments, countermeasures to reduce the subharmonic vibration by varying the conditions of the experiments are also performed. The results of the experiments are evaluated through numerical analysis using the shooting method. The experimental and analytical results were found to be in close agreement.

11:00 Vibroacoustics

Modelling of high-frequency structure-borne sound transmission on FEM grids using the Discrete Flow Mapping technique (2497)

T Hartmann, G Tanner, G Xie, D Chappell, J Bajars

Dynamical Energy Analysis (DEA) combined with the Discrete Flow Mapping technique (DFM) has recently been introduced as a mesh-based high frequency method modelling structure borne sound for complex built-up structures. This has proven to enhance vibro-acoustic simulations considerably by making it possible to work directly on existing finite element meshes circumventing time-consuming and costly re-modelling strategies. In addition, DFM provides detailed spatial information about the vibrational energy distribution within a complex structure in the mid-to-high frequency range. We will present here progress in the development of the DEA method towards handling complex FEM-meshes including Rigid Body Elements. In addition, structure borne transmission paths due to spot welds are considered. We will present applications for a car floor structure.

11:00 Damage Detection and Structural Health Monitoring I

Application of the wave finite element method to reinforced concrete structures with damage (2252)

E El Masri, N Ferguson, T Waters

Vibration based methods are commonly deployed to detect structural damage using sensors placed remotely from potential damage sites. Whilst many such techniques are modal based there are advantages to adopting a wave approach, in which case it is essential to characterise wave propagation in the structure. The Wave Finite Element method (WFE) is an efficient approach to predicting the response of a composite waveguide using a conventional FE model of a just a short segment. The method has previously been applied to different structures such as laminated plates, thinwalled structures and fluid-filled pipes. In this paper, the WFE method is applied to a steel reinforced concrete beam. Dispersion curves and wave mode shapes are first presented from free wave solutions, and these are found to be insensitive to loss of thickness in a single reinforcing bar. A reinforced beam with localised damage is then considered by coupling an FE model of a short damaged segment into the WFE model of the undamaged beam. The fundamental bending, torsion and axial waves are unaffected by the damage but some higher order waves of the cross section are significantly reflected close to their cut-on frequencies. The potential of this approach for detecting corrosion and delamination in reinforced concrete beams will be investigated in future work.

11:00 Biomechanics and Human-Machine Interface

Human-structure interaction effects on the maximum dynamic response based on an equivalent spectral model for pedestrian-induced loading (2494)

E Bassoli, K Van Nimmen, L Vincenzi, P Van den Broeck

This paper investigates the effects of the human-structure interaction (HSI) on the dynamic response based on a spectral model for vertical pedestrian-induced forces. The spectral load model proposed in literature can be applied for the vibration serviceability analysis of footbridges subjected to unrestricted pedestrian traffic as well as in crowded conditions, however, in absence of HSI phenomena. To allow for a more accurate prediction of the maximum structural response, the present study in addition accounts for the vertical mechanical interaction between pedestrians, represented by simple lumped parameter models, and the supporting structure. By applying the classic methods of linear random dynamics, the maximum dynamic response is evaluated based on the analytical expression of the spectral model of the loading and the frequency response function (FRF) of the coupled system. The most significant HSI-effect is in the increase of the effective damping ratio of the coupled system that leads to a reduction of the structural response. However, in some cases the effect of the change in the frequency of the coupled system is more significant, whereby this results into a higher structural response when the HSI-effects are accounted for.

Notes

11:15 Active Vibration Control I

Ground test for vibration control demonstrator (2270)

C Meyer, J Prodigue, G Broux, O Cantinaud, C Poussot-Vassal

In the objective of maximizing comfort in Falcon jets, Dassault Aviation is developing an innovative vibration control technology. Vibrations of the structure are measured at several locations and sent to a dedicated high performance vibration control computer. Control laws are implemented in this computer to analyse the vibrations in real time, and then elaborate orders sent to the existing control surfaces to counteract vibrations. After detailing the technology principles, this paper focuses on the vibration control ground demonstration that was performed by Dassault Aviation in May 2015 on Falcon 7X business jet. The goal of this test was to attenuate vibrations resulting from fixed forced excitation delivered by shakers. The ground test demonstrated the capability to implement an efficient closed-loop vibration control with a significant vibration level reduction and validated the vibration control law design methodology. This successful ground test was a prerequisite before the flight test demonstration that is now being prepared. This study has been partly supported by the JTI CleanSky SFWA-ITD.

11:15 Vehicle Dynamics and Control I

A New Approach for NOx Soft Sensors for the Aftertreatment of Diesel Engines (2153)

S Ishizuka, I Kajiwara, J Sato, Y Hanamura

To maintain the NOX concentration at an appropriate level, traditionally an air-path control that regulates the intake and exhaust system of diesel engines aims to control the mass air flow and the manifold absolute pressure, which influence the production of NOX. To improve the control accuracy, a more recent approach takes the NOX concentration directly as a controlled output variable, but the sensors monitoring the NOX concentration are slow to respond. Consequently, a direct sensor is inappropriate as a feedback controller. Instead a mechanism called a soft sensor, which computes the NOX concentration from state quantities of diesel engines, is used. Because the prediction accuracy from the sensor model greatly affects the control performance, it is important to improve the model accuracy. However, deviations in the steady state indicate an insufficient model accuracy. This study proposes a method to construct an adaptive NOX soft sensor that corrects the parameters of the sensor model sequentially using the simultaneous perturbation stochastic approximation while comparing the values computed by the software to actual measurements as well as examines the effectiveness of the proposed method experimentally.

11:15 Vibroacoustics

Application of FE-SEA hybrid method in vibro-acoustic environment prediction of complex structure (2554)

Z H Qi, Z P Zhang, F Ren, H B Li, Z H Liu, Z Zhang, K Yuan, Y C Wang

Spacecraft sustains the complex and severe vibro-acoustic environments during the flight. Acoustic test is different from random vibration test, but they can complement the energy in different frequency band for each other. Vibro-acoustic environment prediction of structure can provide supports for measuring point arrangement and test condition defining. In this paper, the application of FE-SEA hybrid method in vibro-acoustic environment prediction of complex structure is studied. Structural response is predicted through reasonable loading method and modelling method. Vibro-acoustic test results show the validity of the prediction method.

11:15 Damage Detection and Structural Health Monitoring I

Damage Identification Dependence on Number of Vibration Modes Using Mode Shape Curvature Squares (2269)

R Janeliukstis, S Rucevskis, M Wesolowski, A Chate

In this paper a damage identification algorithm for multiple damage sites based on mode shape curvature square method of vibration mode shapes in aluminium beam is reported. The required mode shape curvature of a healthy structure was obtained via interpolation of mode shape curvature of a damaged structure with Fourier series functions of different orders. Algorithm employed calculations of standardized damage index distributions over beam coordinate. Finite element simulations of proposed methodology involving various artificial noise levels and reduction of mode shape input data points were validated on the damage identification results of experimentally measured mode shapes which were measured using scanning laser vibrometer. Results show that the algorithm is capable of capturing the areas of damage. The term called damage estimate reliability was introduced in terms of likelihood of the chosen approximation function to capture the location of damage.

11:15 Biomechanics and Human-Machine Interface

A study of a steering system algorithm for pleasure boats based on stability analysis of a human-machine system model (2349)

F Ikeda, S Toyama, S Ishiduki, H Seta

Maritime accidents of small ships continue to increase in number. One of the major factors is poor manoeuvrability of the Manual Hydraulic Steering Mechanism (MHSM) in common use. The manoeuvrability can be improved by using the Electronic Control Steering Mechanism (ECSM). This paper conducts stability analyses of a pleasure boat controlled by human models in view of path following on a target course, in order to establish design guidelines for the ECSM. First, to analyse the stability region, the research derives the linear approximated model in a planar global coordinate system. Then, several human models are assumed to develop closed-loop human-machine controlled systems. These human models include basic proportional, derivative, integral and time-delay actions. The stability analysis simulations for those human-machine systems are carried out. The results show that the stability region tends to spread as a ship's velocity increases in the case of the basic proportional human model. The derivative action and time-delay action of human models are effective in spreading the stability region in their respective ranges of frontal gazing points.

Notes

11:30 Active Vibration Control I

Lateral Vibration Attenuation by the Dynamic Adjustment of Bias Currents in Magnetic Suspension System (2275)

T Mizuno, M Takasaki, Y Ishino

Switching stiffness control is applied to attenuate vibration in the lateral directions in an active magnetic suspension system with electromagnets operated in differential mode. The magnetic suspension system using the attractive force between magnetized bodies is inherently unstable in the normal direction so that feedback control is necessary to achieve stable suspension. In contrast, it can be stable in the lateral directions due to the edge effects in the magnetic circuits. In several applications, such passive suspension is used in combination with the active one to reduce cost and space. However, damping in the lateral directions is generally small. As a result, induced vibrations in these directions are hardly attenuated. To suppress such vibration without any additional actuator (electromagnet), switching stiffness control is applied to a magnetic suspension system operated in the differential mode. The stiffness in the lateral direction is adjusted by varying the bias currents of an opposed pair of electromagnets located in the normal direction simultaneously according to the motion of the suspended object. When the varied bias currents are adjusted for the additive normal forces cancel each other, such control does not affect the suspension in the normal direction. The effectiveness of the proposed control methods is confirmed experimentally.

11:30 Vehicle Dynamics and Control I

Optimal Design of Spring Characteristics of Damper for Subharmonic Vibration in Automatic Transmission Powertrain (2154)

T Nakae, T Ryu, K Matsuzaki, S Rosbi, A Sueoka, Y Takikawa, Y Ooi

In the torque converter, the damper of the lock-up clutch is used to effectively absorb the torsional vibration. The damper is designed using a piecewise-linear spring with three stiffness stages. However, a nonlinear vibration, referred to as a subharmonic vibration of order 1/2, occurred around the switching point in the piecewise-linear restoring torque characteristics because of the nonlinearity. In the present study, we analyze vibration reduction for subharmonic vibration. The model used herein includes the torque converter, the gear train, and the differential gear. The damper is modeled by a nonlinear rotational spring of the piecewise-linear spring. We focus on the optimum design of the spring characteristics of the damper in order to suppress the subharmonic vibration. A piecewise-linear spring with five stiffness stages is proposed, and the effect of the distance between switching points on the subharmonic vibration is investigated. The results of our analysis indicate that the subharmonic vibration can be suppressed by designing a damper with five stiffness stages to have a small spring constant ratio between the neighboring springs. The distances between switching points must be designed to be large enough that the amplitude of the main frequency component of the systems does not reach the neighboring switching point.

11:30 Damage Detection and Structural Health Monitoring I

Remote pipeline assessment and condition monitoring using low-frequency axisymmetric waves: a theoretical study of torsional wave motion (2416)

J M Muggleton, E Rustighi, Y Gao

Waves that propagate at low frequencies in buried pipes are of considerable interest in a variety of practical scenarios, for example leak detection, remote pipe detection, and pipeline condition assessment and monitoring. Particularly useful are the n=0, or axisymmetric, modes in which there is no displacement (or pressure) variation over the pipe cross section. Previous work has focused on two of the three axisymmetric wavetypes that can propagate: the s=1, fluid-dominated wave; and the s=2, shell-dominated wave. In this paper, the third axisymmetric wavetype, the s=0 torsional wave, is studied. Whilst there is a large body of research devoted to the study of torsional waves and their use for defect detection in pipes at ultrasonic frequencies, little is known about their behaviour and possible exploitation at lower frequencies. Here, a low-frequency analytical dispersion relationship is derived for the torsional wavenumber for a buried pipe from which both the wavespeed and wave attenuation can be obtained. How the torsional waves subsequently radiate to the ground surface is then investigated, with analytical expressions being presented for the ground surface displacement above the pipe resulting from torsional wave motion within the pipe wall. Example results are presented and, finally, how such waves might be exploited in practice is discussed.

11:30 Biomechanics and Human-Machine Interface

Sports Training Support Method by Self-Coaching with Humanoid Robot (2366)

S Toyama, F Ikeda, T Yasaka

This paper proposes a new training support method called self-coaching with humanoid robots. In the proposed method, two small size inexpensive humanoid robots are used because of their availability. One robot called target robot reproduces motion of a target player and another robot called reference robot reproduces motion of an expert player. The target player can recognize a target technique from the reference robot and his/her inadequate skill from the target robot. Modifying the motion of the target robot as self-coaching, the target player could get advanced cognition. Some experimental results show some possibility as the new training method and some issues of the self-coaching interface program as a future work.

Notes

11:45 Active Vibration Control I

Active vibration isolation through a Stewart platform with piezoelectric actuators (2295)

C Wang, X Xie, Y Chen, Z Zhang

A Stewart platform with piezoelectric actuators is presented for micro-vibration isolation. The Jacobian matrix of the Stewart platform, which reveals the relationship between the position/pointing of the payload and the extensions of the struts, is derived by the kinematic analysis and modified according to measured FRFs(frequency response function). The dynamic model of the Stewart platform is established by the FRF synthesis method to accommodate flexible modes of the platform. In active isolation, the LMS-based adaptive method is adopted and combined with the Jacobian matrix to suppress pure vibrations of the payload. Numerical simulations and experiments were conducted to prove vibration isolation performance of the Stewart platform subjected to periodical disturbances, and the results have demonstrated that considerable attenuations can be achieved.

11:45 Vehicle Dynamics and Control I

Optimization of vehicle-trailer connection systems (2159)

F Sorge

The three main requirements of a vehicle-trailer connection system are: *en route* stability, over- or under-steering restraint, minimum off-tracking along curved path. Linking the two units by four-bar trapeziums, wider stability margins may be attained in comparison with the conventional pintle-hitch for both instability types, divergent or oscillating. The stability maps are traced applying the Hurwitz method or the direct analysis of the characteristic equation at the instability threshold. Several types of four-bar linkages may be quickly tested, with the drawbars converging towards the trailer or the towing unit. The latter configuration appears preferable in terms of self-stability and may yield high critical speeds by optimising the geometrical and physical properties. Nevertheless, the system stability may be improved in general by additional vibration dampers in parallel with the connection linkage. Moreover, the four-bar connection may produce significant corrections of the under-steering or over-steering behaviour of the vehicle-train after a steering command from the driver. The off-tracking along the curved paths may be also optimized or kept inside prefixed margins of acceptableness. Activating electronic stability systems if necessary, fair results are obtainable for both the steering conduct and the off-tracking.

11:45 Damage Detection and Structural Health Monitoring I

A novel method for the remote condition assessment of buried pipelines using low-frequency axisymmetric waves (2418)

J M Muggleton, E Rustighi

“Mapping the Underworld” is a large multi-disciplinary, multi-university research programme taking place in the UK, which aims to revolutionize the way we undertake streetworks. Within this programme, a number of vibration-based techniques for remotely detecting and locating buried pipes have been developed. Relying either on the direct excitation of a pipe as it comes up to the surface or excitation of the ground in the vicinity of a buried pipe, mapping the ground surface vibration response allows information to be gathered concerning the pipe’s exact position. However, contained within this surface response is often information which could, if utilized appropriately, provide insights into the condition of the pipe as well as its location. Furthermore, critical information regarding the condition of the ground in which a pipe is buried could, in some circumstances, be gleaned. In this paper, how this additional information might be extracted, used and eventually exploited is explored. Providing the basis for work currently being undertaken in a new programme, “Assessing the Underworld”, example results are presented which demonstrate the immense potential of the proposed methods.

Notes

12:00 Active Vibration Control I

Vibration attenuation of conductive beams by inducing eddy currents (2317)

L Irazu, M J Elejabarrieta

The increasing requirements for structural vibration control in many industries, require innovative attenuation techniques. In this work, the phenomenon of eddy currents is proposed to reduce the vibration of conductive and non-magnetic beam-like structures without modifying the system, neither the weight nor the stiffness. The motion of a conductive material in a stationary magnetic field induces eddy currents, which in turn generate a repulsive force and attenuate the vibration. In this study, the vibrational response of a thin aluminium beam under a partial and stationary magnetic field is analysed. The influence of the eddy currents is experimentally studied in the bandwidth from 0 to 1 kHz and a preliminary numerical model is proposed. The results show the vibration of all the length of the beam can be attenuated by inducing eddy currents, whereas the natural frequencies of the system remain unmodified. The attenuation of the vibration is more remarkable at low frequencies and when the position of the magnetic field coincides with a maximum vibration of a mode.

12:00 Vehicle Dynamics and Control I

Multibody simulation of vehicles equipped with an automatic transmission (2219)

B Olivier, G Kouroussis

Nowadays automotive vehicles remain as one of the most used modes of transportation. Furthermore automatic transmissions are increasingly used to provide a better driving comfort and a potential optimization of the engine performances (by placing the gear shifts at specific engine and vehicle speeds). This paper presents an effective modeling of the vehicle using the multibody methodology (numerically computed under EasyDyn, an open source and in-house library dedicated to multibody simulations). However, the transmission part of the vehicle is described by the usual equations of motion computed using a systematic matrix approach: del Castillo's methodology for planetary gear trains. By coupling the analytic equations of the transmission and the equations computed by the multibody methodology, the performances of any vehicle can be obtained if the characteristics of each element in the vehicle are known. The multibody methodology offers the possibilities to develop the vehicle modeling from 1D-motion to 3D-motion by taking into account the rotations and implementing tire models. The modeling presented in this paper remains very efficient and provides an easy and quick vehicle simulation tool which could be used in order to calibrate the automatic transmission.

Notes

12:15 Active Vibration Control I

Active partial eigenvalue assignment for friction-induced vibration using receptance method (2664)

Y Liang, H J Ouyang, H Yamaura

Generally, a mechanical system always has symmetric system matrices. Nevertheless, when some non-conservative forces are included, such as friction and aerodynamic force, the symmetry of the stiffness matrix or damping matrix or both violated. Moreover, such an asymmetric system is prone to dynamic instability. Distinct from the eigenvalue assignment for symmetric systems to reassign their natural frequencies, the main purpose of eigenvalue assignment for asymmetric systems is to shift the unstable eigenvalues to the stable region. In this research, only the unstable eigenvalues and eigenvalues which are close to the imaginary axis of the complex eigenvalue plane are assigned due to their predominant influence on the response of the system. The remaining eigenvalues remain unchanged. The state-feedback control gains are obtained by solving the constrained linear least-squares problems in which the linear system matrices are deduced based on the receptance method and the constraint is derived from the unobservability condition. The numerical simulation results demonstrate that the proposed method is capable of partially assigning those targeted eigenvalues of the system for stabilisation.

12:15 Vehicle Dynamics and Control I

Design and implementation of a personal mobility of single spherical drive (2356)

T Hoshino, M Yazawa, R Naganuma, K Takada

This paper deals with a personal electric vehicle driven by a single spherical wheel. Using an appropriate feedback control, this driving strategy realizes dynamic stability in all directions and the vehicle can always be kept upright on the road surface of variety of slopes. It also enables immediate mobility to all directions, unlike personal vehicles of twowheel type. The spherical wheel is driven by omnidirectional wheels as usual; however, since the number and location of wheels have huge effect on the driving performance, the authors firstly analyze kinematics of omnidirectional wheels and sphere and derive new configuration to achieve maximum power. Based on the kinematic analysis, the equation of motion of the vehicle is derived via Lagrangian formulation. The full dynamic model including kinematic constraints is then derived. Using the full model, a stabilizing controller for driving is designed based on partial feedback linearization technique. The vehicle is constructed and tested with a human driver. The proposed configuration of omnidirectional wheels, the controller design model and the control scheme are examined in practice. Results of the experiments, including going over uphill road and uneven ground, show much better driving performance than authors’ previous prototype of the similar.

Notes

14:30 Active Vibration Control II

Passive Micro Vibration Isolator Utilizing Flux Pinning Effect for Satellites (2330)

T Shibata, S Sakai

Information related to the origin of space and evolution of galaxy can be obtained using the observation satellites. In recent years, high pointing accuracy is demanded for getting more detailed data about distant stars and galaxies. As a result, vibration isolators that consist of a main structure and a TTM (Tip Tilt Mirror) have been adopted for observation satellites. However, cutting the low frequency vibrations off passively with the conventional methods is difficult. A vibration isolator that uses pinning effect is proposed for solving this problem. The pinning effect is acquired by cooling the type-II superconductor below the critical temperature and it generates a pinning force to maintain the relative distance and attitude between a type-II superconductor and a material that generates magnetic flux. The mission part and the bus part of the satellite are equipped with superconductors and permanent magnets and these parts perform short distance formation flight by applying the effect. This method can cut vibrations from low to high frequency bands off passively. In addition, Meissner effect can prevent collision of the mission and bus parts. In order to investigate the performance of this system, experiments and simulations are carried out and the results are discussed.

14:30 Vehicle Dynamics and Control II

Study on Vibration Reduction Design of Suspended Equipment of High Speed Railway Vehicles (2397)

Y Sun, D Gong, J Zhou

The design methods of the under-chassis equipment of a high speed railway vehicle based on dynamic vibration absorber (DVA) theory and vibration isolation theory are proposed, respectively. A detailed rigid-flexible coupled dynamic model of a high speed railway vehicle which includes car body flexibility and the excitation of the suspended equipment is established. The vibrations of the car body and the suspension equipment with the proposed design methods are studied. Results show that the elastic vibration of the car body can be decreased effectively by mounting the under-chassis equipment with elastic suspension. Comparing with vibration isolation theory, the method based on DVA theory is more effective for suppressing the car body flexible vibration, but it will increase the vibration of the equipment to a certain extent. The method based on vibration isolation theory can reduce the vibration of both the car body and the equipment at the same time. Therefore, the design method should be selected appropriately according to the specific requirement.

14:30 Structural Acoustics and Noise Control I

Target spectrum matrix definition for multiple-input-multiple-output control strategies applied on direct-field-acoustic-excitation tests (2232)

M Alvarez Blanco, K Janssens, F Bianciardi

During the last two decades there have been several improvements on environmental acoustic qualification testing for launch and space vehicles. Direct field excitation (DFAX) tests using Multiple-Input-Multiple-Output (MIMO) control strategies seems to become the most cost-efficient way for component and subsystem acoustic testing. However there are still some concerns about the uniformity and diffusivity of the acoustic field produced by direct field testing. Lately, much of the documented progresses aimed to solve the non-uniformity of the field by altering the sound pressure level requirement, limiting responses and adding or modifying control microphones positions. However, the first two solutions imply modifying the qualification criteria, which could lead to under-testing, potentially risking the mission. Furthermore, adding or moving control microphones prematurely changes the system configuration, even if it is an optimal geometric layout in terms of wave interference patterns control. This research investigates the target definition as an initial condition for the acoustic MIMO control. Through experiments it is shown that for a given system configuration the performance of a DFAX test strongly depends on the target definition procedure. As output of this research a set of descriptors are presented describing a phenomenon defined as “Energy-sink”.

14:30 Damage Detection and Structural Health Monitoring II

Dynamic behaviour of a rotating cracked beam (2480)

A Yashar, M Ghandchi Tehrani, N Ferguson

This paper presents a new approach to investigate and analyse the vibrational behaviour of cracked rotating cantilever beams, which can for example represent helicopter or wind turbine blades. The analytical Hamiltonian method is used in modelling the rotating beam and two numerical methods, the Rayleigh-Ritz and FEM, are used to study the natural frequencies and the mode shapes of the intact rotating beams. Subsequently, a crack is introduced into the FE model and simulations are performed to identify the modal characteristics for an open cracked rotating beam. The effect of various parameters such as non-dimensional rotating speed, hub ratio and slenderness ratio are investigated for both the intact and the cracked rotating beam, and in both directions of chordwise and flapwise motion. The veering phenomena in the natural frequencies as a function of the rotational speed and the buckling speed are considered with respect to the slenderness ratio. In addition, the mode shapes obtained for the flapwise vibration are compared using the modal assurance criterion (MAC). Finally, a new three dimensional design chart is produced, showing the effect of crack location and depth on the natural frequencies of the rotating beam. This chart will be subsequently important in identifying crack defects in rotating blades.

14:30 Impulse Loading and Impact Dynamics

Rebound Vibration of Two-Plates Bonded Model for an Internal Mirror of SLR Camera (2314)

H Matsumoto, M Kumagai, A Kikuchi

In this study, the rebound vibration characteristics of the internal mirror of an SLR camera are investigated using experimental models. The mechanism of the mirror rebound phenomena is tested by using the two-rectangular-metal-plates model, which has two plates bonded by double-sided tape. The mirror (plates) model is supported by fixing its longitudinal edge on a horizontal rotatable shaft. The bonded-mirror-model swings down freely around a horizontal axis and hits a stopper. A laser displacement meter is used to measures the amount of rebound and the mirror model vibration behavior. The rebound angle varies by the stopper position and the bonded position of the double-sided tape. In the case of a small rebound angle, the mirror part of the plate (upper side plate) vibrates with large amplitude, and its movement is measured by a 3-dimentional high-speed camera.

Notes

14:45 Active Vibration Control II

Test rig with active damping control for the simultaneous evaluation of vibration control and energy harvesting via piezoelectric transducers (2342)

S Perfetto, J Rohlfing, F Infante, D Mayer, S Herold

Piezoelectric transducers can be used to harvest electrical energy from structural vibrations in order to power continuously operating condition monitoring systems local to where they operate. However, excessive vibrations can compromise the safe operation of mechanical systems. Therefore, absorbers are commonly used to control vibrations. With an integrated device, the mechanical energy that otherwise would be dissipated can be converted via piezoelectric transducers. Vibration absorbers are designed to have high damping factors. Hence, the integration of transducers would lead to a low energy conversion. Efficient energy harvesters usually have low damping capabilities; therefore, they are not effective for vibration suppression. Thus, the design of an integrated device needs to consider the two conflicting requirements on the damping. This study focuses on the development of a laboratory test rig with a host structure and a vibration absorber with tunable damping via an active relative velocity feedback. A voice coil actuator is used for this purpose. To overcome the passive damping effects of the back electromagnetic force a novel voltage feedback control is proposed, which has been validated both in simulation and experimentally. The aim of this study is to have a test rig ready for the introduction of piezo-transducers and available for future experimental evaluations of the damping effect on the effectiveness of vibration reduction and energy harvesting efficiency.

14:45 Vehicle Dynamics and Control II

Pneumatic tyres interacting with deformable terrains (2442)

C A Bekakos, G Papazafeiropoulos, D J O’Boy, J Prins

In this study, a numerical model of a deformable tyre interacting with a deformable road has been developed with the use of the finite element code ABAQUS (v. 6.13). Two tyre models with different widths, not necessarily identical to any real industry tyres, have been created purely for research use. The behaviour of these tyres under various vertical loads and different inflation pressures is studied, initially in contact with a rigid surface and then with a deformable terrain. After ensuring that the tyre model gives realistic results in terms of the interaction with a rigid surface, the rolling process of the tyre on a deformable road was studied. The effects of friction coefficient, inflation pressure, rebar orientation and vertical load on the overall performance are reported. Regarding the modelling procedure, a sequence of models were analysed, using the coupling implicit – explicit method. The numerical results reveal that not only there is significant dependence of the final tyre response on the various initial driving parameters, but also special conditions emerge, where the desired response of the tyre results from specific optimum combination of these parameters.

14:45 Structural Acoustics and Noise Control I

Optimization of natural frequencies of large-scale two-stage raft system (2260)

L V Zhiqiang, H Lin, S Changgeng

A multi-parameter optimization method for the natural frequencies of two-stage raft system is presented in this paper. The method can limit the natural frequencies in a relatively narrow band by quantitatively adjusting the natural frequencies of the system, which helps to avoid resonances and isolate vibration effectively. This method is of great significance in ship noise reduction engineering.

14:45 Damage Detection and Structural Health Monitoring II

Structural Dynamic Response Compressing Technique in Bridges using a Cochlea-inspired Artificial Filter Bank(CAFB) (2611)

G Heo, J Jeon, B Son, C Kim, S Jeon, C Lee

In this study, a cochlea-inspired artificial filter bank (CAFB) was developed to efficiently obtain dynamic response of a structure, and a dynamic response measurement of a cable-stayed bridge model was also carried out to evaluate the performance of the developed CAFB. The developed CAFB used a band-pass filter optimizing algorithm (BOA) and peak-picking algorithm (PPA) to select and compress dynamic response signal containing the modal information which was significant enough. The CAFB was then optimized about the El-Centro earthquake wave which was often used in the construction research, and the software implementation of CAFB was finally embedded in the unified structural management system (USMS). For the evaluation of the developed CAFB, a real time dynamic response experiment was performed on a cable-stayed bridge model, and the response of the cable-stayed bridge model was measured using both the traditional wired system and the developed CAFB-based USMS. The experiment results showed that the compressed dynamic response acquired by the CAFB-based USMS matched significantly with that of the traditional wired system while still carrying sufficient modal information of the cable-stayed bridge.

14:45 Impulse Loading and Impact Dynamics

Impact analyses for negative flexural responses (hogging) in railway prestressed concrete sleepers (2548)

S Kaewunruen, T Ishida, A M Remennikov

By nature, ballast interacts with railway concrete sleepers in order to provide bearing support to track system. Most train-track dynamic models do not consider the degradation of ballast over time. In fact, the ballast degradation causes differential settlement and impact forces acting on partial and unsupported tracks. Furthermore, localised ballast breakages underneath railseat increase the likelihood of centrebound cracks in concrete sleepers due to the unbalanced support under sleepers. This paper presents a dynamic finite element model of a standard-gauge concrete sleeper in a track system, taking into account the tensionless nature of ballast support. The finite element model was calibrated using static and dynamic responses in the past. In this paper, the effects of centre-bound ballast support on the impact behaviours of sleepers are highlighted. In addition, it is the first to demonstrate the dynamic effects of sleeper length on the dynamic design deficiency in concrete sleepers. The outcome of this study will benefit the rail maintenance criteria of track resurfacing in order to restore ballast profile and appropriate sleeper/ballast interaction.

Notes

15:00 Active Vibration Control II

Suppressing self-excited vibrations of mechanical systems by impulsive force excitation (2348)

T Pumhössel

In this contribution, self-excited mechanical systems subjected to force excitation of impulsive type are investigated. It is shown that applying force impulses which are equally spaced in time, but whose impulsive strength depends in a certain manner on the state-variables of the mechanical system, results in a periodic energy exchange between lower and higher modes of vibration. Moreover, in the theoretical case of Dirac delta impulses, it is possible that no energy crosses the system boundary while energy is transferred across modes, i.e. neither external energy is fed to the mechanical system, nor energy is extracted from the mechanical system. Shifting energy to higher modes of vibration, whose natural damping is larger compared to lower ones, results in a faster dissipation of energy. An analytical stability investigation is presented using the assumption of impulsive forcing of Dirac delta type, which allows deciding easily about the stability by evaluating the eigenvalues of the coefficient matrix of a corresponding set of difference equations. It is shown that the developed impulsive forcing concept is capable to suppress self-excited vibrations of mechanical systems. Some numerical results of a simple mechanical system with two degrees of freedom underline the presented approach.

15:00 Vehicle Dynamics and Control II

Characterisation of vibration input to flywheel used on urban bus (2454)

L Wang, S Kanarachos, J Christensen

Vibration induced from road surface has an impact on the durability and reliability of electrical and mechanical components attached on the vehicle. There is little research published relevant to the durability assessment of a flywheel energy recovery system installed on city and district buses. Relevant international standards and legislations were reviewed and large discrepancy was found among them, in addition, there are no standards exclusively developed for kinetic energy recovery systems on vehicles. This paper describes the experimentation of assessment of road surface vibration input to the flywheel on a bus as obtained at the MIRA Proving Ground. Power density spectra have been developed based on the raw data obtained during the experimentation. Validation of this model will be carried out using accelerated life time tests that will be carried out on a shaker rig using an accumulated profile based on the theory of fatigue damage equivalence in time and frequency domain aligned with the model predictions.

15:00 Structural Acoustics and Noise Control I

A study on calculation method for mechanical impedance of air spring (2283)

S Changgeng, L Penghui, E Rustighi

This paper proposes an approximate analytic method of obtaining the mechanical impedance of air spring. The sound pressure distribution in cylindrical air spring is calculated based on the linear air wave theory. The influences of different boundary conditions on the acoustic pressure field distribution in cylindrical air spring are analysed. A 1-order ordinary differential matrix equation for the state vector of revolutionary shells under internal pressure is derived based on the non-moment theory of elastic thin shell. Referring to the transfer matrix method, a kind of expanded homogeneous capacity high precision integration method is introduced to solve the non-homogeneous matrix differential equation. Combined the solved stress field of shell with the calculated sound pressure field in air spring under the displacement harmonic excitation, the approximate analytical expression of the input and transfer mechanical impedance for the air spring can be achieved. The numerical simulation with the Comsol Multiphysics software verifies the correctness of theoretical analysis result.

15:00 Damage Detection and Structural Health Monitoring II

The Detection of Vertical Cracks in Asphalt Using Seismic Surface Wave Methods (2434)

M Iodice, J Muggleton, E Rustighi

Assessment of the location and of the extension of cracking in road surfaces is important for determining the potential level of deterioration in the road overall and the infrastructure buried beneath it. Damage in a pavement structure is usually initiated in the tarmac layers, making the Rayleigh wave ideally suited for the detection of shallow surface defects. This paper presents an investigation of two surface wave methods to detect and locate top-down cracks in asphalt layers. The aim of the study is to understand the differences between the well-established Multichannel Analysis of Surface Waves (MASW) and the more recent Multiple Impact of Surface Waves (MISW) in the presence of a discontinuity and to suggest the best surface wave technique for evaluating the presence and the extension of vertical cracks in roads. The study is conducted through numerical simulations alongside experimental investigations and it considers the cases for which the cracking is internal and external to the deployment of sensors. MISW is found to enhance the visibility of the reflected waves in the frequency wavenumber (*f*-*k*) spectrum, helping with the detection of the discontinuity. In some cases, by looking at the *f*-*k* spectrum obtained with MISW it is possible to extract information regarding the location and the depth of the cracking.

15:00 Impulse Loading and Impact Dynamics

Research of hail impact on aircraft wheel door with lattice hybrid structure (2630)

S Li, F Jin, W Zhang, X Meng

Aimed at a long lasting issue of hail impact on aircraft structures and aviation safety due to its high speed, the resistance performance of hail impact on the wheel door of aircraft with lattice hybrid structure is investigated. The proper anti-hail structure can be designed both efficiency and precision based on this work. The dynamic responses of 8 different sandwich plates in diverse impact speed are measured. Smoothed Particle Hydrodynamic (SPH) method is introduced to mimic the speciality of solid-liquid mixture trait of hailstone during the impact process. The deformation and damage degree of upper and lower panel of sandwich plate are analysed. The application range and failure mode for the relevant structure, as well as the energy absorbing ratio between lattice structure and aluminium foam are summarized. Results show that the tetrahedral sandwich plate with aluminium foam core is confirmed the best for absorbing energy. Furthermore, the high absorption characteristics of foam material enhance the capability of the impact resistance for the composition with lattice structure without increasing the structure surface density. The results of study are of worth to provide a reliable basis for reduced weight aircraft wheel door.

Notes

15:15 Active Vibration Control II

Time-varying shunted electro-magnetic tuneable vibration absorber (2362)

E Turco, P Gardonio, L Dal Bo

This paper presents a theoretical study on the design and implementation of a time–varying shunted electro–magnetic Tuneable Vibration Absorber (TVA) for broad band vibration control of thin structures. A time–varying RL–shunt is used to harmonically vary the stiffness and damping properties of the TVA so that its mechanical fundamental resonance frequency is continuously swept in a given frequency band and its damping ratio is set to maximise the vibration absorption at each frequency. The paper first discusses the design of the time–varying shunt circuit. The vibration and noise control effectiveness produced by an array of shunted TVA mounted on a thin walled cylinder is then assessed numerically. The study shows that the array of proposed TVAs effectively controls the flexural response and interior noise of the hosting cylinder over a broad frequency band.

15:15 Vehicle Dynamics and Control II

Study on the precision of the guide control system of independent wheel (2463)

Y Ji, L Ren, R Li, W Sun

The torque ripple of permanent magnet synchronous motor vector with active control is studied in this paper. The ripple appears because of the impact of position detection and current detection, the error generated in inverter and the influence of motor ontology (magnetic chain harmonic and the cogging effect and so on). Then, the simulation dynamic model of bogie with permanent magnet synchronous motor vector control system is established with MATLAB/Simulink. The stability of bogie with steering control is studied. The relationship between the error of the motor and the precision of the control system is studied. The result shows that the existing motor does not meet the requirements of the control system.

15:15 Structural Acoustics and Noise Control I

A numerical method for seeking the relationship between structural modes and acoustic radiation modes of complicated structures (2213)

C-W Su, H-C Zhu, C-G Shuai, R-F Mao

Both structural modes and acoustic radiation modes play important roles in the investigation of structure-borne sound. However, little work has been done for inherent relations between these two kinds of modes. Previous work has mainly dealt with simple and regular structures such as rectangular plates and single-layer cylindrical shells. Therefore, the relationship between structural modes and acoustic radiation modes of complicated structures which has great theory significance and utility value is an important problem that must be studied. This paper presents a numerical method for seeking the relationship between structural modes and acoustic radiation modes of complicated structures. First, a governing equation for relating these two kinds of modes is given based on the characteristics of the modes. Then, substitute the normal structural mode shape matrix and the acoustic radiation mode shape matrix which are obtained by FEM into the governing equation, the modal participating coefficients can be solved, thus we can get the corresponding relations between these two kinds of modes. Using the model of a simply supported truncated conical shell, a numerical example is presented with the numerical method which this paper has proposed. And then, the radiated sound power is calculated to verify the effectiveness of this method and the correctness of this conclusion. The results show that the numerical method proposed in this paper is feasible.

Notes

16:00 Active Vibration Control III

Vibration Control by a Shear Type Semi-active Damper Using Magnetorheological Grease (2377)

T Shiraishi, H Misaki

This paper describes semi-active vibration control by a controllable damper with high reliability and wide dynamic range using magnetorheological (MR) grease. Some types of cylindrical controllable dampers based on pressure difference between chambers in the dampers using "MR fluid", whose rheological properties can be varied by applying a magnetic field, have been reported as a semi-active device. However, there are some challenging issues of them. One is to improve dispersion stability. The particles dispersed in MR fluid would make sedimentation after a period. Another is to expand dynamic range. Since cylindrical dampers require sealing elements because of pressure difference in the dampers, the dynamic range between the maximum and minimum damping force according to a magnetic field is reduced. In this study, a controllable damper using the MR effect was proposed and its performance was experimentally verified to improve the dispersion stability by using "MR grease", which includes grease as the carrier of magnetic particles, and to expand the dynamic range by adopting a shear type structure not requiring sealing elements. Furthermore, semiactive vibration control experiments by the MR grease damper using a simple algorithm based on the skyhook damper scheme were conducted and its performance was investigated.

16:00 Vehicle Dynamics and Control III

A Study on Automatic Passenger Mover Envelope Gauge (2474)

Y Ji, L Ren, Y Song

Based on structural feature of running gear of APM and referring to research achievement, the method of calculating APM envelope gauge is discussed and an example is illustrated. A reference for drawing up the standard of APM envelope gauge is provided.

16:00 Structural Acoustics and Noise Control II

Noise Control for a Moving Evaluation Point Using Neural Networks (2395)

T Maeda, T Shiraishi

This paper describes the noise control for a moving evaluation point using neural networks by making the best use of its learning ability. Noise control is a technology which is effective on low-frequency noise. Based on the principle of superposition, a primary sound wave can be cancelled at an evaluation point by emitting a secondary opposite sound wave. To obtain good control performance, it is important to precisely identify the characteristics of all the sound paths. One of the most popular algorithms of noise control is filtered-x LMS algorithm. This algorithm can deliver a good result while all the sound paths do not change. However, the control system becomes uncontrollable while the evaluation point is moving. To solve the problem, the characteristics of all the paths are must be identified at all time. In this paper, we applied neural networks with the learning ability to the noise control system to follow the time-varying paths and verified its control performance by numerical simulations. Then, dropout technique for the networks is also applied. Dropout is a technique that prevent the network from overfitting and enables better control performance. By applying dropout for noise control, it prevents the system from diverging.

16:00 Rotor Dynamics and Control

Enhancing stability of industrial turbines using adjustable partial arc bearings (2515)

A Chasalevris, F Dohnal

The paper presents the principal of operation, the simulation and the characteristics of two partial-arc journal bearings of variable geometry and adjustable/controllable stiffness and damping properties. The proposed journals are supposed to consist of a scheme that enables the periodical variation of bearing properties. Recent achievements of suppressing rotor vibrations using plain circular journal bearings of variable geometry motivate the further extension of the principle to bearings of applicable geometry for industrial turbines. The paper describes the application of a partial-arc journal bearing to enhance stability of high speed industrial turbines. The proposed partial-arc bearings with adjustable/controllable properties enhance stability and they introduce stable margins in speeds much higher than the 1st critical.

16:00 Fluid-Structure Interaction

Dynamic strain measurements of marine propellers under non-uniform inflow (2155)

J Tian, P Croaker, Z Zhang, H Hua

An experimental investigation was conducted to determine the dynamic strain characteristics of marine propellers under non-uniform inflow. Two 7-bladed highly skewed model propellers of identical geometries, but different elastic characteristics were tested at various rotational speeds and free stream velocities in the water tunnel. Two kinds of wire mesh wake screens located 400mm upstream of the propeller plane were used to generate four-cycle and six-cycle inflows. A laser doppler velocimetry (LDV) system located 100mm downstream of the wake screen plane was used to measure the axial velocity distributions produced by the wake screens. Strain gauges were bonded onto the propeller blades in different positions. A customized underwater data acquisition system which can record data off-line was used to record the dynamic strain. The results show that the frequency properties of the blade dynamic strain are determined by the harmonics of the inflow and that the stiffness of the propeller has an essential effect on the dynamic strain amplitudes.

Notes

16:15 Active Vibration Control III

Wave absorption of an orthotropic rectangular panel based on direct feedback (2378)

H Iwamoto, N Tanaka

This paper presents a new methodology of realizing an active wave control for an orthotropic rectangular panel. In general, an ideal wave controller is expressed by non-causal function which is impossible to be realized practically. The static direct feedback is introduced to overcome this problem. Firstly, a transfer matrix method for an orthotropic rectangular panel is introduced to describe the wave dynamics of the structure. This is followed by the derivation of feedback control laws for absorbing reflected waves. Then, static direct feedback is presented to realize the perfect wave absorption at single frequency. Finally, from a viewpoint of numerical analyses, control effects of the proposed method are verified by evaluating the absolute displacement distribution. It is found that the reflected wave absorbing control enables the inactivation of all vibration modes in the controlled direction.

16: 15 Vehicle Dynamics and Control III

Study on coupled shock absorber system using four electromagnetic dampers (2510)

Y Fukumori, R Hayashi, H Okano, Y Suda, K Nakano

Recently, the electromagnetic damper, which is composed of an electric motor, a ball screw, and a nut, was proposed. The electromagnetic damper has high responsiveness, controllability, and energy saving performance. It has been reported that it improved ride comfort and drivability. In addition, the authors have proposed a coupling method of two electromagnetic dampers. The method enables the characteristics of bouncing and rolling or pitching motion of a vehicle to be tuned independently. In this study, the authors increase the number of coupling of electromagnetic dampers from two to four, and propose a method to couple four electromagnetic dampers. The proposed method enables the characteristics of bouncing, rolling and pitching motion of a vehicle to be tuned independently. Basic experiments using proposed circuit and motors and numerical simulations of an automobile equipped with the proposed coupling electromagnetic damper are carried out. The results indicate the proposed method is effective.

16:15 Structural Acoustics and Noise Control II

Active structural acoustic control using the remote sensor method (2447)

J Cheer, S Daley

Active structural acoustic control (ASAC) is an effective method of reducing the sound radiation from vibrating structures. In order to implement ASAC systems using only structural actuators and sensors, it is necessary to employ a model of the sound radiation from the structure. Such models have been presented in the literature for simple structures, such as baffled rectangular plates, and methods of determining the radiation modes of more complex practical structures using experimental data have also been explored. A similar problem arises in the context of active noise control, where cancellation of a disturbance is required at positions in space where it is not possible to locate a physical error microphone. In this case the signals at the cancellation points can be estimated from the outputs of remotely located measurement sensors using the “remote microphone method”. This remote microphone method is extended here to the ASAC problem, in which the pressures at a number of microphone locations must be estimated from measurements on the structure of the radiating system. The control and estimation strategies are described and the performance is assessed for a typical structural radiation problem.

16:15 Rotor Dynamics and Control

Preventing the oil film instability in rotor-dynamics (2161)

F Sorge

Horizontal rotor systems on lubricated journal bearings may incur instability risks depending on the load and the angular speed. The instability is associated with the asymmetry of the stiffness matrix of the bearings around the equilibrium position, in like manner as the internal hysteretic instability somehow, where some beneficial effect is indeed obtainable by an anisotropic configuration of the support stiffness. Hence, the idea of the present analysis is to check if similar advantages are also obtainable towards the oil film instability. The instability thresholds are calculated by usual methods, such as the Routh criterion or the direct search for the system eigenvalues. The results indicate that the rotor performances may be improved in the range of low Sommerfeld numbers by softening the support stiffness in the vertical plane, and hardening it on the horizontal one, up to the complete locking, though this advantage has to be paid by rather lower instability thresholds for large Sommerfeld numbers. Nevertheless, a “two-mode” arrangement is conceivable, with some vertical flexibility of the supports for large journal eccentricity, and complete locking for small eccentricity. As another alternative, the support anisotropy may be associated with the use of step bearings, whose particular characteristic is to improve the stability for small eccentricities.

16:15 Fluid-Structure Interaction

Vibro-acoustics of porous materials – waveguide modelling approach (2162)

R Darula, S Sorokin

The porous material is considered as a compound multi-layered waveguide (i.e. a fluid layer surrounded with elastic layers) with traction free boundary conditions. The attenuation of the vibro-acoustic waves in such a material is assessed. This approach is compared with a conventional Biot's model and a qualitative agreement in phase velocities as well as damping estimates is found. The waveguide model predicts four waves, out of which two are attenuated when the viscous fluid is considered (while the elastic layer being ideally lossless). One of these waves is found to be significantly controlled by the fluid viscosity, while for the other the effect of viscosity was observed for very small frequencies. The Biot's model predicts only one of these attenuated waves, where the latter one is not predicted. Thus the proposed waveguide approach provide additional information about the wave propagation in porous materials.

Notes

16:30 Active Vibration Control III

Experimental investigation on a colloidal damper rendered controllable under the variable magnetic field generated by moving permanent magnets (2410)

B Suciu

In this work, a colloidal damper rendered controllable under variable magnetic fields is proposed and its controllability is experimentally evaluated. This absorber employs a waterbased ferrofluid (FERROTEC MSGW10) in association with a liquid-repellent nanoporous solid matrix, consisted of particles of gamma alumina or/and silica gel. Control of the dynamic characteristics is obtained by moving permanent neodymium annular magnets, which are placed either on the piston head (axial magnetic field) or on the external surface of the cylinder (radial magnetic field). In order to properly select these magnets, flow visualizations inside of a transparent model damper were performed, and the quantity of the displaced liquid by the magnets through the damper's filter and through the nanoporous solid matrix was determined. Experimental data concerning variation of the magnetic flux density at the magnet surface versus the height of the magnet, and versus the target distance was collected. Based on such data, the suitable magnet geometry was decided. Then, the 3D structural model of the trial colloidal damper obtained by using Solidworks, and the excitation test rig are presented. From excitation tests on a ball-screw shaker, one confirmed larger damping abilities of the proposed absorber relative to the traditional colloidal damper, and also the possibility to adjust the damping coefficient according to the excitation type.

16:30 Vehicle Dynamics and Control III

Steering Dynamics of Tilting Narrow Track Vehicle with Passive Front Wheel Design (2514)

J T C Tan, H Arakawa, Y Suda

In recent years, narrow track vehicle has been emerged as a potential candidate for the next generation of urban transportation system, which is greener and space effective. Vehicle body tilting has been a symbolic characteristic of such vehicle, with the purpose to maintain its stability with the narrow track body. However, the coordination between active steering and vehicle tilting requires considerable driving skill in order to achieve effective stability. In this work, we propose an alternative steering method with a passive front wheel that mechanically follows the vehicle body tilting. The objective of this paper is to investigate the steering dynamics of the vehicle under various design parameters of the passive front wheel. Modeling of a three-wheel tilting narrow track vehicle and multibody dynamics simulations were conducted to study the effects of two important front wheel design parameters, i.e. caster angle and trail toward the vehicle steering dynamics in steering response time, turning radius, steering stability and resiliency towards external disturbance. From the results of the simulation studies, we have verified the relationships of these two front wheel design parameters toward the vehicle steering dynamics.

16:30 Structural Acoustics and Noise Control II

Active Structural Acoustic Control in an Original A400M Aircraft Structure (2483)

C Koehne, D Sachau, K Renger

Low frequency noise has always been a challenge in propeller driven aircraft. At low frequencies passive noise treatments are not as efficient as active noise reduction systems. The Helmut-Schmidt-University has built up a full-scale test rig with an original A400M aircraft structure. This provides a good opportunity to develop and test active noise reduction systems in a realistic environment. The currently installed system consists of mechanical actuators and acoustical sensors. The actuators are called TVAs (Tuneable Vibration Absorber) and contain two spring-mass systems whose natural frequencies are adjusted to the BPFs (Blade Passage Frequency) of the propellers. The TVAs are mounted to the frames and the force direction is normal to the skin. The sensors are condenser microphones which are attached to the primary structure of the airframe. The TVAs are equipped with signal processing devices. These components carry out Fourier transforms and signal amplification for the sensor data and actuator signals. The communication between the TVAs and the central control unit is implemented by the CAN Bus protocol and mainly consists of complex coefficients for the sensor and actuator data. This paper describes the basic structure of the system, the hardware set-up and function tests of the controller.

16:30 Rotor Dynamics and Control

Vibration attenuation of rotating machines by application of magnetorheological dampers to minimize energy losses in the rotor support (2185)

J Zapomĕl, P Ferfecki

A frequently used technological solution for minimization of undesirable effects caused by vibration of rotating machines consists in placing damping devices in the rotor supports. The application of magnetorheological squeeze film dampers enables their optimum performance to be achieved in a wide range of rotating speeds by adapting their damping effect to the current operating conditions. The damping force, which is produced by squeezing the layer of magnetorheological oil, can be controlled by changing magnetic flux passing through the lubricant. The force acting between the rotor and its frame is transmitted through the rolling element bearing, the lubricating layer and the squirrel spring. The loading of the bearing produces a time variable friction moment, energy losses, uneven rotor running, and has an influence on the rotor service life and the current fluctuation in electric circuits. The carried out research consisted in the development of a mathematical model of a magnetorheological squeeze film damper, its implementation into the computational models of rotor systems, and in performing the study on the dependence of the energy losses and variation of the friction moment on the damping force and its control. The new and computationally stable mathematical model of a magnetorheological squeeze film damper, its implementation in the computational models of rigid rotors and learning more on the energy losses generated in the rotor supports in dependence on the damping effect are the principal contributions of this paper. The results of the computational simulations prove that a suitable control of the damping force enables the energy losses to be reduced in a wide velocity range.

16:30 Fluid-Structure Interaction

Development of Overflow-Prevention Valve with Trigger Mechanism (2325)

Y Ishino, T Mizuno, M Takasaki

A new overflow-prevention valve for combustible fluid is developed which uses a trigger mechanism. Loading arms for combustible fluid are used for transferring oil from a tanker to tanks and vice versa. The loading arm has a valve for preventing overflow. Overflow-prevention valves cannot use any electric component to avoid combustion. Therefore, the valve must be constructed only by mechanical parts. The conventional overflow-prevention valve uses fluid and pneumatic forces. It consists of a sensor probe, a cylinder, a main valve for shutting off the fluid and a locking mechanism for holding an open state of the main valve. The proposed overflow-prevention valve uses the pressure due to the height difference between the fluid level of the tank and the sensor probe. However, the force of the cylinder produced by the pressure is too small to release the locking mechanism. Therefore, a trigger mechanism is introduced between the cylinder and the locking mechanism. The trigger mechanism produces sufficient force to release the locking mechanism and close the main valve when the height of fluid exceeds a threshold value. A trigger mechanism is designed and fabricated. The operation necessary for closing the main valve is conformed experimentally.

Notes

16:45 Active Vibration Control III

Development of simple operation crane system for the real application (2472)

M Wada, Y Mori,Y Tagawa, E Kawajiri, K Nouzuka

In each industry, the weight of the transportation work and quantity of the load has increased. Thus, now the crane equipment is introduced than ever. For overhead crane used in factories and warehouses, efficient operation which suppresses the swaying of the suspended load during transport is strongly demanded. In particular, it is necessary to suppress the initial shaking or disturbance due to the shift of the center of gravity and the hanging point position at the time of raising the suspended load. Therefore, we need to develop the simple operation crane system that enables the operation of the same level as the person skilled in the crane operation in order to improve the safety and efficiency. The author have investigated the control using Dual Model Matching method based on characteristic transfer function matrix to a configuration of the controller. By implementing feedback control on an actual overhead crane in practical use, the efficacy and operability of the system and the method were discussed. The purpose of this study, by developing the simple operation crane system that allows the same operation as the skilled operator, is to improve the safety and efficiency of the crane operation.

16:45 Vehicle Dynamics and Control III

Integrated navigation of aerial robot for GPS and GPS-denied environment (2556)

S Suzuki, H Min, T Wada, K Nonami

In this study, novel robust navigation system for aerial robot in GPS and GPS-denied environments is proposed. Generally, the aerial robot uses position and velocity information from Global Positioning System (GPS) for guidance and control. However, GPS could not be used in several environments, for example, GPS has huge error near buildings and trees, indoor, and so on. In such GPS-denied environment, Laser Detection and Ranging (LIDER) sensor based navigation system have generally been used. However, LIDER sensor also has an weakness, and it could not be used in the open outdoor environment where GPS could be used. Therefore, it is desired to develop the integrated navigation system which is seamlessly applied to GPS and GPS-denied environments. In this paper, the integrated navigation system for aerial robot using GPS and LIDER is developed. The navigation system is designed based on Extended Kalman Filter, and the effectiveness of the developed system is verified by numerical simulation and experiment.

16:45 Structural Acoustics and Noise Control II

Theoretical investigation into tunable band gaps of an Euler-Bernoulli beam with 2DOF LR structures (2579)

Z Xingqian, S Changgeng, G Yan, E Rustighi

This paper is concerned with an intelligent phonotic crystals (IPC) consisting of an Euler-Bernoulli beam attached with 2DOF locally resonant (LR) structures. The novel design of the dielectric electroactive polymer (DEAP) rings acting as the springs of oscillators is presented that could be employed to control the transmission of flexural waves on the beam. Tunable band gaps (BGs) can be realized by changing the stiffness of each oscillator driven by the external electric field, where the DEAPs transform electric energy directly into mechanical work under the applied voltage. Discrete copper (Cu) strips are then attached to the DEAP to allow the deformation of DEAP rings. The transfer matrix (TM) theory is adopted to assist readers to better understand the formation of the BG. Simulation results show that this particular configuration is effective for attenuating the flexural waves at low frequencies below 1000Hz where the tunable BGs may occur. Moreover, it is found that a wider BG can be achieved and shifts towards higher frequencies by increasing the applied voltages.

16:45 Rotor Dynamics and Control

Predicting Critical Speeds in Rotordynamics: A New Method (2094)

J D Knight, L N Virgin, R H Plaut

In rotordynamics, it is often important to be able to predict critical speeds. The passage through resonance is generally difficult to model. Rotating shafts with a disk are analyzed in this study, and experiments are conducted with one and two disks on a shaft. The approach presented here involves the use of a relatively simple prediction technique, and since it is a black-box data-based approach, it is suitable for in-situ applications.

16:45 Fluid-Structure Interaction

Discrete Flow Mapping in coupled two and three dimensional domains: a global interface problem (2529)

J Bajars, D Chappell, T Hartmann, G Tanner

Discrete Flow Mapping (DFM) was recently introduced as a mesh-based high frequency method for modelling structure-borne sound in complex structures comprised of two-dimensional shell and plate subsystems. The method has now been extended to model three-dimensional meshed structures, giving a wider range of applicability and also naturally leading to the question of how to couple the two- and three-dimensional substructures. We consider this problem for the case of a three dimensional interior fluid domain, enclosed by a two dimensional shell/plate system. In Discrete Flow Mapping, the transport of vibrational energy between substructures is typically described via a local interface treatment where wave theory is employed to generate reflection/transmission and mode coupling coefficients. In our case the entire two-dimensional substructure forms a global interface whose radiating properties will depend on both the geometry and the frequency. In this paper we discuss how such a model may be formulated, including both structural radiation and the back-loading of the fluid pressure on the structure.

Notes

17:00 Active Vibration Control III

Hybrid Fluid-borne Noise Control in Fluid-filled Pipelines (2481)

M Pan, N Johnston, A Plummer

This article reports on an initial investigation of a hybrid fluid-borne noise control system in hydraulic pipelines. The hybrid system is built by integrating an active feedforward noise controller with passive tuned flexible hoses. The active attenuator is designed to cancel the dominant harmonic pressure pulsations in the fluid line, while the passive hose is tuned to attenuate the residual high frequency pulsations. The active attenuator can effectively decrease the fluid-borne noise by superimposing a secondary anti-phase control signal. Adaptive notch filters with the filtered-X least mean square algorithm were applied for the controller and a frequency-domain least mean square filter was used for the secondary path on-line identification. The transmission line model was used to model the pipeline, and a time-domain hose model which includes coupling of longitudinal wall and fluid waves was used to model the flexible hose. Simulation results show that very good noise cancellation was achieved using the proposed approach, which has several advantages over existing fluid-borne noise control systems, being effective for a wide range of frequencies without impairing the system dynamic response much. While the flexible hoses may be less effective than purpose-built passive silencers, they can form an inexpensive and practical solution in combination with active control.

17:00 Vehicle Dynamics and Control III

Model Predictive Control considering Reachable Range of Wheels for Leg / Wheel Mobile Robots (2564)

N Suzuki, K Nonaka, K Sekiguchi

Obstacle avoidance is one of the important tasks for mobile robots. In this paper, we study obstacle avoidance control for mobile robots equipped with four legs comprised of three DoF SCARA leg/wheel mechanism, which enables the robot to change its shape adapting to environments. Our previous method achieves obstacle avoidance by model predictive control (MPC) considering obstacle size and lateral wheel positions. However, this method does not ensure existence of joint angles which achieves reference wheel positions calculated by MPC. In this study, we propose a model predictive control considering reachable mobile ranges of wheels positions by combining multiple linear constraints, where each reachable mobile range is approximated as a convex trapezoid. Thus, we achieve to formulate a MPC as a quadratic problem with linear constraints for nonlinear problem of longitudinal and lateral wheel position control. By optimization of MPC, the reference wheel positions are calculated, while each joint angle is determined by inverse kinematics. Considering reachable mobile ranges explicitly, the optimal joint angles are calculated, which enables wheels to reach the reference wheel positions. We verify its advantages by comparing the proposed method with the previous method through numerical simulations.

17:00 Structural Acoustics and Noise Control II

Response of a shell structure subject to distributed harmonic excitation (2599)

R Cao, J S Bolton

Previously, a coupled, two-dimensional structural-acoustic ring model was constructed to simulate the dynamic and acoustical behavior of pneumatic tires. Analytical forced solutions were obtained and were experimentally verified through laser velocimeter measurement made using automobile tires. However, the two-dimensional ring model is incapable of representing higher order, in-plane modal motion in either the circumferential or axial directions. Therefore, in this paper, a three-dimensional pressurized circular shell model is proposed to study the in-plane shearing motion and the effect of different forcing conditions. Closed form analytical solutions were obtained for both free and forced vibrations of the shell under simply supported boundary conditions. Dispersion relations were calculated and different wave types were identified by their different speeds. Shell surface mobility results under various input distributions were also studied and compared. Spatial Fourier series decompositions were also performed on the spatial mobility results to give the forced dispersion relations, which illustrate clearly the influence of input force spatial distribution. Such a model has practical application in identifying the sources of noise and vibration problems in automotive tires.

17:00 Rotor Dynamics and Control

Modal interaction and vibration suppression in industrial turbines using adjustable journal bearings (2516)

A Chasalevris, F Dohnal

The vibration suppression by deliberately introducing a parametric excitation in the fluid-film bearings is investigated for an industrial turbine rotor system. A journal bearing with variable adjustable geometry is operated in such a way that the effective stiffness and damping properties vary periodically in time. The proposed bearing is designed for having the ability of changing the bearing fluid film thickness in a semi-active manner. Such an adjustment of the journal bearing properties introduces in the system a time-periodic variation of the effective stiffness and damping properties of the fluid-film. If the time-periodicity is tuned properly to match a parametric anti-resonance, vibration suppression is achieved in the overall system. The paper presents the principle of operation of the recently developed bearings. The simulation of an industrial turbine rotor-bearing shaft line at induced parametric excitation motivates the further development and application of such bearings since the vibration amplitudes are considerably decreased in critical speeds.

17:00 Fluid-Structure Interaction

Suppression of two-dimensional vortex-induced vibration with active velocity feedback controller (2202)

B Ma, N Srinil

Vortex-induced vibrations (VIV) establish key design parameters for offshore and subsea structures subject to current flows. Understanding and predicting VIV phenomena have been improved in recent years. Further, there is a need to determine how to effectively and economically mitigate VIV effects. In this study, linear and nonlinear velocity feedback controllers are applied to actively suppress the combined cross-flow and in-line VIV of an elastically-mounted rigid circular cylinder. The strongly coupled Fluid-Structure Interactions are numerically modelled and investigated using a calibrated reduced-order wake oscillator derived from the vortex strength concept. The importance of structural geometrical nonlinearities is studied which highlights the model ability in matching experimental results. The effectiveness of linear vs nonlinear controllers are analysed with regard to the control direction, gain and power. Parametric studies are carried out which allow us to choose the linear vs nonlinear control, depending on the target controlled amplitudes and associated power requirements.

Notes

17:15 Active Vibration Control III

Development of sensorless easy-to-use overhead crane system via simulation based control (2487)

Y Tagawa, Y Mori, M Wada, E Kawajiri, K Nouzuka

This paper describes the newly developed overhead crane which has a sensorless vibration control system. Generally, loads which are carried by the overhead cranes are easy to vibrate and only skilled people can operate the cranes. Therefore, a lot of studies have been done to solve this problem by using feedback control with vibration sensors. However vibration sensors often break down in severe industrial environment and more reliable control systems are required. For this reason, we have been developing sensorless control system for overhead cranes. In this paper, we firstly introduce basic idea of simulation based control which is called IDCS, then overview and modeling of the overhead crane is presented. Next, the control system design of the overhead crane is discussed, and experimental results are shown for real overhead crane with 2 axes.

17:15 Vehicle Dynamics and Control III

Design and Experimental Verification of Vibration Suppression Device on the Lift of Wheelchair-accessible Vehicles (2577)

Y Hatano,, M Takahashi

In recent years, the number of wheelchair-accessible vehicles has increased with the aging of the population. Such vehicles are effective in reducing the burden on caregivers because the wheelchair user does not have to move from his/her wheelchair to a seat of the vehicle. Wheelchair-accessible vehicles are expected to be widely used in the future. However, wheelchair users have reported poor ride comfort. It is thus necessary to suppress the vibration of the vehicle considering the wheelchair user. We designed a passive damping device on the lift of wheelchair-accessible vehicles to improve the ride comfort for wheelchair users. The vibration due to road disturbances reaches the wheelchair user's body through the vehicle and wheelchair. Our control device decreases the acceleration of the torso and improves the ride comfort by ensuring that the frequency of the vibration reaching the wheelchair user differs from the resonance frequency band of the acceleration of the torso, which is the body part that feels the most discomfort. The effectiveness of the control device is verified experimentally.

17:15 Structural Acoustics and Noise Control II

Enhanced acoustic transmission into dissipative solid materials through the use of inhomogeneous plane waves (2600)

D C Woods, J S Bolton, J F Rhoads

A number of applications, for instance ultrasonic imaging and nondestructive testing, involve the transmission of acoustic energy across fluid-solid interfaces into dissipative solids. However, such transmission is generally hindered by the large impedance mismatch at the interface. In order to address this problem, inhomogeneous plane waves were investigated in this work for the purpose of improving the acoustic energy transmission. To this end, under the assumption of linear hysteretic damping, models for Fluid-Structure Interaction were developed that allow for both homogeneous and inhomogeneous incident waves. For low-loss solids, the results reveal that, at the Rayleigh angle, a unique value of the wave inhomogeneity can be found which minimizes the reflection coefficient, and consequently maximizes the transmission. The results also reveal that with sufficient dissipation levels in the solid material, homogeneous incident waves yield lower reflection values than inhomogeneous waves, due to the large degrees of inhomogeneity inherent in the transmitted waves. Analytical conditions have also been derived which predict the dependence of the optimal incident wave type on the dissipation level and wave speeds in the solid medium. Finally, implications related to the use of acoustic beams of limited spatial extent are discussed.

17:15 Rotor Dynamics and Control

Mathematic study of the rotor motion with a pendulum self-balancing device (2627)

O P Ivkina, G R Ziyakaev, E N Pashkov

The rotary machines used in manufacturing may become unbalanced leading to vibration. In some cases, the problem may be solved by installing self-balancing devices (SBDs). Certain factors, however, exhibit a pronounced effect on the efficiency of these devices. The objective of the research comprised of establishing the most beneficial spatial position of pendulums to minimize the necessary time to repair the rotor unbalance. The mathematical research of the motion of a rotor with pendulum SBDs in the situation of their misalignment was undertaken. This objective was achieved by using the Lagrange equations of the second type. The analysis identified limiting cases of location of the rotor unbalance vector and the vector of housing's unbalance relative to each other, as well as the minimum capacity of the pendulum. When determining pendulums' parameters during the SBD design process, it is necessary to take into account the rotor unbalance and the unbalance of the machine body, which is caused by the misalignment of rotor axis and pendulum's axis of rotation.

17:15 Fluid-Structure Interaction

Hydrodynamic and hydrostatic modelling of hydraulic journal bearings considering small displacement condition (2359)

C-Y Chen, J-C Chuang, J-Y Tu

This paper proposes modified coefficients for the dynamic model of hydraulic journal bearing system that integrates the hydrodynamic and hydrostatic properties. In recent years, design of hydraulic bearing for machine tool attracts worldwide attention, because hydraulic bearings are able to provide higher capacity and accuracy with lower friction, compared to conventional bearing systems. In order to achieve active control of the flow pressure and enhance the operation accuracy, the dynamic model of hydraulic bearings need to be developed. Modified coefficients of hydrostatic stiffness, hydrodynamic stiffness, and squeeze damping of the dynamic model are presented in this work, which are derived referring to small displacement analysis from literature. The proposed modified coefficients and model, which consider the pressure variations, relevant geometry size, and fluid properties of the journal bearings, are able to characterise the hydrodynamic and hydrostatic properties with better precision, thus offering the following pragmatic contribution: (1) on-line prediction of the eccentricity and the position of the shaft in the face of external force that results in vibration; (2) development of active control system to regulate the supply flow pressure and to minimize the eccentricity of the shaft. Theoretical derivation and simulation results with different vibration cases are discussed to verify the proposed techniques.

Notes

17:30 Active Vibration Control III

Application of a load-bearing passive and active vibration isolation system in hydraulic drives (2527)

O Unruh, T Haase, M Pohl

Hydraulic drives are widely used in many engineering applications due to their high power to weight ratio. The high power output of the hydraulic drives produces high static and dynamic reaction forces and moments which must be carried by the mounts and the surrounding structure. A drawback of hydraulic drives based on rotating pistons consists in multi-tonal disturbances which propagate through the mounts and the load bearing structure and produce structure borne sound at the surrounding structures and cavities. One possible approach to overcome this drawback is to use an optimised mounting, which combines vibration isolation in the main disturbance direction with the capability to carry the reaction forces and moments. This paper presents an experimental study, which addresses the vibration isolation performance of an optimised mounting. A dummy hydraulic drive is attached to a generic surrounding structure with optimised mounting and excited by multiple shakers. In order to improve the performance of the passive vibration isolation system, piezoelectric transducers are applied on the mounting and integrated into a feed-forward control loop. It is shown that the optimised mounting of the hydraulic drive decreases the vibration transmission to the surrounding structure by 8 dB. The presented study also reveals that the use of the active control system leads to a further decrease of vibration transmission of up to 14 dB and also allows an improvement of the vibration isolation in an additional degree of freedom and higher harmonic frequencies.

17:30 Vehicle Dynamics and Control III

A Hierarchical Model Predictive Tracking Control for Independent Four-Wheel Driving/Steering Vehicles with Coaxial Steering Mechanism (2582)

M Itoh, Y Hagimori, K Nonaka, K Sekiguchi

In this study, we apply a hierarchical model predictive control to omni-directional mobile vehicle, and improve the tracking performance. We deal with an independent four-wheel driving/steering vehicle (IFWDS) equipped with four coaxial steering mechanisms (CSM). The coaxial steering mechanism is a special one composed of two steering joints on the same axis. In our previous study with respect to IFWDS with ideal steering, we proposed a model predictive tracking control. However, this method did not consider constraints of the coaxial steering mechanism which causes delay of steering. We also proposed a model predictive steering control considering constraints of this mechanism. In this study, we propose a hierarchical system combining above two control methods for IFWDS. An upper controller, which deals with vehicle kinematics, runs a model predictive tracking control, and a lower controller, which considers constraints of coaxial steering mechanism, runs a model predictive steering control which tracks the predicted steering angle optimized an upper controller. We verify the superiority of this method by comparing this method with the previous method.

17:30 Structural Acoustics and Noise Control II

Active Noise Control for Dishwasher noise (2643)

N Lee, Y Park

The dishwasher is a useful home appliance and continually used for automatically washing dishes. It's commonly placed in the kitchen with built-in style for practicality and better use of space. In this environment, people are easily exposed to dishwasher noise, so it is an important issue for the consumers, especially for the people living in open and narrow space. Recently, the sound power levels of the noise are about 40–50 dBA. It could be achieved by removal of noise sources and passive means of insulating acoustical path. For more reduction, such a quiet mode with the lower speed of cycle has been introduced, but this deteriorates the washing capacity. Under this background, we propose active noise control for dishwasher noise. It is observed that the noise is propagating mainly from the lower part of the front side. Control speakers are placed in the part for the collocation. Observation part of estimating sound field distribution and control part of generating the anti-noise are designed for active noise control. Simulation result shows proposed active noise control scheme could have a potential application for dishwasher noise reduction.

17:30 Rotor Dynamics and Control

Dynamic analysis on rotor-bearing system with coupling faults of crack and rub-impact (2631)

Z Huang

Rub-impact and fatigue crack are two important rotor faults. Based on the crack theory, an improved switching crack model is presented. Dynamic characteristics of a rotor-bearing system with imbalance, rub-impact and transverse crack are attempted. Various nonlinear dynamic phenomena are analyzed using numerical method. The results reveal that unstable form of the rotor system with coupling faults is extremely complex as the rotating speed increases and there are some low frequencies with large amplitude. The influence of crack depth and angle on the dynamic behavior of a cracked rotor is important insomuch as the quasi-periodical and chaotic motions in system response will occur along with different parameters. It is indicated that this study can contribute to a further understanding of the non-linear dynamics of such a rotor system with coupling faults of crack and rub-impact.

17:30 Fluid-Structure Interaction

Methodology for Dynamic Analysis of Nuclear Reactor Vessel and Reactor Internals (2748)

J B Park, N C Park, J S Kim

Recently, a nuclear power generation takes large percentages of energy generation systems. However, the accidents of nuclear power plants cause critical effects to humanity. On that account, nuclear power plants should be designed robustly. In this research, especially, we concentrated on the dynamic characteristics of nuclear reactor vessel and reactor internals. To identify the dynamic characteristics and perform the dynamic analysis, finite element method (FEM) was used. In order to construct the exact FE Model, complex geometries of the structures and Fluid-Structure Interactions (FSI) were considered carefully based on scale-down model of nuclear reactor vessel and reactor internals. Finally, the dynamic characteristics were calculated based on the scale similarity theory. These dynamic information can be used to enhance the safety of nuclear reactor assembly in the future.

Notes

17:45 Active Vibration Control III

Acceleration control system for semi-active in-car crib with joint application of regular and inverted pendulum mechanisms (2288)

T Kawashima

To reduce the risk of injury to an infant in an in-car crib (or in a child safety bed) collision shock during a car crash, it is necessary to maintain a constant force acting on the crib below a certain allowable value. To realize this objective, we propose a semi-active in-car crib system with the joint application of regular and inverted pendulum mechanisms. The arms of the proposed crib system support the crib like a pendulum while the pendulum system itself is supported like an inverted pendulum by the arms. In addition, the friction torque of each arm is controlled using a brake mechanism that enables the proposed in-car crib to decrease the acceleration of the crib gradually and maintain it around the target value. This system not only reduces the impulsive force but also transfers the force to the infant's back using a spin control system, i.e., the impulse force acts is made to act perpendicularly on the crib. The spin control system was developed in our previous work. This work focuses on the acceleration control system. A semi-active control law with acceleration feedback is introduced, and the effectiveness of the system is demonstrated using numerical simulation and model experiment.

17:45 Vehicle Dynamics and Control III

Automated Driving System Architecture to Ensure Safe Delegation of Driving Authority (2587)

S Yun, H Nishimura

In this paper, the architecture of an automated driving system (ADS) is proposed to ensure safe delegation of driving authority between the ADS and a driver. Limitations of the ADS functions may activate delegation of driving authority to a driver. However, it leads to severe consequences in emergency situations where a driver may be drowsy or distracted. To address these issues, first, the concept model for the ADS in the situation for delegation of driving authority is described taking the driver's behaviour and state into account. Second, the behaviour / state of a driver and functional flow / state of ADS and the interactions between them are modelled to understand the context where the ADS requests to delegate the driving authority to a driver. Finally, the proposed architecture of the ADS is verified under the simulations based on the emergency braking scenarios. In the verification process using simulation, we have derived the necessary condition for safe delegation of driving authority is that the ADS should assist s driver even after delegating driving authority to a driver who has not enough capability to regain control of the driving task.

17:45 Structural Acoustics and Noise Control II

Nonlinear Microstructured Material to Reduce Noise and Vibrations at Low Frequencies (2263)

D Lavazec, G Cumunel, D Duhamel, C Soize, A Batou

At low frequencies, for which the wavelengths are wide, the acoustic waves and the mechanical vibrations cannot easily be reduced in the structures at macroscale by using dissipative materials, contrarily to the middle- and high-frequency ranges. The final objective of this work is to reduce the vibrations and the induced noise on a broad low-frequency band by using a microstructured material by inclusions that are randomly arranged in the material matrix. The dynamical regimes of the inclusions will be imposed in the nonlinear domain in order that the energy be effectively pumped over a broad frequency band around the resonance frequency, due to the nonlinearity. The first step of this work is to design and to analyze the efficiency of an inclusion, which is made up of a hollow frame including a point mass centered on a beam. This inclusion is designed in order to exhibit nonlinear geometric effects in the low-frequency band that is observed. For this first step, the objective is to develop the simplest mechanical model that has the capability to roughly predict the experimental results that are measured. The second step, which is not presented in the paper, will consist in developing a more sophisticated nonlinear dynamical model of the inclusion. In this paper, devoted to the first step, it is proved that the nonlinearity induces an attenuation on a broad frequency band around the resonance, contrarily to its linear behavior for which the attenuation is only active in a narrow frequency band around the resonance. We will present the design in terms of geometry, dimension and materials for the inclusion, the experimental manufacturing of this system realized with a 3D printing system, and the experimental measures that have been performed. We compare the prevision given by the stochastic computational model with the measurements. The results obtained exhibit the physical attenuation over a broad low-frequency band, which were expected.

Notes

09:00 PLENARY SESSION

Recent advances in magnetic suspension technology

T Mizuno

Professor, Department Chair of Mechanical Engineering, Saitama University, Japan

The suspension of an object with no visible means is still fascinating to most people. Magnetic suspension utilizes magnetic force for achieving such suspension. There is no contact between stator and object (floator). No mechanical friction and wear is expected in operation even without lubrication. This advantage has already given rise to a lot of industrial applications such as Maglev system, and active magnetic bearing (AMB) for complete contact-free suspension of rotating object. The most successful application is turbo machinery such as turbo-molecular pump.

Researches and developments on magnetic suspension have been actively pursued for several decades and some people may consider this technology to be rather mature now. However, to fully utilize this unique technology and to increase industrial applications, technical advances are still important.

This report presents several recent innovations and advances in magnetic suspension technology. An overview of technological fundamentals is presented first, which is followed by reports on the recent works of the author.

14:00 PLENARY SESSION

Motion and vibration control for railway vehicles

R Goodall

Professor of Control Systems Engineering, MA, PhD, FREng, FIMechE, FIET, Loughborough University, UK

Active control of the dynamic characteristics of railway vehicles provides important possibilities for enhanced performance, and is applicable to a variety of vehicle systems: to the secondary suspension for improving ride quality, to the running gear on the bogies for enhanced dynamic characteristics, also to the pantographs which are used to collect electrical power from the overhead wires. The paper will provide an overview of the opportunities and requirements for each application, illustrate them with examples and identify key research challenges. It will conclude with a vision for the design of future railway vehicles and their operation if the full range of motion and vibration control opportunities are exploited.

Notes

10:30 Nonlinear Vibrations I

The Characteristics of Vibration Isolation System with Damping and Stiffness Geometrically Nonlinear (2131)

Z-Q Lu, L-Q Chen, M J Brennan, J-H Li, H Ding

The paper concerns an investigation into the use of both stiffness and damping nonlinearity in the vibration isolator to improve its effectiveness. The nonlinear damping and nonlinear stiffness are both achieved by horizontal damping and stiffness as the way of the geometrical nonlinearity. The harmonic balance method is used to analyze the force transmissibility of such vibration isolation system. It is found that as the horizontal damping increasing, the height of the force transmissibility peak is decreased and the high-frequency force transmissibility is almost the same. The results are also validated by some numerical method. Then the RMS of transmissibility under Gaussian white noise is calculated numerically, the results demonstrate that the beneficial effects of the damping nonlinearity can be achieved under random excitation.

10:30 Railway Induced Noise and Vibration I

Vibration analysis of concrete bridges during a train pass-by using various models (2167)

Q Li, K Wang, S Cheng, W Li, X Song

The vibration of a bridge must be determined in order to predict the bridge noise during a train pass-by. It can be generally solved with different models either in the time domain or the frequency domain. The computation cost and accuracy of these models vary a lot in a wide frequency band. This study aims to compare the results obtained from various models for recommending the most suitable model in further noise prediction. First, train-track-bridge models in the time domain are developed by using the finite element method and mode superposition method. The rails are modeled by Timoshenko beam elements and the bridge is respectively modeled by shell elements and volume elements. Second, power flow models for the coupled system are established in the frequency domain. The rails are modelled by infinite Timoshenko beams and the bridge is respectively represented by three finite element models, an infinite Kirchhoff plate, and an infinite Mindlin plate model. The vibration at given locations of the bridge and the power input to the bridges through the rail fasteners are calculated using these models. The results show that the shear deformation of the bridge deck has significant influences on the bridge vibration at medium-to-high frequencies. The Mindlin plate model can be used to represent the U-shaped girder to obtain the power input to the bridge with high accuracy and efficiency.

10:30 Stochastic Dynamics and Random Vibrations

Multiaxis Rainflow Fatigue Methods for Nonstationary Vibration (2136)

T Irvine

Mechanical structures and components may be subjected to cyclical loading conditions, including sine and random vibration. Such systems must be designed and tested according. Rainflow cycle counting is the standard method for reducing a stress time history to a table of amplitude-cycle pairings prior to the Palmgren-Miner cumulative damage calculation. The damage calculation is straightforward for sinusoidal stress but very complicated for random stress, particularly for nonstationary vibration. This paper evaluates candidate methods and makes a recommendation for further study of a hybrid technique.

10:30 Vibration Control Devices I

Analysis of a vibration isolation table comprising post-buckled Γ-shaped beam isolators (2196)

T Sasaki, T P Waters

In this paper, the static and dynamic characteristics of a nonlinear passive vibration isolation table is investigated through finite element analysis. The intended application is specifically isolation in the vertical direction where the isolator is required to be sufficiently stiff statically to bear the weight of the isolated object and soft dynamically for small oscillations about its equilibrium position. The modelled configuration consists of a rigid isolation table mounted on two Γ-shaped beam isolators which are loaded to their post-buckled state in their unstable buckling mode by the weight of the isolated mass. A nonlinear static analysis is presented to establish the negative stiffness provided by the buckled beams, and two linear springs are then added in parallel which are chosen to have just sufficient stiffness to restore stability. Modal analysis of the linearized system about its statically deformed position (1mm) gives a natural frequency of just 1Hz which is considerably lower than is achievable by a linear isolator. Motion transmissibility of the linearized system shows a non-resonant isolation region spanning two decades when the system is perfectly symmetric but additional resonance peaks appear when asymmetries are included in either the mass or stiffness distribution. Several strategies are explored for reducing the prominence of these resonances.

10:30 Control of Civil Infrastructures

Application of the nonlinear substructuring control method to nonlinear 2-degree-of-freedom systems (2272)

R Enokida, D Stoten, K Kajiwara

A nonlinear substructuring control (NLSC) method is developed as a more generalised form of linear substructuring control (LSC) by incorporating nonlinear signal-based control (NSBC) into a dynamical substructuring system (DSS). An advantage of NLSC is that it can be designed using the linearized models of the substructured systems without the need for accurate nonlinear dynamic models. In this study, the use of the NLSC method is demonstrated via substructured tests on nonlinear physical and numerical substructures. A series of substructuring tests were also conducted on a test rig, constructed within the ACTLab at the University of Bristol, which incorporated a pure time delay of 6.0 ms due to the presence of discrete-time elements. In the substructured tests, a trilinear hysteresis with piecewise linearity, commonly used in structural engineering, was embedded into the numerical substructure as the nonlinearity. The NLSC method was found to achieve stable and reliable substructured responses, even when the substructured systems had significant nonlinearity as well as the pure time delay term.

Notes

10:45 Nonlinear Vibrations I

Chaotic motions of a tethered satellite system in circular orbit (2150)

D P Jin, Z J Pang, H Wen, B S Yu

The paper studies the chaotic motions of a tethered satellite system by utilizing a ground-based experimental system. Based on dynamics similarity principle, a dynamical equivalent model between the on-orbit tethered satellite and its ground physical model is obtained. As a result, the space dynamics environment of the tethered satellite can be simulated via the thrust forces and the torque of the momentum wheel on the satellite simulator. The numerical results of the on-orbit tethered satellite show the chaotic motions of the attitude motion of mother satellite. The experiment shows that the torque of momentum wheel as a negative damping is able to suppress the chaotic motion.

10:45 Railway Induced Noise and Vibration I

Sound transmission loss of windows on high speed trains (2191)

Y Zhang, X Xiao, D Thompson, G Squicciarini, Z Wen, Z Li, Y Wu

The window is one of the main components of the high speed train car body structure through which noise can be transmitted. To study the windows' acoustic properties, the vibration of one window of a high speed train has been measured for a running speed of 250 km/h. The corresponding interior noise and the noise in the wheel-rail area have been measured simultaneously. The experimental results show that the window vibration velocity has a similar spectral shape to the interior noise. Interior noise source identification further indicates that the window makes a contribution to the interior noise. Improvement of the window's Sound Transmission Loss (STL) can reduce the interior noise from this transmission path. An STL model of the window is built based on wave propagation and modal superposition methods. From the theoretical results, the window's STL property is studied and several factors affecting it are investigated, which provide indications for future low noise design of high speed train windows.

10:45 Stochastic Dynamics and Random Vibrations

Response moments of dynamic systems under non-Gaussian random excitation by the equivalent non-Gaussian excitation method (2168)

T Tsuchida, K Kimura

Equivalent non-Gaussian excitation method is proposed to obtain the response moments up to the 4th order of dynamic systems under non-Gaussian random excitation. The non-Gaussian excitation is prescribed by the probability density and the power spectrum, and is described by an Itô stochastic differential equation. Generally, moment equations for the response, which are derived from the governing equations for the excitation and the system, are not closed due to the nonlinearity of the diffusion coefficient in the equation for the excitation even though the system is linear. In the equivalent non-Gaussian excitation method, the diffusion coefficient is replaced with the equivalent diffusion coefficient approximately to obtain a closed set of the moment equations. The square of the equivalent diffusion coefficient is expressed by a quadratic polynomial. In numerical examples, a linear system subjected to non-Gaussian excitations with bimodal and Rayleigh distributions is analyzed by using the present method. The results show that the method yields the variance, skewness and kurtosis of the response with high accuracy for non-Gaussian excitation with the widely different probability densities and bandwidth. The statistical moments of the equivalent non-Gaussian excitation are also investigated to describe the feature of the method.

10:45 Vibration Control Devices I

On the undamped vibration absorber with cubic stiffness characteristics (2331)

G Gatti

In order to improve the performance of a vibration absorber, a nonlinear spring can be used on purpose. This paper presents an analytical insight on the characteristics of an undamped nonlinear vibration absorber when it is attached to a linear spring-mass-damper oscillator. In particular, the nonlinear attachment is modelled as a Duffing's oscillator with a spring characteristics having a linear positive stiffness term plus a cubic stiffness term. The effects of the nonlinearity, mass ratio and frequency ratio are investigated based on an approximate analytical formulation of the amplitude-frequency equation. Comparisons to the linear case are shown in terms of the frequency response curves. The nonlinear absorber seems to show an improved robustness to mistuning respect to the corresponding linear device. However, such a better robustness may be limited by some instability of the expected harmonic response.

10:45 Control of Civil Infrastructures

Experimental evaluation of a control system for active mass dampers consisting of a position controller and neural oscillator (2301)

T Sasaki, D Iba, J Hongu, M Nakamura, I Moriwaki

This paper shows experimental performance evaluation of a new control system for active mass dampers (AMDs). The proposed control system consists of a position controller and neural oscillator, and is designed for the solution of a stroke limitation problem of an auxiliary mass of the AMDs. The neural oscillator synchronizing with the response of a structure generates a signal, which is utilized for switching of motion direction of the auxiliary mass and for travel distances of the auxiliary mass. According to the generated signal, the position controller drives the auxiliary mass to the target values, and the reaction force resulting from the movement of the auxiliary mass is transmitted to the structure, and reduces the vibration amplitude of the structure. Our previous research results showed that the proposed system could reduce the vibration of the structure while the motion of auxiliary mass was suppressed within the restriction; however the control performance was evaluated numerically. In order to put the proposed system to practical use, the system should be evaluated experimentally. This paper starts by illustrating the relation among subsystems of the proposed system, and then, shows experimental responses of a structure model with the AMD excited by earthquakes on a shaker to confirm the validity of the system.

Notes

11:00 Nonlinear Vibrations I

Periodic response of an axially high-speed moving beam under 3:1 internal resonance (2192)

H Ding, X-Y Mao, L-Q Chen

In the supercritical speed range, nonlinear forced vibration of an axially moving viscoelastic beam in the presence of 3:1 internal resonance is investigated. The straight beam becomes buckled due to the supercritical moving speed. The governing equation is cast for motion around buckled configuration by using a coordinate transform. Moreover, the first two modes of the buckled beam are set to 3:1 by adjusting the axial moving speed. Then the corresponding equation is approximately analyzed by utilizing the multi-scale method. For the beam subjected to the primary resonances and super-harmonic resonance with internal resonance, frequency-amplitude relationship of steady-state responses is constructed. Numerical examples discovered the influence of internal resonance on the nonlinear dynamic characteristics of the axially moving beam. Specifically, the energy transfer between the first two order modes is found for an axially supercritical moving beam. Moreover, several typical nonlinear phenomenon, such as double jumping phenomenon, hysteretic phenomenon and saturation-like phenomenon, are discovered in the nonlinear vibration of the axially moving beam. By comparing with numerically simulative results via the finite difference method and the Galerkin method, it is confirmed that the method of multi-scale in the present work is quite credible.

11:00 Railway Induced Noise and Vibration I

Experimental investigation on the dissipative and elastic characteristics of a yaw colloidal damper destined to carbody suspension of a bullet train (2409)

B Suciu, T Tomioka

Yaw damper represents a major source of excitation for flexural vibration of the railway carbody. In order to reduce transmissibility of such undesired excitation, yaw damper should allow for large force transmission at low working frequencies, but should behave as vibration isolator at high working frequencies. Unfortunately, the yaw oil damper (OD), which is nowadays in service, has poor intrinsic elastic capabilities and provides damping forces varying as a power function versus the piston speed. Since colloidal damper (CD) has intrinsic elastic capabilities and larger damping forces at lower excitation frequencies, it occurs as an attractive alternative solution to traditional yaw dampers. In this work, a yaw CD destined to carbody suspension of a bullet train was designed and manufactured; then, its dynamic characteristics, produced by both the frictional and colloidal effects, were evaluated from the experimental results, obtained during horizontal vibration tests, performed on a ball-screw shaker. Compared to the corresponding classical yaw OD, the trial yaw CD allowed for: weight reduction of 31.6 %; large damping force, dissipated energy and spring constant at long piston stroke under low excitation frequency; low damping force, dissipated energy and spring constant at short piston stroke under high excitation frequency. Elastic properties were justified by introducing a model for the spring constant that included the effect of pore size distribution.

11:00 Stochastic Dynamics and Random Vibrations

Stability of a nonlinear second order equation under parametric bounded noise excitation (2177)

R Wiebe, W-C Xie

The motivation for the following work is a structural column under dynamic axial loads with both deterministic (harmonic transmitted forces from the surrounding structure) and random (wind and/or earthquake) loading components. The bounded noise used herein is a sinusoid with an argument composed of a random (Wiener) process deviation about a mean frequency. By this approach, a noise parameter may be used to investigate the behaviour through the spectrum from simple harmonic forcing, to a bounded random process with very little harmonic content. The stability of both the trivial and non-trivial stationary solutions of an axially-loaded column (which is modeled as a second order nonlinear equation) under parametric bounded noise excitation is investigated by use of Lyapunov exponents. Specifically the effect of noise magnitude, amplitude of the forcing, and damping on stability of a column is investigated. First order averaging is employed to obtain analytical approximations of the Lyapunov exponents of the trivial solution. For the non-trivial stationary solution however, the Lyapunov exponents are obtained via Monte Carlo simulation as the stability equations become analytically intractable.

11:00 Vibration Control Devices I

Dynamics of a passive micro-vibration isolator based on a pretensioned plane cable net structure and fluid damper (2337)

Y Chen, Q Lu, B Jing, Z Zhang

This paper addresses dynamic modelling and experiments on a passive vibration isolator for application in the space environment. The isolator is composed of a pretensioned plane cable net structure and a fluid damper in parallel. Firstly, the frequency response function (FRF) of a single cable is analysed according to the string theory, and the FRF synthesis method is adopted to establish a dynamic model of the plane cable net structure. Secondly, the equivalent damping coefficient of the fluid damper is analysed. Thirdly, experiments are carried out to compare the plane cable net structure, the fluid damper and the vibration isolator formed by the net and the damper, respectively. It is shown that the plane cable net structure can achieve substantial vibration attenuation but has a great amplification at its resonance frequency due to the light damping of cables. The damping effect of fluid damper is acceptable without taking the poor carrying capacity into consideration. Compared to the plane cable net structure and the fluid damper, the isolator has an acceptable resonance amplification as well as vibration attenuation.

11:00 Control of Civil Infrastructures

Accelerometer-based estimation and modal velocity feedback vibration control of a stress-ribbon bridge with pneumatic muscles (2444)

X Liu, T Schauer, A Goldack, A Bleicher, M Schlaich

Lightweight foo*tbridges are very elegant but also prone to vibration. By employing active vibration control, smart footbridges could accomplish not only the architectural concept but also the required serviceability and comfort. Inertial sensors such as accelerometers allow the estimation of nodal velocities and displacements. A Kalman filter together with a band-limited multiple Fourier linear combiner (BMFLC) is applied to enable a drift-free estimation of these signals for the quasi-periodic motion under pedestrian excitation without extra information from other kinds of auxiliary sensors. The modal velocities of the structure are determined by using a second Kalman filter with the known applied actuator forces as inputs and the estimated nodal displacement and velocities as measurements. The obtained multi-modal velocities are then used for feedback control. An ultra-lightweight stress-ribbon footbridge built in the Peter-Behrens-Halle at the Technische Universität Berlin served as the research object. Using two inertial sensors in optimal points we can estimate the dominant modal characteristics of this bridge. Real-time implementation and evaluation results of the proposed estimator will be presented in comparison to signals derived from classical displacement encoders. The real-time estimated modal velocities were applied in a multi-modal velocity feedback vibration control scheme with lightweight pneumatic muscle actuators. Experimental results demonstrate the feasibility of using inertial sensors for active vibration control of lightweight footbridges.

Notes

11:15 Nonlinear Vibrations I

Robust simulation of buckled structures using reduced order modeling (2176)

R Wiebe, R A Perez, S M Spottswood

Lightweight metallic structures are a mainstay in aerospace engineering. For these structures, stability, rather than strength, is often the critical limit state in design. For example, buckling of panels and stiffeners may occur during emergency high-g maneuvers, while in supersonic and hypersonic aircraft, it may be induced by thermal stresses. The longstanding solution to such challenges was to increase the sizing of the structural members, which is counter to the ever present need to minimize weight for reasons of efficiency and performance. In this work we present some recent results in the area of reduced order modeling of postbuckled thin beams. A thorough parametric study of the response of a beam to changing harmonic loading parameters, which is useful in exposing complex phenomena and exercising numerical models, is presented. Two error metrics that use but require no time stepping of a (computationally expensive) truth model are also introduced. The error metrics are applied to several interesting forcing parameter cases identified from the parametric study and are shown to yield useful information about the quality of a candidate reduced order model. Parametric studies, especially when considering forcing and structural geometry parameters, coupled environments, and uncertainties would be computationally intractable with finite element models. The goal is to make rapid simulation of complex nonlinear dynamic behavior possible for distributed systems via fast and accurate reduced order models. This ability is crucial in allowing designers to rigorously probe the robustness of their designs to account for variations in loading, structural imperfections, and other uncertainties.

11:15 Railway Induced Noise and Vibration I

Study of the shadow effect caused by a railway tunnel (2256)

Q Jin, D Thompson

When a train runs in a tunnel the largest vibration on the ground surface may not occur directly above the tunnel but at some lateral distance away from the tunnel alignment. This has been called the ‘shadow effect’. The characteristics of this shadow effect can help in understanding the distribution of vibration on the ground surface. For the current study it is first shown, using an analytical ground model, that a shadow region may occur for a force at some depth in the ground even in the absence of a tunnel; the extent of this effect depends on the Poisson’s ratio of the soil. To introduce the tunnel a 2.5D finite element/boundary element model has been used to represent the coupled tunnel-ground situation. When the tunnel is present the vibration caused by excitation at the tunnel base shares many of the features found in the absence of the tunnel. However, the existence of the tunnel structure also influences these features, especially at high frequencies. It is found that, rather than the tunnel structure shielding the vibration from reaching the ground surface, its dominant effect is to transmit vibration from the tunnel base to the crown at high frequencies. The dependence of these effects on various parameters is studied, in particular the tunnel diameter, wall thickness and depth.

11:15 Stochastic Dynamics and Random Vibrations

A simplified method for random vibration analysis of structures with random parameters (2200)

M Ghienne, C Blanzé

Piezoelectric patches with adapted electrical circuits or viscoelastic dissipative materials are two solutions particularly adapted to reduce vibration of light structures. To accurately design these solutions, it is necessary to describe precisely the dynamical behaviour of the structure. It may quickly become computationally intensive to describe robustly this behaviour for a structure with nonlinear phenomena, such as contact or friction for bolted structures, and uncertain variations of its parameters. The aim of this work is to propose a non-intrusive reduced stochastic method to characterize robustly the vibrational response of a structure with random parameters. Our goal is to characterize the eigenspace of linear systems with dynamic properties considered as random variables. This method is based on a separation of random aspects from deterministic aspects and allows us to estimate the first central moments of each random eigenfrequency with a single deterministic finite elements computation. The method is applied to a frame with several Young's moduli modeled as random variables. This example could be expanded to a bolted structure including piezoelectric devices. The method needs to be enhanced when random eigenvalues are closely spaced. An indicator with no additional computational cost is proposed to characterize the "proximity" of two random eigenvalues.

11:15 Vibration Control Devices I

Prediction of peak response values of structures with and without TMD subjected to random pedestrian flows (2443)

K Lievens, K Van Nimmen, G Lombaert, G De Roeck, P Van den Broeck

In civil engineering and architecture, the availability of high strength materials and advanced calculation techniques enables the construction of slender footbridges, generally highly sensitive to human-induced excitation. Due to the inherent random character of the human-induced walking load, variability on the pedestrian characteristics must be considered in the response simulation. To assess the vibration serviceability of the footbridge, the statistics of the stochastic dynamic response are evaluated by considering the instantaneous peak responses in a time range. Therefore, a large number of time windows are needed to calculate the mean value and standard deviation of the instantaneous peak values. An alternative method to evaluate the statistics is based on the standard deviation of the response and a characteristic frequency as proposed in wind engineering applications. In this paper, the accuracy of this method is evaluated for human-induced vibrations. The methods are first compared for a group of pedestrians crossing a lightly damped footbridge. Small differences of the instantaneous peak value were found by the method using second order statistics. Afterwards, a TMD tuned to reduce the peak acceleration to a comfort value, was added to the structure. The comparison between both methods in made and the accuracy is verified. It is found that the TMD parameters are tuned sufficiently and good agreements between the two methods are found for the estimation of the instantaneous peak response for a strongly damped structure.

11:15 Control of Civil Infrastructures

Seismic Vibration Control of Elevated Water Tank by TLD and Validation of Full-Scale TLD Model through Real-Time-Hybrid-Testing (2594)

A Roy, A Staino, A D Ghosh, B Basu, S Chatterjee

Elevated water tanks (EWTs), being top-heavy structures, are highly vulnerable to earthquake forces, and several have experienced damage/failure in past seismic events. However, as these are critical facilities whose continued performance in the post-earthquake scenario is of vital concern, it is significant to investigate their seismic vibration control using reliable and cost-effective passive dampers such as the Tuned Liquid Damper (TLD). Here, this aspect is studied for flexible EWT structures, such as those with annular shaft supports. The criterion of tuning the sloshing frequency of the TLD to the structural frequency necessitates dimensions of the TLD larger than those hitherto examined in literature. Hence the nonlinear model of the TLD based on established shallow water wave theory is verified for large container size by employing Real-Time-Hybrid-Testing (RTHT). Simulation studies are further carried out on a realistic example of a flexible EWT structure with TLDs. Results indicate that the TLD can be applied very effectively for the seismic vibration mitigation of EWTs.

Notes

11:30 Nonlinear Vibrations I

A Method for Stable Deployment of an Electrodynamic Tethered Satellite in Three-Dimensional Space (2183)

B S Yu, D P Jin, H Wen

The paper presents an asymptotic stabilization strategy for the deployment of a controlled tethered satellite system in three-dimensional space, in which the tether length rate is taken as the control variable. Firstly, a rigid-rod tether model is employed to establish the nonlinear dynamic equations of in-plane and out-of-plane motions of the system. Then, by stability analysis of the linearized system at a preassigned direction to deploy, the control law and asymptotic stability condition for the deployment are obtained. The electrodynamic tethered satellite in equatorial plane is discussed. As a result, the large swing motions during deployment are stabilized asymptotically through reliance on the electrodynamic force and the tether length rate. The case studies in the paper well demonstrate the proposed stabilization control strategy.

11:30 Railway Induced Noise and Vibration I

Prediction of radiation ratio and sound transmission of complex extruded panel using wavenumber domain finite element and boundary element methods (2360)

H Kim, J Ryue, D J Thompson, A D Müller

Recently, complex shaped aluminium panels have been adopted in many structures to make them lighter and stronger. The vibro-acoustic behaviour of these complex panels has been of interest for many years but conventional finite element and boundary element methods are not efficient to predict their performance at higher frequencies. Where the cross-sectional properties of the panels are constant in one direction, wavenumber domain numerical analysis can be applied and this becomes more suitable for panels with complex cross-sectional geometries. In this paper, a coupled wavenumber domain finite element and boundary element method is applied to predict the sound radiation from and sound transmission through a double-layered aluminium extruded panel, having a typical shape used in railway carriages. The predicted results are compared with measured ones carried out on a finite length panel and good agreement is found.

11:30 Stochastic Dynamics and Random Vibrations

CR-Calculus and adaptive array theory applied to MIMO random vibration control tests (2249)

U Musella, S Manzato, B Peeters, P Guillaume

Performing Multiple-Input Multiple-Output (MIMO) tests to reproduce the vibration environment in a user-defined number of control points of a unit under test is necessary in applications where a realistic environment replication has to be achieved. MIMO tests require vibration control strategies to calculate the required drive signal vector that gives an acceptable replication of the target. This target is a (complex) vector with magnitude and phase information at the control points for MIMO Sine Control tests while in MIMO Random Control tests, in the most general case, the target is a complete spectral density matrix. The idea behind this work is to tailor a MIMO random vibration control approach that can be generalized to other MIMO tests, e.g. MIMO Sine and MIMO Time Waveform Replication. In this work the approach is to use gradient-based procedures over the complex space, applying the so called CR-Calculus and the adaptive array theory. With this approach it is possible to better control the process performances allowing the step-by-step Jacobian Matrix update. The theoretical bases behind the work are followed by an application of the developed method to a two-exciter two-axis system and by performance comparisons with standard methods.

11:30 Vibration Control Devices I

Design of an Active Bumper with a Series Elastic Actuator for Pedestrian Protection of Small Unmanned Vehicles (2504)

N Terumasa, T Tomoki, Y Hiroshi, S Takahiro

When autonomous unmanned vehicles are operated on sidewalks, the vehicles must have high safety standards such as avoiding injury when they come in contact with pedestrians. In this study, we established a design for preventing serious injury when such collisions occur. We designed an active bumper with a series elastic actuator, with the goal of avoiding serious injury to a pedestrian in a collision with a small unmanned vehicle. The series elastic actuator comprised an elastic element in series with a table driven by a ball screw and servo motor. The active bumper was used to control the contact force between a vehicle and a pedestrian. The optimal force for minimizing the deflection of the object of the collision was derived, and the actuator controlled to apply this optimal force. Numerical simulations showed that the active bumper was successful in improving the collision safety of small unmanned vehicles.

11:30 Control of Civil Infrastructures

Research on Hybrid Seismic Response Control System for Motion Control of Two Span Bridge (2610)

G Heo, C Kim, S Jeon, S Seo, J Jeon

In this paper, a hybrid seismic response control (HSRC) system was developed to control bridge motion caused by seismic load. It was aimed at optimum vibration control, composed of a rubber bearing of passive type and a MR-damper of semi-active type. The bridge model was built for experiment, a two-span bridge of 8.3 meters in length with the HSRC system put up on it. Then, inflicting El-centro seismic load on it, shaking table tests were carried out to confirm the system's validity. The experiments were conducted under the basic structure state (without an MR-damper applied) first, and then under the state with an MR-damper applied. It was also done under the basic structure state with a reinforced rubber bearing applied, then the passive on/off state of the HSRC system, and finally the semi-active state where the control algorithm was applied to the system. From the experiments, it was observed that collision rather increased when the MR-damper alone was applied, and also that the application of the HSRC system effectively prevented it from occurring. As a result, the HSRC system was proven to be effective in mitigating responses of the two-span bridge under seismic load.

Notes

11:45 Nonlinear Vibrations I

Exploration of nonlinearly shunted piezoelectrics as vibration absorbers (2253)

B Zhou, C Zang, X Wang

Practical realization of a nonlinearly shunted piezoelectric vibration absorber is numerically explored in this research. It is widely known that the linear resonant piezoelectric shunting strategy, acting as a tuned mass damper, is limited by the massive inductance required in low-frequency cases and sensitivity to drifts in structural frequencies. In order to overcome this limitation, a nonlinear piezoelectric shunting strategy is proposed based on the nonlinear energy sink theory. The essential idea is to passively absorb vibrational energy from the host structure through the intentional use of nonlinearity in piezoelectric shunting. The nonlinearly shunted piezoelectrics are supposed to work over a broad frequency band with a smaller inductance requirement compared with the linear resonant shunting. The nonlinearly shunted piezoelectric vibration absorber is built and applied in a cantilevered beam. Major challenges coming from the nonlinear tuning design for an effective vibration absorber exempted from high isolated response curves will be covered in this research. This numerical study is supposed to pave the way for experimental investigations that are currently in process.

11:45 Railway Induced Noise and Vibration I

The response of a high-speed train wheel to a harmonic wheelrail force (2408)

X Sheng, Y Liu, X Zhou

The maximum speed of China's high-speed trains currently is 300km/h and expected to increase to 350-400km/h. As a wheel travels along the rail at such a high speed, it is subject to a force rotating at the same speed along its periphery. This fast moving force contains not only the axle load component, but also many components of high frequencies generated from wheel-rail interactions. Rotation of the wheel also introduces centrifugal and gyroscopic effects. How the wheel responds is fundamental to many issues, including wheel-rail contact, traction, wear and noise. In this paper, by making use of its axial symmetry, a special finite element scheme is developed for responses of a train wheel subject to a vertical and harmonic wheel-rail force. This FE scheme only requires a 2D mesh over a cross-section containing the wheel axis but includes all the effects induced by wheel rotation. Nodal displacements, as a periodic function of the cross-section angle θ, can be decomposed, using Fourier series, into a number of components at different circumferential orders. The derived FE equation is solved for each circumferential order. The sum of responses at all circumferential orders gives the actual response of the wheel.

11:45 Stochastic Dynamics and Random Vibrations

Dynamic Modeling and Very Short-term Prediction of Wind Power Output Using Box-Cox Transformation (2299)

K Urata, M Inoue, D Murayama, S Adachi

We propose a statistical modeling method of wind power output for very short-term prediction. The modeling method with a nonlinear model has cascade structure composed of two parts. One is a linear dynamic part that is driven by a Gaussian white noise and described by an autoregressive model. The other is a nonlinear static part that is driven by the output of the linear part. This nonlinear part is designed for output distribution matching: we shape the distribution of the model output to match with that of the wind power output. The constructed model is utilized for one-step ahead prediction of the wind power output. Furthermore, we study the relation between the prediction accuracy and the prediction horizon.

11:45 Vibration Control Devices I

The effect of beam inclination on the performance of a passive vibration isolator using buckled beams (2165)

H Mori, T Waters, N Saotome, T Nagamine, Y Sato

Passive vibration isolators are desired to have both high static stiffness to support large static load and low local stiffness to reduce the displacement transmissibility at frequencies greater than resonance. Utilization of a vertical buckled beam as a spring component is one way to realize such a stiffness characteristic since it exhibits a smaller ratio of local stiffness to static stiffness than that of a linear spring. This paper investigates the behaviour of a vibration isolator using inclined beams as well as vertical ones and examines the effect of beam inclination for the purpose of improving the isolation performance. The experimental system investigated has an isolated mass which is supported by a combination of two types of beams: buckled beams and constraining beams. The buckled beams can be inclined from the vertical by attachment devices, and the constraining beams are employed to prevent off-axis motion of the isolated mass. The results demonstrate that the inclination of the buckled beams reduces the resonance frequency and improves the displacement transmissibility at frequencies greater than resonance.

11:45 Control of Civil Infrastructures

Passive vibration suppression using inerters for a multi-storey building structure (2233)

S Y Zhang, J Z Jiang, S Neild

This paper investigates the use of inerters for vibration suppression of a multi-storey building structure. The inerter was proposed as a two-terminal replacement for the mass element, with the property that the applied force is proportional to the relative acceleration across its terminals. It completes the force-current mechanical-electrical network analogy, providing the mechanical equivalent to a capacitor. Thus allows all passive mechanical impedances to be synthesised. The inerter has been used in Formula 1 racing cars and applications to various systems such as vehicle suspension have been identified. Several devices that incoporate inerter(s), as well as spring(s) and damper(s), have also been identified for vibration suppression of building structures. These include the tuned inerter damper (TID) and the tuned viscous mass damper (TVMD). In this paper, a three-storey building model with an absorber located at the bottom subjected to base excitation is studied. Four simple absorber layouts, in terms of how spring, damper and inerter components should be arranged, have been studied. In order to minimise the maximum relative displacement of the building, the optimum parameter values for each of the layouts have been obtained with respect to the inerter's size.

Notes

12:00 Nonlinear Vibrations I

Effect of asymmetry in the restoring force of the “click” mechanism in insect flight (2255)

A Abolfathi, M A Changizi, M J Brennan

The aim of this paper is to examine the effect of asymmetry in the force-deflection characteristics of an insect flight mechanism on its nonlinear dynamics. An improved simplified model for insect flight mechanism is suggested and numerical methods are used to study its dynamics. The range at which the mechanism may operate is identified. The asymmetry can lead to differences in the velocity in the upward and downward movements which can be beneficial for the insect flight.

12:00 Railway Induced Noise and Vibration I

Effects of rail dynamics and friction characteristics on curve squeal (2415)

B Ding, G Squicciarini, D J Thompson

Curve squeal in railway vehicles is an instability mechanism that arises in tight curves under certain running and environmental conditions. In developing a model the most important elements are the characterisation of friction coupled with an accurate representation of the structural dynamics of the wheel. However, the role played by the dynamics of the rail is not fully understood and it is unclear whether this should be included in a model or whether it can be safely neglected. This paper makes use of previously developed time domain and frequency domain curve squeal models to assess whether the presence of the rail and the falling characteristics of the friction force can modify the instability mechanisms and the final response. For this purpose, the time-domain model has been updated to include the rail dynamics in terms of its state space representation in various directions. Frequency domain and time domain analyses results show that falling friction is not the only reason for squeal and rail dynamics can play an important role, especially under constant friction conditions.

12:00 Stochastic Dynamics and Random Vibrations

Exact statistical energy analysis of systems excited by time correlated random excitations (2603)

C Lecomte

Exact statistical energy (SEA) of systems excited by time correlated random excitations is presented and analysed. This is in contrast of one of the main usual assumptions of SEA that excitations are uncorrelated or 'rain-on-the-roof'. It is shown here that the exact expressions of the expected energy in a dynamic system can be obtained, in particular when the system if excited by random excitations whose time correlation is Gaussian. The expressions are expressed in terms of frequency average and frequency variance of the deterministic response of the system. It has already been shown that these frequency average and variance have analytical expressions and that the frequency average can be expressed quasi-analytically in terms of just a few reduced terms. It is therefore hoped that this contribution will lead to a generalisation of SEA that supports more realistic time correlated excitations.

12:00 Vibration Control Devices I

An energy approach for the active vibration control of an oscillator with two translational degrees of freedom using two auxiliary rotating masses (2403)

R Bäumer, R Terrill, U Starossek

An active mass damper implementing two auxiliary masses rotating about a single axis is presented. This device is used for the vibration control of an oscillator performing translational motion in a plane (two translational degrees of freedom). In a preferred mode of operation, both auxiliary masses rotate with the same constant angular velocity in opposite directions. The resultant of the produced harmonic centrifugal forces is used for the vibration control. The direction of this control force can be altered by slightly varying the angular velocity of the auxiliary masses. Using an energy approach, a control algorithm was derived. The control algorithm ensures that the control force effectively damps the oscillator when it is displaced in a single, arbitrary direction. Numerical simulations were performed, showing that the presented device with the corresponding control algorithm effectively damps the vibrations on the oscillator.

12:00 Control of Civil Infrastructures

Experimental Study on a Tuned-Mass Damper of Offshore for Vibration Reduction (2452)

Q Wu, X Zhao, R Zheng

With the development of industry, oceanic oil production is one of the most important energy resources. Normally, offshore platform, located in the hostile environment, is easily subjected to unstable environmental loading, such as wind, wave, ice, and earthquake, and it becomes a critical problem to ensure the stability of offshore platform for safely engineering operations. In recent years, tuned-mass damper (TMD) technology has been adopted to reduce vibrations from wind and earthquake influences. Due to the complexity of earthquake excitations, most of researchers were focused on controlling response of structures under wind loads; however, less attention has been put on controlling earthquake response. Therefore, this study concentrates on the seismic reduction of offshore platform by application of a TMD system, and a comprehensively experimental study was processed to validate its effectiveness exposed to different earthquake. A 4-column offshore platform was built according to the actual size of approximately 1:200 ratios, and a TMD system was prepared for the experiment. By the different performance analyses, experimental results indicated that the proposed TMD system can effectively suppress the earthquake stimulus and keep the stability of offshore platform.

Notes

12:15 Railway Induced Noise and Vibration I

Rail roughness and rolling noise in tramways (2417)

L Chiacchiari, D J Thompson, G Squicciarini, E Ntotsios, G Loprencipe

Companies which manage railway networks have to cope continually with the problem of operating safety and maintenance intervention issues related to rail surface irregularities. A lot of experience has been gained in recent years in railway applications but the case of tramways is quite different; in this field there are no specific criteria to define any intervention on rail surface restoration. This paper shows measurements carried out on some stretches of a tram network with the CAT equipment (particulartly for short wavelengths between 6.3 mm and 500 mm) for the principal purpose of detecting different states of degradation of the rails and identifying a level of deterioration to be associated with the need for maintenance through rail grinding. The measured roughness is used as an input parameter into prediction models for both rolling noise and ground vibration to show the potential effect that high levels of roughness can have in urban environment. Rolling noise predictions are also compared with noise measurements to illustrate the applicability of the modelling approach. Particular attention is given to the way the contact filter needs to be modelled in the specific case of trams that generally operate at low speed. Finally an empirical approach to assess vibration levels in buildings is presented.

12:15 Stochastic Dynamics and Random Vibrations

Multi-dimensional Fokker-Planck equation analysis using the modified finite element method (2171)

J Náprstek, R Král

The Fokker-Planck equation (FPE) is a frequently used tool for the solution of cross probability density function (PDF) of a dynamic system response excited by a vector of random processes. FEM represents a very effective solution possibility, particularly when transition processes are investigated or a more detailed solution is needed. Actual papers deal with single degree of freedom (SDOF) systems only. So the respective FPE includes two independent space variables only. Stepping over this limit into MDOF systems a number of specific problems related to a true multi-dimensionality must be overcome. Unlike earlier studies, multi-dimensional simplex elements in any arbitrary dimension should be deployed and rectangular (multi-brick) elements abandoned. Simple closed formulae of integration in multi-dimension domain have been derived. Another specific problem represents the generation of multi-dimensional finite element mesh. Assembling of system global matrices should be subjected to newly composed algorithms due to multi-dimensionality. The system matrices are quite full and no advantages following from their sparse character can be profited from, as is commonly used in conventional FEM applications in 2D/3D problems. After verification of partial algorithms, an illustrative example dealing with a 2DOF non-linear aeroelastic system in combination with random and deterministic excitations is discussed.

12:15 Vibration Control Devices I

Development of optimal design theory for series multiple tuned mass dampers considering stroke and multiple structural modes (2406)

J F Wang, C C Lin

A tuned mass damper (TMD) system generates structural control forces through large motions of mass units. Therefore, it may not be functional if the stroke capacity of its spring and damper components are insufficient. This paper focuses on a novel mass-damper system, the series multiple tuned mass damper (SMTMD) system, which consists of multiple interconnected TMDs, of which only the first is connected to the primary structure. The main purpose of this paper is to compare the control effectiveness and TMD stroke of SMTMDs with those of a conventional TMD device. In addition, the ability of the studied SMTMD to suppress multiple structural modes is also investigated. First, the optimal design theory for an SMTMD installed on an arbitrary floor of a multi-storey building is developed. To optimize the SMTMD parameters, two performance indices are established by combining multiple modal responses of the primary structure. The developed theory is demonstrated analytically by using a three-story building. The results show that the SMTMD with a higher number of TMD units places lower demands on the TMD stroke and is more adaptive in controlling multiple structural modes of the primary structure.

12:15 Control of Civil Infrastructures

Damping Performance of Taut Cables with Passive Absorbers Incorporating Inerters (2399)

J Luo, J Zheng, J H G Macdonald

As stay cables are prone to vibrations due to their low inherent damping, a common method to limit unwanted vibrations is to install a viscous damper normal to the cable near one of its supports. This paper investigates the potential performance improvement that can be delivered by a numbers of candidate absorbers that incorporate inerters. The inerter device is the true network dual of a spring, with the property that the force is proportional to the relative acceleration between its two terminals. A finite element taut cable model is used for this study. A specific cost function indicating the damping performance of a cable with an absorber attached is proposed. An optimisation of the performance is then carried out. Based on optimisation results, the best damping performance for each of the candidate absorber structures against a specific range of inertance values is presented.

Notes

12:30 Poster Exhibition

A novel test rig for the dynamic characterization of large size tilting pad journal bearings (2186)

P Forte, E Ciulli, D Saba

The present work concerns the realization of a test bench for the dynamic characterization of high performance tilting pad journal bearings, within a collaboration between the Department of Civil and Industrial Engineering of Pisa, GE Oil&Gas and AM Testing. The objective is to cover journal diameters of interest of GE, from 150 to 300 mm, with peripheral speeds up to 150 m/s, static load up to 270 kN, dynamic loads up to 30 kN and frequencies up to 350 Hz, performances that make the apparatus very competitive worldwide. The adopted configuration has the test article (TA) floating at the mid-span of a rotor supported by two rolling bearings. The TA is statically loaded by a hydraulic actuator and excited dynamically by two orthogonal hydraulic actuators. Construction was recently concluded and preliminary tests are under way. In order to assess in advance the possible accuracy of the tests, a dynamic lumped parameter model of the test bench was developed to perform virtual experiments, including several possible sources of experimental errors and uncertainties. The model was implemented using reduced stiffness and mass matrices obtained from Finite Element Analysis by Component Modal Synthesis.

Finite element parametric study of the influence of friction pad material and morphological characteristics on disc brake vibration phenomena (2188)

P Forte, F Frendo, R N Rodrigues

Since nowadays the NVH performance of vehicles has become an important priority, the noise radiating from brakes is considered a source of considerable passenger discomfort and dissatisfaction. Creep groan and squeal that show up with annoying vibrations and noise in specific frequency ranges are typical examples of self-excited brake vibrations caused by the stick-slip effect, the former, by the mode coupling of brake disc and friction pads or calliper, the latter. In both cases, the friction coefficient, which depends, among other factors, on the morphology of the mating surfaces and on the operating conditions, is a fundamental parameter but not the only one for the occurrence of the vibratory phenomena. Finite element complex eigenvalue parametric analyses were performed on a disc brake assembly to evaluate propensity to dynamic instability of brakes with multiple pads, as in railway brakes, as a function of the number of pads, pad shape and size, and material parameters.

Experimental and numerical investigations on the dynamic response of turbine blades with tip pin dampers (2324)

S Zucca, T Berruti, L Cosi

Friction dampers are used to reduce vibration amplitude of turbine blades. The dynamics of these assemblies (blades + dampers) is nonlinear and the analysis is challenging from both the experimental and the numerical point of view. The study of the dynamics of blades with a tip damper is the aim of the present paper. The blades with axial-entry fir tree attachment carry a damper in a pocket between the blade covers. Pin dampers significantly affect the resonance frequency of the first blade bending mode and introduces non linearity due to friction contacts. A test rig, made of two blades held in a fixture by a hydraulic press with one damper between the blades was used for the experimental activity. Three different types of dampers (cylindrical, asymmetrical, wedge) have been experimentally investigated and experiments have shown that asymmetrical damper performs better than the others. The response of the blades with the asymmetrical damper was then simulated with a nonlinear code based on the Harmonic Balance Method (HBM). In the analysis, both the blade and the damper are modelled with the Finite Elements and then the matrices reduced with the Craig-Bampton Component Mode Synthesis (CB-CMS), while the periodical contact forces are modelled with state-of-the-art node-to-node contact elements. Numerical analysis has shown a strong influence of the actual extent of the contact area on the dynamics of the assembly. A model updating process was necessary. In the end, the numerical predictions match very well with the experimental curves.

Modeling and feedforward controller design in 2-dimensional shaking table systems (2344)

K Seki

This paper presents the modeling and basic controller design approach for multi-axis shaking table systems. A target shaking table system in this paper is composed of 4 actuators to move a table in horizontal plane, where coordinated action of each actuator is required to achieve the accurate table motion. In this paper, the simulation model of shaking table mechanism is constructed on the computer aided by multibody dynamics software. Based on the model, feedforward compensators for each actuator are designed to improve the tracking performance.

Study on Walking Training System using High-Performance Shoes constructed with Rubber Elements (2428)

Y Hayakawa, S Kawanaka, K Kanezaki, S Doi

The number of accidental falls has been increasing among the elderly as society has aged. The main factor is a deteriorating center of balance due to declining physical performance. Another major factor is that the elderly tend to have bowlegged walking and their center of gravity position of the body tend to swing from side to side during walking. To find ways to counteract falls among the elderly, we developed walking training system to treat the gap in the center of balance. We also designed High-Performance Shoes that showed the status of a person's balance while walking. We also produced walk assistance from the insole in which insole stiffness corresponded to human sole distribution could be changed to correct the person's walking status. We constructed our High-Performances Shoes to detect pressure distribution during walking. Comparing normal sole distribution patterns and corrected ones, we confirmed that our assistance system helped change the user's posture, thereby reducing falls among the elderly.

Vibration Reduction of Wind Turbines Using Tuned Liquid Column Damper Using Stochastic Analysis (2502)

M H Alkmim, M V G de Morais, A T Fabro

Passive energy dissipation systems encompass a range of materials and devices for enhancing damping. They can be used both for natural hazard mitigation and for rehabilitation of aging or deficient structures. Among the current passive energy dissipation systems, tuned liquid column damper (TLCD), a class of passive control that utilizes liquid in a "U" shape reservoir to control structural vibration of the primary system, has been widely researched in a variety of applications. This paper focus in TLCD application for wind turbines presenting the mathematical model as well as the methods used to overcome the nonlinearity embedded in the system. Optimization methods are used to determine optimum parameters of the system. Additionally, a comparative analysis is done considering the equivalent linearized system and the nonlinear system under random excitation with the goal of compare the nonlinear model with the linear equivalent and investigated the effectiveness of the TLCD. The results are shown using two types of random excitation, a white noise and a first order filters spectrum, the latter presents more satisfactory results since the excitation spectrum is physically more realistic than white noise spectrum model. The results indicate that TLCDs at optimal tuning can significantly dissipate energy of the primary structure between 3 to 11%.

Research on damping properties optimization of variable-stiffness plate (2566)

Q Wen-kai, Y Xian-tao, S Cheng

This paper investigates damping optimization design of variable-stiffness composite laminated plate, which means fibre paths can be continuously curved and fibre angles are distinct for different regions. First, damping prediction model is developed based on modal dissipative energy principle and verified by comparing with modal testing results. Then, instead of fibre angles, the element stiffness and damping matrixes are translated to be design variables on the basis of novel Discrete Material Optimization (DMO) formulation, thus reducing the computation time greatly. Finally, the modal damping capacity of arbitrary order is optimized using MMA (Method of Moving Asymptotes) method. Meanwhile, mode tracking technique is employed to investigate the variation of modal shape. The convergent performance of interpolation function, first order specific damping capacity (SDC) optimization results and variation of modal shape in different penalty factor are discussed. The results show that the damping properties of the variable-stiffness plate can be increased by 50%-70% after optimization.

Model updating in flexible-link multibody systems (2589)

R Belotti, G Caneva, I Palomba, D Richiedei, A Trevisani

The dynamic response of flexible-link multibody systems (FLMSs) can be predicted through nonlinear models based on finite elements, to describe the coupling between rigid-body and elastic behaviour. Their accuracy should be as high as possible to synthesize controllers and observers. Model updating based on experimental measurements is hence necessary. By taking advantage of the experimental modal analysis, this work proposes a model updating procedure for FLMSs and applies it experimentally to a planar robot. Indeed, several peculiarities of the model of FLMS should be carefully tackled. On the one hand, nonlinear models of a FLMS should be linearized about static equilibrium configurations. On the other, the experimental mode shapes should be corrected to be consistent with the elastic displacements represented in the model, which are defined with respect to a fictitious moving reference (the equivalent rigid link system). Then, since rotational degrees of freedom are also represented in the model, interpolation of the experimental data should be performed to match the model displacement vector. Model updating has been finally cast as an optimization problem in the presence of bounds on the feasible values, by also adopting methods to improve the numerical conditioning and to compute meaningful updated inertial and elastic parameters.

Vibration control using nonlinear damped coupling (2618)

M G Tehrani, V Gattulli

In this paper, a dynamical system, which consists of two linear mechanical oscillators, coupled with a nonlinear damping device is considered. First, the dynamic equations are derived, then, an analytical method such as harmonic balance method, is applied to obtain the response to a harmonic base excitation. The response of the system depends on the excitation characteristics. A parametric study is carried out based on different base excitation amplitudes, frequencies, and different nonlinear damping values and the response of the system is fully described. For validation, time domain simulations are carried out to obtain the nonlinear response of the coupled system.

Application of the Wave and Finite Element Method to Calculate Sound Transmission Through Cylindrical Structures (2128)

M J Kingan, Y Yang, B R Mace

This paper concerns the prediction of sound transmission through a cylindrical structure. The problem considered is that of sound generated by a line source located exterior to a two-dimensional circular cylinder which produces sound waves which transmit through the cylinder to an internal medium. An analytical solution is presented for the case of sound transmission through a thin cylindrical shell, by modelling the shell response using the Flugge-Byrne-Lur'ye equations. This solution is then compared to calculations where the response of the cylinder is calculated using the Wave and Finite Element (WFE) method. The WFE method involves modelling a small segment of a structure using traditional finite element (FE) methods. The mass and stiffness matrices of the segment are then used to calculate the response of the structure to excitation by an acoustic field. The WFE approach for calculating sound transmission is validated by comparison with the analytic solution. Formulating analytic solutions for more complicated structures can be cumbersome whereas using a numerical technique, such as the WFE method, is relatively straightforward.

On the synchronization of two metronomes and their related dynamics (2404)

J C Carranza, M J Brennan, B Tang

Synchronization was first reported by Christiaan Huygens in 1665 when he observed anti-phase synchronization achieved by two pendulum clocks hanging on a common base. Since then researchers have tried to understand the results reported by Huygens using their own ways to reproduce his experiment and applying several methods of analysis. Each researcher has reported different results, even compared with those reported by Huygens. In this paper a simple model is proposed to study in-phase and anti-phase synchronization of two metronomes based on a normal mode analysis using van der Pol oscillators. The instantaneous frequency of the responses from both simulations and experimental data is used in the analysis. Unlike previous studies, measurements are made using videos and the time domain responses of the metronomes extracted by means of tracking software. Plots showing how the initial conditions lead to both synchronization states are also presented.

Notes

15:00 Nonlinear Vibrations II

Insight into the dynamic behaviour of the Van der Pol/Raleigh oscillator using the internal stiffness and damping forces (2388)

M J Brennan, B Tang, J C Carranza

The van der Pol oscillator is an archetypal nonlinear oscillator that has been studied for many years. It is a self-sustaining oscillator that vibrates in a limit cycle, and has the characteristic that it generates energy in the part of the cycle when the displacement is small and dissipates energy in the part of the cycle when the displacement is large. Almost all analyses for this type of oscillator have been conducted in a strict mathematical framework using the displacement and velocity of the mass to describe the motion in the phase plane. Physical insight into the behaviour is then generally only possible for very small or for very large damping nonlinearity. In this paper a fresh approach is taken. The internal forces of the Rayleigh oscillator are studied rather than van der Pol's equation as the key damping force is a function of only velocity. Simulations are presented which show how the stiffness and damping forces vary when the system is vibrating in a steady-state limit cycle.

15:00 Railway Induced Noise and Vibration II

Development of a model to assess acoustic treatments to reduce railway noise (2426)

H Jeong, G Squicciarini, D J Thompson, J Ryue

Porous materials have recently been used in absorptive treatments around railway tracks to reduce noise emissions. To investigate the effect of porous materials, a finite element model has been developed. 2D models for porous materials have been considered either as an equivalent fluid or as a poroelastic material based on the Biot theory. The two models have been validated and compared with each other to check the effect of the skeleton vibration. The poroelastic FE model has been coupled with a 2D acoustic boundary element model for use in railway applications. The results show that it may be necessary to include the frame vibration, especially at low frequencies where a frame resonance occurs. A method for the characterization of porous materials is also discussed. From this it is shown that the elastic properties of the material determine the resonance frequency and the magnitude.

15:00 Control Theory

Linear Matrix Inequality Method for a Quadratic Performance Index Minimization Problem with a class of Bilinear Matrix Inequality Conditions (2277)

M Tanemura, Y Chida

There are a lot of design problems of control system which are expressed as a performance index minimization under BMI conditions. However, a minimization problem expressed as LMIs can be easily solved because of the convex property of LMIs. Therefore, many researchers have been studying transforming a variety of control design problems into convex minimization problems expressed as LMIs. This paper proposes an LMI method for a quadratic performance index minimization problem with a class of BMI conditions. The minimization problem treated in this paper includes design problems of state-feedback gain for switched system and so on. The effectiveness of the proposed method is verified through a state-feedback gain design for switched systems and a numerical simulation using the designed feedback gains.

15:00 Vibration Control Devices II

Characterization and performance evaluation of a vertical seismic isolator using link and crank mechanism (2511)

N Tsujiuchi, A Ito, Y Sekiya, C Nan, M Yasuda

In recent years, various seismic isolators have been developed to prevent earthquake damage to valuable art and other rare objects. Many seismic isolators only defend against horizontal motions, which are the usual cause of falling objects. However, the development of a seismic isolator designed for vertical vibration is necessary since such great vertical vibration earthquakes as the 2004 Niigata Prefecture Chuetsu Earthquake have occurred, and their increased height characteristics are undesirable. In this study, we developed a vertical seismic isolator that can be installed at a lower height and can support loads using a horizontal spring without requiring a vertical spring. It has a mechanism that combines links and cranks. The dynamic model was proposed and the frequency characteristics were simulated when the sine waves were the input. Shaking tests were also performed. The experimental value of the natural frequency was 0.57 Hz, and the theoretical values of the frequency characteristics were close to the experimental values. In addition, we verified this vertical seismic isolator's performance through shaking tests and simulation for typical seismic waves in Japan. We verified the seismic isolation's performance from the experimental result because the average reduction rate of the acceleration was 0.21.

15:00 Civil Engineering Structures

Bidirectional Connected Control Method Applied to an Experimental Structural Model Split into Four Substructures (2334)

T Watanabe, K Seto, H Toyoda, T Takano

Connected Control Method (CCM) is a well-known mechanism in the field of civil structural vibration control that utilizes mutual reaction forces between plural buildings connected by dampers as damping force. However, the fact that CCM requires at least two buildings to obtain reaction force prevents CCM from further development. In this paper, a novel idea to apply CCM onto a single building by splitting the building into four substructures is presented. An experimental model structure split into four is built and CCM is applied by using four magnetic dampers. Experimental analysis is carried out and basic performance and effectiveness of the presented idea is confirmed.

Notes

15:15 Nonlinear Vibrations II

Nonlinear Dynamics of Structures with Material Degradation (2607)

P Soltani, D J Wagg, C Pinna, R Whear, C Briody

Structures usually experience deterioration during their working life. Oxidation, corrosion, UV exposure, and thermo-mechanical fatigue are some of the most well-known mechanisms that cause degradation. The phenomenon gradually changes structural properties and dynamic behaviour over their lifetime, and can be more problematic and challenging in the presence of nonlinearity. In this paper, we study how the dynamic behaviour of a nonlinear system changes as the thermal environment causes certain parameters to vary. To this end, a nonlinear lumped mass modal model is considered and defined under harmonic external force. Temperature dependent material functions, formulated from empirical test data, are added into the model. Using these functions, bifurcation parameters are defined and the corresponding nonlinear responses are observed by numerical continuation. A comparison between the results gives a preliminary insight into how temperature induced properties affects the dynamic response and highlights changes in stability conditions of the structure.

15:15 Railway Induced Noise and Vibration II

Analysis of dynamic stiffness effect of primary suspension helical springs on railway vehicle vibration (2453)

W Sun, D J Thompson, J Zhou, D Gong

Helical springs within the primary suspension are critical components for isolating the whole vehicle system from vibration generated at the wheel/rail contact. As train speeds increase, the frequency region of excitation becomes larger, and a simplified static stiffness can no longer represent the real stiffness property in a vehicle dynamic model. Coil springs in particular exhibit strong internal resonances, which lead to high vibration amplitudes within the spring itself as well as degradation of the vibration isolation. In this paper, the dynamic stiffness matrix method is used to determine the dynamic stiffness of a helical spring from a vehicle primary suspension. Results are confirmed with a finite element analysis. Then the spring dynamic stiffness is included within a vehicle-track coupled dynamic model of a high speed train and the effect of the dynamic stiffening of the spring on the vehicle vibration is investigated. It is shown that, for frequencies above about 50 Hz, the dynamic stiffness of the helical spring changes sharply. Due to this effect, the vibration transmissibility increases considerably which results in poor vibration isolation of the primary suspension. Introducing a rubber layer in series with the coil spring can attenuate this effect.

15:15 Control Theory

Experimental Verification of a Vehicle Localization based on Moving Horizon Estimation Integrating LRS and Odometry (2522)

K Sakaeta, K Nonaka, K Sekiguchi

Localization is an important function for the robots to complete various tasks. For localization, both internal and external sensors are used generally. The odometry is widely used as the method based on the internal sensors, but it suffers from cumulative errors. In the method using the laser range sensor (LRS) which is a kind of external sensor, the estimation accuracy is affected by the number of available measurement data. In our previous study, we applied moving horizon estimation (MHE) to the vehicle localization for integrating the LRS measurement data and the odometry information where the weightings of them are balanced relatively adapting to the number of the available LRS measurement data. In this paper, the effectiveness of the proposed localization method is verified through both numerical simulations and experiments using a 1/10 scale vehicle. The verification is conducted in the situations where the vehicle position cannot be localized uniquely on a certain direction using the LRS measurement data only. We achieve accurate localization even in such a situation by integrating the odometry and LRS based on MHE. We also show the superiority of the method through comparisons with a method using extended Kalman filter (EKF).

15:15 Vibration Control Devices II

A simple levitation system using wireless power supply system and Lorentz force (2624)

K Oka, M Tanaka

A new type of magnetic levitation mechanism has been proposed. The feature of this mechanism is using wireless power supply system and Lorentz forces for levitation. The stability of levitation is performed by passive control by magnetic flux configuration between permanent magnets and active control of electromagnets. In this paper, the concept of levitation mechanism is introduced, FEM analyses for levitation force and wireless power supply performance is examined. In concept two types of levitation systems which are different on the point of active control directions are introduced. In FEM analyses, the required current for levitation and the directions of generating forces are calculated. In the study of wireless power supply system, the required voltage for the levitation is expected. Finally the feasibility of the proposed levitation system will be verified.

15:15 Civil Engineering Structures

Wave propagation in rods with an exponentially varying cross-section - modelling and experiments (2547)

M K Kalkowski, J M Muggleton, E Rustighi

In this paper we analyse longitudinal wave propagation in exponentially tapered rods from both a theoretical and an experimental perspective. The tapering introduces significant changes to the behaviour of the rod. The longitudinal wave does not propagate from zero frequency, its cut-off frequency depending on the coefficient in the exponent. The analytical description of this phenomenon is well established, however little experimental work has been published to date. After a brief review of the classical solution of the exponential rod equation, we derive a methodology allowing the wavenumbers to be estimated from a set of equally spaced dynamic responses. Our approach is verified numerically against a finite element simulation and validated experimentally, both showing very good agreement. To further explain the results and provide an outlook for future work, we present a finite element model of the tapered rod embedded in an infinite solid medium. We conclude with a discussion on the effects of the surrounding medium on the behaviour of the structure and resulting characteristic features of the wavenumber.

Notes

15:30 Nonlinear Vibrations II

A model identification technique to characterize the low frequency behaviour of surrogate explosive materials (2619)

J Paripovic, P Davies

The mechanical response of energetic materials, especially those used in improvised explosive devices, is of great interest to improve understanding of how mechanical excitations may lead to improved detection or detonation. The materials are comprised of crystals embedded into a binder. Microstructural modelling can give insight into the interactions between the binder and the crystals and thus the mechanisms that may lead to material heating and but there needs to be validation of these models and they also require estimates of constituent material properties. Addressing these issues, nonlinear viscoelastic models of the low frequency behavior of a surrogate material-mass system undergoing base excitation have been constructed, and experimental data have been collected and used to estimate the order of components in the system model and the parameters in the model. The estimation technique is described and examples of its application to both simulated and experimental data are given. From the estimated system model the material properties are extracted. Material properties are estimated for a variety of materials and the effect of aging on the estimated material properties is shown.

15:30 Railway Induced Noise and Vibration II

Transient wave propagation analysis of a pantograph-catenary system (2596)

K Nagao, A Masuda

This paper proposes a systematic method to analyze the dynamic response of an overhead catenary with pantographs moving at constant speed. The overhead catenary is modeled as a one-dimensional infinite-length string, which is periodically supported by hangers. On the other hand, the pantograph is a sub-structure moving at a constant speed, which is modeled as a lumped mass system contacting the catenary. In this study, the whole system is divided into elements in the manner of the transfer matrix method. Then, the relationship among traveling waves in every element is systematically obtained in the Laplace domain following the method of reverberation-ray matrix. Since the governing equation of the system changes periodically with time, the analysis of the temporal evolution of the system can be realized by repeating a single period analysis starting from the instant when the pantograph comes into a unit cell by means of the reverberation-ray matrix analysis followed by the inverse Laplace transform. When the pantograph reaches the opposite hanger, the whole elements are shifted backward, and the catenary response of the forehead element is used as the initial condition of the next period.

15:30 Control Theory

Moving Horizon Estimation for Vehicle Robots using Partial Marker Information of Motion Capture System (2576)

M Takahashi, K Nonaka, K Sekiguchi

The measurement using a motion capture camera is fluctuated by white noise and outliers. In addition, markers to be measured are frequently hidden from cameras by occlusion, then the position and heading angle of a vehicle cannot be uniquely determined because of failure to detect sufficient number of markers. Thus, robust estimation method is required which suppresses the influence of the white noise, the outlier and the occlusion. In this study, we introduce Moving Horizon Estimation (MHE) using partial marker information of motion capture system. It optimizes the objective function using both the marker information in the evaluation range and the constraints on the robot dynamics. By virtue of introduction of constraints, even if the cameras fail to measure the actual state of the robot, the estimated value is determined by MHE. It is the difference from our previous research which assumed that sufficient number of markers are available. In this paper, we estimate the position of the vehicle robot by MHE using the information of the measured markers on the robot, even if several markers are hidden. We will prove the effectiveness of the proposed method by comparing MHE with EKF.

15:30 Vibration Control Devices II

Force transmissibility and vibration power flow behaviour of inerter-based vibration isolators (2650)

J Yang

This paper investigates the dynamics and performance of inerter-based vibration isolators. Force / displacement transmissibility and vibration power flow are obtained to evaluate the isolation performance. Both force and motion excitations are considered. It is demonstrated that the use of inerters can enhance vibration isolation performance by enlarging the frequency band of effective vibration isolation. It is found that adding inerters can introduce anti-resonances in the frequency-response curves and in the curves of the force and displacement transmissibility such that vibration transmission can be suppressed at interested excitation frequencies. It is found that the introduction of inerters enhances inertial coupling and thus have a large influence on the dynamic behaviour at high frequencies. It is shown that force and displacement transmissibility increases with the excitation frequency and tends to an asymptotic value as the excitation frequency increases. In the high-frequency range, it was shown that adding inerters can result in a lower level of input power. These findings provide a better understanding of the effects of introducing inerters to vibration isolation and demonstrate the performance benefits of inerter-based vibration isolators.

15:30 Civil Engineering Structures

Ambient modal testing of a double-arch dam: the experimental campaign and model updating (2622)

J H García-Palacios, J M Soria, I M Díaz, F Tirado-Andrés

A finite element model updating of a double-curvature-arch dam (La Tajera, Spain) is carried out hereof using the modal parameters obtained from an operational modal analysis. That is, the system modal dampings, natural frequencies and mode shapes have been identified using output-only identification techniques under environmental loads (wind, vehicles). A finite element model of the dam-reservoir-foundation system was initially created. Then, a testing campaing was then carried out from the most significant test points using high-sensitivity accelerometers wirelessly synchronized. Afterwards, the model updating of the initial model was done using a Monte Carlo based approach in order to match it to the recorded dynamic behaviour. The updated model may be used within a structural health monitoring system for damage detection or, for instance, for the analysis of the seismic response of the arch damreservoir-foundation coupled system.

Notes

15:45 Railway Induced Noise and Vibration II

Contact force control of an active pantograph for high speed trains (2557)

M T Ko, M Yokoyama, Y Yamashita, S Kobayashi, T Usuda

In this paper, a mathematical model of the pantograph with flexibility is developed based on experiments, and then an optimal controller together with a sliding observer is proposed to regulate the contact force in the presence of variation with respect to the equivalent stiffness of the catenary system. Furthermore, some physical interpretations of the closed-loop dynamics and pole-zero cancelations are given by analysis from a viewpoint of the output zeroing.

15:45 Control Theory

Improving active eigenvector assignment through passive modifications (2588)

R Belotti, D Richiedei

Specifications on the dynamic behavior of feedback-controlled vibrating systems are often expressed in terms of its eigenstructure, i.e. eigenvalues and eigenvectors. The notion of controllability establishes the possibility to assign eigenvalues through state feedback, but it is not adequate to assure the assignment of arbitrary eigenvectors. Indeed, assignable eigenvectors are just those belonging to the allowable vector subspace, which depends on the physical properties of the vibrating system (mass, damping and stiffness matrices) and of the actuators. To overcome this limitation, this paper proposes a hybrid approach that exploits passive modification of the system physical parameters to modify the allowable subspace in such a way that it spans (or closely approximates) the desired eigenvectors. Then, once that the system modifications have been computed, standard techniques for control synthesis can be employed to compute the gains assigning the desired poles and the eigenvectors. The modification of the allowable subspace is cast in this work as a rank minimization problem, which can be efficiently tackled through semi-definite programming. The proposed method is numerically validated on a lumped parameter system, by proving that the assignment of eigenvectors by hybrid control is significantly enhanced compared with sole active control.

15:45 Civil Engineering Structures

Numerical and experimental investigation on the effects of non-structural components on the elastic fundamental period of buildings (2625)

R Ditommaso, F C Ponzo, C Iacovino, G Auletta, A Nigro

In this work a parametric study has been performed in order to evaluate the elastic fundamental period of vibration of buildings as function of structural morphology (height, plan area, ratio between plan dimensions), infills distribution and soil characteristics. Recent earthquakes highlighted the significant effects derived from the interaction between structural and non-structural elements on the main dynamic parameters of a structure and the lateral distribution of the inertial forces. Usually, non-structural elements acts together with the structural elements, adding both masses and stiffness. The presence of infill elements is generally not taken into account in the design process of structural elements, although these elements can significantly increase the lateral stiffness of a building leading to a modification in dynamic properties. Particularly, at the Damage Limit State (where an elastic behaviour is expected), soil-structure interaction effects and non-structural elements may further affect the elastic natural period of buildings, changing the spectral accelerations compared with those provided by seismic codes in case of static analyses. Using a numerical and an experimental campaign, the effects of these parameters on the elastic dynamic behaviour of buildings have been studied taking into account presence and distribution of non-structural elements.

Notes

16:30 Nonlinear Vibrations III

Dynamic response of a nonlinear parametrically excited system subject to harmonic base excitation (2412)

B Zaghari, E Rustighi, M G Tehrani

A Nonlinear Parametrically Excited (NPE) system subjected to a harmonic base excitation is presented. Parametric amplification, which is the process of amplifying the system's response with a parametric excitation, has been observed in mechanical and electrical systems. This paper includes an introduction to the equation of motion of interest, a brief analysis of the equations nonlinear response, and numerical results. The present work describes the effect of cubic stiffness nonlinearity, cubic parametric nonlinearity, and the relative phase between the base excitation and parametric excitation under parametric amplification. The nonlinearities investigated in this paper are generated by an electromagnetic system. These nonlinearities were found both experimentally and analytically in previous work [1]; however, their effect on a base excited NPE is demonstrated in the scope of this paper. This work has application in parametric amplification for systems, which are affected by strong stiffness nonlinearities and excited by harmonic motion. A careful selection of system parameters, such as relative phase and cubic parametric nonlinearity can result in significant parametric amplification, and prevent the jump from upper stable solutions to the lower stable solutions.

16:30 ANTARES-EMVEM

Flywheel proof mass actuator for velocity feedback control (2218)

A Kras, P Gardonio

This paper presents four new proof mass actuators used in velocity feedback control systems to reduce the vibration of flexible structures. A classical proof mass actuator is formed by a coil–magnet linear motor, with the magnet suspended on soft springs. This arrangement produces a net force effect at frequencies above the fundamental resonance frequency of the springs–magnet system. Thus, it could be used to implement point velocity feedback loops, although the dynamic response and static deflection of the springs-magnet system may limit the stability and control performance. The four proof mass actuators presented in this study include a flywheel element, which is used to augment the inertia effect of the suspended proof mass. The paper shows that the axial and angular inertia effects of the flywheel element modify both the dynamic response and static deflection of the springs-magnet system and thus the stability and control performance of velocity feedback loops using these actuators are significantly improved.

16:30 Innovative Combustion Technology

Study on Model Based Combustion Control of Diesel Engine with Multi Fuel Injection (2567)

R Ikemura, Y Yamasaki, S Kaneko

A controller for model-based control of diesel engine with triple injection were developed with a combustion model. In the combustion model, an engine cycle is discretized into several representative points in order to improve calculation speed, while physical equations are employed to expand the versatility. The combustion model can predict in-cylinder pressure and temperature in these discrete points. Prediction accuracy of the combustion model was evaluated by comparison with experimental result. A controller was designed with the combustion model in order to calculate optimal fuel injection pattern for controlling in-cylinder pressure peak timing. The controller's performance was evaluated through simulation in which the combustion model was used as a plant model.

16:30 Modal Analysis and Structural Modification

A Structured Model Reduction Method for Linear Interconnected Systems (2250)

R Sato, M Inoue, S Adachi

This paper develops a model reduction method for a large-scale interconnected system that consists of linear dynamic components. In the model reduction, we aim to preserve physical characteristics of each component. To this end, we formulate a structured model reduction problem that reduces the model order of components while preserving the feedback structure. Although there are a few conventional methods for such structured model reduction to preserve stability, they do not explicitly consider performance of the reduced-order feedback system. One of the difficulties in the problem with performance guarantee comes from nonlinearity of a feedback system to each component. The problem is essentially in a class of nonlinear optimization problems, and therefore it cannot be efficiently solved even in numerical computation. In this paper, application of an equivalent transformation and a proper approximation reduces this nonlinear problem to a problem of the weighted linear model reduction. Then, by using the weighted balanced truncation technique, we construct a reduced-order model with preserving the feedback structure to ensure small modeling error. Finally, we verify the effectiveness of the proposed method through numerical experiments.

16:30 Sensors and Actuators

The Development of an Intelligent Hybrid Active-passive Vibration Isolator (2264)

C Shuai, J Ma, E Rustighi

A hybrid active-passive vibration isolator made up of electromagnetic actuator and air spring in parallel can be used to effectively isolate the broadband and line spectrum vibration of mechanical equipment simultaneously. However, due to its reliability and safety problems caused by the impact, its application in ships is limited. In this paper, an impact-resistant structure and an air gap self-sensing method of the passive-active hybrid vibration isolator are proposed and developed on the base of modelling, simulation and analysis. A thin magnetic rubber is filled into the air gap of electromagnetic actuator, which can avoid rigid collision between the armature and the permanent magnet under the action of impact. A suspension armature structure including pre-compression spring is suggested, which can automatically compensate the deformation caused by impact and protect the coil and permanent magnet from impact damage. An air gap self-sensing method is developed through detecting the voltage between the input and output terminals of actuator, which is verified by experiments.

Notes

16:45 Nonlinear Vibrations III

Studies of parametrically excited non-linear MDOF systems at parametric resonances (2424)

T J Kniffka, B R Mace, H Ecker, R Halkyard

An increasing number of MEMS devices use parametric excitation (PE) to outperform conventional designs. These systems are operated at parametric resonance. Different to standard cases of resonance, at parametric resonances the vibration's amplitudes increase faster and within a smaller interval. The amplification is much larger and only limited by non-linearities. So far the focus has mostly been on one degree of freedom (1DOF) systems. This is partly caused by a lack of methods to investigate and design multi degree of freedom (MDOF) systems time-efficiently. Restricting the systems to 1DOF ignores the opportunity to make use of PE effects only available in MDOF systems: parametric combination resonances and parametric anti-resonances, where an enhanced damping behaviour can be observed. The paper demonstrates how to approximate non-linear MDOF PE systems with 1DOF models. This leads to a generalised, dimensionless model applicable to many systems. Approaches are presented for investigating such a reduced non-linear 1DOF PE model analytically and semi-analytically at parametric resonances using averaging methods. For a 2DOF system the results are validated numerically by continuation methods and time simulations. Limits of both the analytical and the semi-analytical approaches are discussed.

16:45 ANTARES-EMVEM

Sweeping piezoelectric patch vibration absorbers (2363)

D Casagrande, P Gardonio, M Zilletti

This paper presents a simulation study concerning the low-mid frequencies control of flexural vibration in a lightly damped thin plate, equipped with five time-varying shunted vibration absorbers. The panel is excited by a rain-on-the-roof broad frequency band stationary disturbance. The absorbers are composed of piezoelectric patches connected to time-varying RL shunt circuits. Continuous, sweeping, variations over time of the shunts are implemented in such a way as to swing the resonance frequency and damping factor of the absorbers within certain ranges and in this way to reduce the resonant response of multiple flexural modes of the hosting plate. A single patch absorber implementing the sweeping shunt is first presented and its performance is compared to that of a classical patch absorber with time-invariant RL shunt. The same analysis is conducted for a multiple patch system using five shunted absorbers. The control performance is assessed considering the spectrum of the total flexural kinetic energy of the system in the 20 Hz to 1000 Hz frequency band. The study shows that the configuration with five time-varying shunted piezoelectric patches reduces the resonance peaks of the kinetic energy spectrum by 5 to 15 dB.

16:45 Innovative Combustion Technology

Combustion Control System Design of Diesel Engine via ASPR based Output Feedback Control Strategy with a PFC (2461)

I Mizumoto, J Tsunematsu, S Fujii

In this paper, a design method of an output feedback control system with a simple feedforward input for a combustion model of diesel engine will be proposed based on the almost strictly positive real-ness (ASPR-ness) of the controlled system for a combustion control of diesel engines. A parallel feedforward compensator (PFC) design scheme which renders the resulting augmented controlled system ASPR will also be proposed in order to design a stable output feedback control system for the considered combustion model. The effectiveness of our proposed method will be confirmed through numerical simulations.

16:45 Modal Analysis and Structural Modification

Dynamic similarity design method for an aero-engine dual-rotor test rig (2286)

H Miao, C Zang, M I Friswell

This paper presents a dynamic similarity design method to design a scale dynamic similarity model (DSM) for a dual-rotor test rig of an aero-engine. Such a test rig is usually used to investigate the major dynamic characteristics of the full-size model (FSM) and to reduce the testing cost and time for experiments on practical aero engine structures. Firstly, the dynamic equivalent model (DEM) of a dual-rotor system is modelled based on its FSM using parametric modelling, and the first 10 frequencies and mode shapes of the DEM are updated to agree with the FSM by modifying the geometrical shapes of the DEM. Then, the scaling laws for the relative parameters (such as geometry sizes of the rotors, stiffness of the supports, inherent properties) between the DEM and its scale DSM were derived from their equations of motion, and the scaling factors of the above-mentioned parameters are determined by the theory of dimensional analyses. After that, the corresponding parameters of the scale DSM of the dual-rotor test rig can be determined by using the scaling factors. In addition, the scale DSM is further updated by considering the coupling effect between the disks and shafts. Finally, critical speed and unbalance response analysis of the FSM and the updated scale DSM are performed to validate the proposed method.

16:45 Sensors and Actuators

Steering Law Controlling the Constant Speeds of Control Moment Gyros (2291)

Y Koyasako, M Takahashi

To enable the agile control of satellites, using control moment gyros (CMGs) has become increasingly necessary because of their ability to generate large amounts of torque. However, CMGs have a singularity problem whereby the torque by the CMGs degenerates from three dimensions to two dimensions, affecting spacecraft attitude control performance. This study proposes a new steering control law for CMGs by controlling the constant speed of a CMG. The proposed method enables agile attitude changes, according to the required task, by managing the total angular momentum of the CMGs by considering the distance to external singularities. In the proposed method, the total angular momentum is biased in a specific direction and the angular momentum envelope is extended. The design method can increase the net angular momentum of CMGs which can be exchanged with the satellite. The effectiveness of the proposed method is demonstrated by numerical simulations.

Notes

17:00 Nonlinear Vibrations III

Vibration suppression of a flywheel system using a novel nonlinear vibration absorber with an Euler buckled beam (2496)

L Haiping, S Wenhua

The micro-vibration from flywheel system, as one of the main disturbances, has restricted the effective use of high sensitive payloads in satellites. In order to suppress the low-frequency line spectrum from the flywheel, a novel nonlinear vibration absorber (NVA) using Euler buckled beam is developed. The proposed NVA is attached on the supporting structure of the flywheel assembly, aiming to attenuate the line spectrum introduced by the flywheel in operation. A discrete multi-degree-of-freedom dynamic model, which includes the NVA, the flywheel and the supporting structure by taking into account of the gyroscopic effect of the flywheel, is built. The NVA is represented by a linear positive stiffness spring and parallel Euler buckled beams. The systematic dynamic equations with and without the NVA under the micro-vibration from the flywheel, respectively, are solved by using fourth-order Runge-Kutta method in time-domain. In addition, the effects of initial imperfection, oblique angle and damping coefficient of the Euler buckled beam on the vibration suppression performance are studied. The calculating results reveal that a typical nonlinear dynamic absorber for controlling the micro-vibration from the flywheel is constructed successfully based on the provided designing parameters of the Euler buckled beam. Compared with the vibration responses of the combined system with and without the NVA, it can be concluded that the NVA has better attenuation performance. The initial imperfection and damping coefficient of the Euler buckled beam exist optimum values, and with the increase of the oblique angle, the vibration controlling characteristics of the NVA have been improved.

17:00 ANTARES-EMVEM

Active control of turbulent boundary layer sound transmission into a vehicle interior (2433)

A Caiazzo, N Alujević, B Pluymers, W Desmet

In high speed automotive, aerospace, and railway transportation, the turbulent boundary layer (TBL) is one of the most important sources of interior noise. The stochastic pressure distribution associated with the turbulence is able to excite significantly structural vibration of vehicle exterior panels. They radiate sound into the vehicle through the interior panels. Therefore, the air flow noise becomes very influential when it comes to the noise vibration and harshness assessment of a vehicle, in particular at low frequencies. Normally, passive solutions, such as sound absorbing materials, are used for reducing the TBL-induced noise transmission into a vehicle interior, which generally improve the structure sound isolation performance. These can achieve excellent isolation performance at higher frequencies, but are unable to deal with the low-frequency interior noise components. In this paper, active control of TBL noise transmission through an acoustically coupled double panel system into a rectangular cavity is examined theoretically. The Corcos model of the TBL pressure distribution is used to model the disturbance. The disturbance is rejected by an active vibration isolation unit reacting between the exterior and the interior panels. Significant reductions of the low-frequency vibrations of the interior panel and the sound pressure in the cavity are observed.

17:00 Innovative Combustion Technology

H_∞ control of combustion in diesel engines using a discrete dynamics model (2460)

M Hirata, S Ishizuki, M Suzuki

This paper proposes a control method for combustion in diesel engines using a discrete dynamics model. The proposed two-degree-of-freedom control scheme achieves not only good feedback properties such as disturbance suppression and robust stability but also a good transient response. The method includes a feedforward controller constructed from the inverse model of the plant, and a feedback controller designed by an H1 control method, which reduces the effect of the turbocharger lag. The effectiveness of the proposed method is evaluated via numerical simulations.

17:00 Modal Analysis and Structural Modification

Understanding the effect of hammering process on the vibration characteristics of cymbals (2290)

F Kuratani, T Yoshida, T Koide, T Mizuta, K Osamura

Cymbals are thin domed plates used as percussion instruments. When cymbals are struck, they vibrate and radiate sound. Cymbals are made through spin forming, hammering, and lathing. The spin forming creates the basic shape of the cymbal, which determines its basic vibration characteristics. The hammering and lathing produce specific sound adjustments by changing the cymbal's vibration characteristics. In this study, we study how hammering cymbals affects their vibration characteristics. The hammering produces plastic deformation (small, shallow dents) on the cymbal's surface, generating residual stresses throughout it. These residual stresses change the vibration characteristics. We perform finite element analysis of a cymbal to obtain its stress distribution and the resulting change in vibration characteristics. To reproduce the stress distribution, we use thermal stress analysis, and then with this stress distribution we perform vibration analysis. These results show that each of the cymbal's modes has a different sensitivity to the thermal load (i.e., hammering). This difference causes changes in the frequency response and the deflection shape that significantly improves the sound radiation efficiency. In addition, we explain the changes in natural frequencies by the stress and modal strain energy distributions.

17:00 Sensors and Actuators

An application review of dielectric electroactive polymer actuators in acoustics and vibration control (2323)

Z Zhao, C Shuai, Y Gao, E Rustighi, Y Xuan

Recent years have seen an increasing interest in the dielectric electroactive polymers (DEAPs) and their potential in actuator applications due to the large strain capabilities. This paper starts with an overview of some configurations of the DEAP actuators and follows with an in-depth literature and technical review of recent advances in the field with special considerations given to aspects pertaining to acoustics and vibration control. Significant research has shown that these smart actuators are promising replacement for many conventional actuators. The paper has been written with reference to a large number of published papers listed in the reference section.

Notes

17:15 Nonlinear Vibrations III

Exploiting modal interaction during run-up of a magnetically supported Jeffcott rotor (2545)

F Dohnal, A Chasalevris

Introducing a parametric anti-resonance in a vibrating system couples two of the many vibration modes and enables an energy exchange between those two. This feature is employed during the run-up of a Jeffcott rotor supported by two active magnetic bearings. The vibration performance at bearing stiffness modulation is compared to the well-known performance at nominal bearing characteristics for a simple run-up at a constant acceleration. It is shown that by introducing a specific periodic change of the bearing stiffness coefficients, a mode coupling between two selected modes is activated. This coupling impacts the maximum amplitude developed during passage through resonance. At each critical speed transient vibrations of the corresponding mode are excited. Due to the modal coupling, if one mode is excited at a critical speed then energy is exchanged with the coupled mode. On one hand, the maximum amplitude at the first critical speed is decreased by modulation since some vibration energy is transferred to the highly damped second mode where it is partly dissipated. On the other hand, the maximum amplitude at the second critical speed is increased by modulation since some vibration energy is transferred to the lightly damped first mode. The concept is outlined in detail based on numerical studies.

17:15 ANTARES-EMVEM

Dynamic analysis of nonlinear behaviour in inertial actuators (2467)

M Dal Borgo, M G Tehrani, S J Elliott

Inertial actuators are devices typically used to generate the control force on a vibrating structure. Generally, an inertial actuator comprises a proof-mass suspended in a magnetic field. The inertial force due to the moving mass is used to produce the secondary force needed to control the vibration of the primary structure. Inertial actuators can show nonlinear behaviour, such as stroke saturation when driven at high input voltages. If the input voltage is beyond their limit, they can hit the end stop of the actuator casing and saturate. In this paper, the force generated by an inertial actuator is measured experimentally and numerical simulations of a linear piecewise stiffness model are carried out and compared with the results of analytical methods. First, a numerical model for a symmetric bilinear stiffness is derived and a parametric study is carried out to investigate the change of the end stop stiffness. In addition, the variation of the amplitude of the excitation is considered and a comparison is made with the analytical solution using the harmonic balance method. Finally, experimental measurements are carried out and the results are compared with simulated data to establish the accuracy of the model.

17:15 Innovative Combustion Technology

Control of the low-load region in partially premixed combustion (2568)

G Ingesson, L Yin, R Johansson, P Tunestål

Partially premixed combustion (PPC) is a low temperature, direct-injection combustion concept that has shown to give promising emission levels and efficiencies over a wide operating range. In this concept, high EGR ratios, high octane-number fuels and early injection timings are used to slow down the auto-ignition reactions and to enhance the fuel and are mixing before the start of combustion. A drawback with this concept is the combustion stability in the low-load region where a high octane-number fuel might cause misfire and low combustion efficiency. This paper investigates the problem of low-load PPC controller design for increased engine efficiency. First, low-load PPC data, obtained from a multi-cylinder heavy-duty engine is presented. The data shows that combustion efficiency could be increased by using a pilot injection and that there is a non-linearity in the relation between injection and combustion timing. Furthermore, intake conditions should be set in order to avoid operating points with unfavourable global equivalence ratio and in-cylinder temperature combinations. Model predictive control simulations were used together with a calibrated engine model to find a gas-system controller that fulfilled this task. The findings are then summarized in a suggested engine controller design. Finally, an experimental performance evaluation of the suggested controller is presented.

17:15 Modal Analysis and Structural Modification

Optimization of a tuned vibration absorber in a multibody system by operational analysis (2347)

F Infante, S Perfetto, D Mayer, S Herold

Mechanical vibration in a drive-train can affect the operation of the system and must be kept below structural thresholds. For this reason tuned vibration absorbers (TVA) are usually employed. They are optimally designed for a single degree of freedom system using the Den Hartog technique. On the other hand, vibrations can be used to produce electrical energy exploitable locally avoiding the issues to transfer it from stationary devices to rating parts. Thus, the design of an integrated device for energy harvesting and vibration reduction is proposed to be employed in the drive-train. By investigation of the dynamic torque in the system under real operation, the accuracy of a numerical model for the multibody is evaluated. In this study, this model is initially used for the definition of the TVA. An energetic procedure is applied in order to reduce the multibody in an equivalent single degree of freedom system for a particular natural mode. Hence, the design parameters of the absorber are obtained. Furthermore, the introduction of the TVA in the model is considered to evaluate the vibration reduction. Finally, an evaluation of the power generated by the piezo transducer and its feedback on the dynamic of the drive-train is performed.

Notes

17:30 Nonlinear Vibrations III

Complex Dynamics of Delay-Coupled Neural Networks (2281)

X Mao

This paper reveals the complicated dynamics of a delay-coupled system that consists of a pair of sub-networks and multiple bidirectional couplings. Time delays are introduced into the internal connections and network-couplings, respectively. The stability and instability of the coupled network are discussed. The sufficient conditions for the existence of oscillations are given. Case studies of numerical simulations are given to validate the analytical results. Interesting and complicated neuronal activities are observed numerically, such as rest states, periodic oscillations, multiple switches of rest states and oscillations, and the coexistence of different types of oscillations.

17:30 ANTARES-EMVEM

Active vibration control of an inertial actuator subject to broadband excitation (2492)

S Camperi, M G Tehrani, M Zilletti, S J Elliott

Active vibration control has been widely used in many engineering applications in order to minimise vibrations in structures, when subjected to broadband random disturbances. Feedback control in the form of velocity feedback is considered in this paper, which generates a damping force proportional to the velocity. The control gain is tuned in such a way to minimise the kinetic energy of the system. In this paper, an inertial actuator excited by a random voltage is considered and an active control is implemented. The dynamic equations of the system are derived and the response is obtained with and without control. The stability of the system is analysed using the Nyquist plot. The response of the actuator is obtained from time domain simulations using Matlab. The effect of the control gains are also investigated on the responses. Energy analysis shows how the energy in the system decreases by increasing the feedback gain up to a stability limit.

17:30 Innovative Combustion Technology

Combustion Control of Diesel Engine using Feedback Error Learning with Kernel Online Learning Approach (2456)

E S Widayaka, H Ohmori

This paper shows how to design Multivariable Model Reference Adaptive Control System (MRACS) for “Tokyo University discrete-time engine model” proposed by Yasuda et al (2014). This controller configuration has the structure of “Feedback error learning (FEL)” and adaptive law is based on kernel method. Simulation results indicate that “kernelized” adaptive controllers can improve the tracking performance, the speed of convergence and the robustness to disturbances.

17:30 Modal Analysis and Structural Modification

Static and dynamic behaviours of helical spring in MR fluid (2549)

S Kaewunruen, O Akintoye, Y Takeuchi, M Papaelias

MR fluid has been used in automobile industry for vibration suppression device. However its dynamic interaction between structural spring and electro-magnetised MR fluid has not been thoroughly investigated. As a result, this paper highlights static and dynamic behaviours of helical spring interacting with MR fluid magnetised at various levels. Static hysteresis behaviours have been evaluated altogether with the dynamic modal properties of the system. Modal impact hammer testing technique was used to investigate the modal parameters. It is found that MR fluid improves the hysteresis capacity and dynamic properties of the systems when it is electro-magnetised. The outcome of this study will lead to a new development of new spring-dashpot system using MR fluid for better control in adaptive tuneable vibration damping and stiffness suppressing real-time dynamic motions such as the train body, passenger seats, train door, etc.

Notes

17:45 Nonlinear Vibrations III

Force, displacement and strain nonlinear transfer function estimation (2451)

K A Sweitzer, N S Ferguson

The analysis of surface strain, displacement and acceleration data from the nonlinear response of a beam under base excitation is performed using frequency domain based reverse path identification. The uncorrelated nonlinear contributions of the dynamic response are used as inputs to produce repeatable transfer function estimates with the applied base acceleration as the output. The two stage process of displacements to strain to applied base excitation is proposed and also investigated. System identification of the reverse transfer functions is shown to be reasonably successful in quantifying the main frequency dependent contributions which occur at and around the fundamental natural frequency and harmonics due to the geometrical nonlinearity present.

17:45 ANTARES-EMVEM

Plate Metamaterial for broad-band vibration control (2693)

M Zientek, P Gardonio

This paper presents a simulation study on the feasibility of a plate metamaterial, which is designed to control the flexural vibration in a wide frequency band. The plate is equipped with a dense two dimensional array of spring – mass vibration absorbers, which are regularly spaced in such a way as to produce a considerable reduction of the flexural response in a given frequency stop-band. The plate is exposed to a rain on the roof time and spatial stochastic excitation. The stop band effect is obtained both via the spatial spacing of the absorbers and the physical properties of the absorbers. The paper first considers a simplified model problem, which is composed by a beam structure with a one dimensional array of absorbers. A wave model is introduced to derive the wave transmission and reflection effects by the absorbers, which is used to illustrate the physics of the vibration attenuation mechanism produced by the array of vibration absorbers. Then a modal model for the response of the plate structure with a two dimensional array of vibration absorbers is introduced. The overall response of the plate is derived in terms of the time averaged total kinetic energy of the plate. The vibration attenuation properties of this system are then analysed and interpreted in view of the physical effects enlighten in the one dimensional wave analysis for the flexural response of the beam.

17:45 Modal Analysis and Structural Modification

Error localization of finite element updating model based on element strain energy (2375)

Z Huang, C Zang, X Wang, Y Jiang

An error localization indicator based on modal strain energy changes is proposed and used for selecting design parameters to be updated in model updating process. Taking an aero-engine combustor casing structure as an example, the ‘supermodel’ of combustor casing was established and validated with the test data and the reduced model (also called the design model) was built with the simplification of modelling. By comparing the modal strain energy changes between ‘supermodel’ and design model of combustor casing, the error locations of the reduced combustor casing modelling was highlighted by the error localization indicator. Then, the updating parameters of the design model were selected as the areas with significant variations of modal strain energy changes based on the error localization indicator. Defining the updating object function with the minimum of natural frequency errors between the FE model prediction and the modal test data, model updating of the design combustor casing model based sensitivity analysis method was carried out using the experimental modal data. After model updating, the maximum frequency error of the first ten modes was decreased from 27.1% to 1.2%, compared with the test data. The result shows the effectiveness of the proposed method and certain significance in parameter selection for model updating.

Notes

09:00 PLENARY SESSION

Reducing vibrations in structures using structural control

D Wagg

BEng, PhD, CEng, FIMechE Professor of Nonlinear Dynamics, Departmental Director of Research and Innovation, University of Sheffield, UK

In this presentation three recent developments in structural dynamics which can be used to reduce vibrations will be discussed. All three have the objective of reducing unwanted vibrations in structures. The first is the "tuned-inerter- damper" concept that is analogous to a tuned-mass-damper, but replaces the mass with an inerter. The inerter is an acceleration driven device that has been developed relatively recently. Its main application area has been the automotive industry, but a much wider variety of applications are currently being investigated. We will present experimental and theoretical results showing how the inerter behaviour can be exploited to reduce structural vibrations. The potential advantages of the tuned-inerter-damper will also be discussed. The second topic discussed in this talk is the combination of active and semi-active control. In this scenario, the active actuator is used to help "assist" the semi-active actuator. The control is implemented using a immersion and invariance control technique, and has applications to railway pantograph systems. The third and final example we will discuss is the idea of using nonlinear spring stiffness to create a lightweight vibration isolator. The nonlinear spring is formed by combining a linear spring with a bistable composite plate. This application is used to increase the isolation effect that can be obtained using just linear stiffness by creating a nonlinear stiffness function. The concept is sometimes called the "high static low dynamic stiffness" spring. We present numerical and experimental results which show how the transmissibility of the system is improved by designing the nonlinear spring as part of an isolation mount.

Notes

10:30 Energy Harvesting I

On The Dynamics and Design of a Two-body Wave Energy Converter (2405)

C Liang, L Zuo

A two-body wave energy converter oscillating in heave is studied in this paper. The energy is extracted through the relative motion between the floating and submerged bodies. A linearized model in the frequency domain is adopted to study the dynamics of such a two-body system with consideration of both the viscous damping and the hydrodynamic damping. The closed form solution of the maximum absorption power and corresponding power take-off parameters are obtained. The suboptimal and optimal designs for a two-body system are proposed based on the closed form solution. The physical insight of the optimal design is to have one of the damped natural frequencies of the two body system the same as, or as close as possible to, the excitation frequency. A case study is conducted to investigate the influence of the submerged body on the absorption power of a two-body system subjected to suboptimal and optimal design under regular and irregular wave excitations. It is found that the absorption power of the two-body system can be significantly higher than that of the single body system with the same floating buoy in both regular and irregular waves. In regular waves, it is found that the mass of the submerged body should be designed with an optimal value in order to achieve the maximum absorption power for the given floating buoy. The viscous damping on the submerged body should be as small as possible for a given mass in both regular and irregular waves.

10:30 Smart Structures

Advanced design of integrated vibration control systems for adjacent buildings under seismic excitations (2230)

F Palacios-Quiñonero, J Rubió-Massegú, J M Rossell, H R Karimi

In vibration control of adjacent buildings under seismic excitations, a twofold objective has to be considered: (i) to mitigate the vibrational response of the individual structures and (ii) to provide a suitable protection against interbuilding impacts (pounding). An interesting strategy to deal with this complex control problem consists in considering an integrated control system, which combines interbuilding actuation devices with local control systems implemented in the individual buildings. In this paper, an effective computational strategy to design this kind of integrated control systems is presented. The proposed design methodology is based on a linear matrix inequality formulation, allows including active and passive actuation devices, and makes it possible to deal with important information constraints associated to the problem. The main ideas are illustrated by means of a two-building system equipped with three actuation devices: two interstory actuation devices implemented at the ground level of the buildings, plus an interbuilding actuation device installed at the top level of the lowest building. For this control setup, two different integrated controllers are designed. A proper set of numerical simulations is conducted to assess the performance of the proposed controllers with positive results.

10:30 Dynamics and Control of Multibody Systems I

Dynamics and control of robotic spacecrafts for the transportation of flexible elements (2148)

H Wen, T Chen, B Yu, D Jin

The technology of robotic spacecrafts has been identified as one of the most appealing solutions to the on-orbit construction of large space structures in future space missions. As a prerequisite of a successful on-orbit construction, it is needed to use small autonomous spacecrafts for the transportation of flexible elements. To this end, the paper presents an energy-based scheme to control a couple of robotic spacecrafts carrying a flexible slender structure to its desired position. The flexible structure is modelled as a long beam based on the formulation of absolute nodal coordinates to account for the geometrical nonlinearity due to large displacement. Meanwhile, the robotic spacecrafts are actuated on their rigid-body degrees of freedom and modelled as two rigid bodies attached to the flexible beam. The energy-based controller is designed using the technique of energy shaping and damping injection such that translational and rotational maneuvers can be achieved with the suppression of the flexible vibrations of the beam. Finally, numerical case studies are performed to demonstrate the proposed schemes.

10:30 Uncertain Dynamical Systems

A framework for the analysis of vibrations of structures with uncertain attachments (2152)

S Li, B R Mace, N S Ferguson, R Halkyard

Attachments affect the dynamic response of an assembled structure. When engineers are modelling structures, small attachments will often not be included in the “bare” model, especially in the initial design stages. The location of these attachments might be poorly known, yet they affect the response of the structure. This paper considers how attachments jointed to the structure at uncertain points, can be included in the dynamic model of a structure. Two approaches are proposed. In the time domain, a combination of component mode synthesis, characteristic constraint modes and modal analysis gives a computationally efficient basis for subsequent analysis using, for example, Monte Carlo simulation. The frequency domain approach is based on assembly of frequency response functions of bare structure and attachment. Numerical examples of a beam and a plate with a point mass added at an uncertain location are considered and predictions compared with experiment results.

10:30 Experimental techniques

A pseudodynamic testing algorithm for obtaining seismic responses of structures (2174)

S Y Chang, C L Huang

A new family method is proposed for pseudodynamic tests. This family method can integrate favourable numerical properties together, such as the unconditional stability, explicit formulation, second-order accuracy and favourable numerical dissipation. Since the proposed family method can generally have an explicit formulation of each time step its pseudodynamic implementation involves no iteration procedure. Hence, the pseudodynamic tests can be easily conducted when compared to an implicit pseudodynamic method, where an iteration procedure must be involved for each time step. On the other hand, the properties of unconditional stability, second order accuracy and numerical dissipation indicate that the proposed pseudodynamic algorithm is promising for solving inertial problems, where the total response is dominated by low frequency modes and the high frequency responses are of no interest. The unconditional stability implies that there is no limitation on step size for the high frequency modes. Besides, the dominated low frequency modes can be reliably integrated by choosing an appropriate time step since the proposed family method can have a second order accuracy. Finally, the spurious growth of high frequency responses can be suppressed or filtered out by the desired numerical dissipation. As a result, the proposed pseudodynamic algorithm is very promising for a general pseudodynamic test or a substructure pseudodynamic test.

Notes

10:45 Energy Harvesting I

Inverse design of nonlinearity in energy harvesters for optimum damping (2170)

M G Tehrani, S J Elliott

This paper presents the inverse design method for the nonlinearity in an energy harvester in order to achieve an optimum damping. A single degree-of-freedom electro-mechanical oscillator is considered as an energy harvester, which is subjected to a harmonic base excitation. The harvester has a limited throw due to the physical constraint of the device, which means that the amplitude of the relative displacement between the mass of the harvester and the base cannot exceed a threshold when the device is driven at resonance and beyond a particular amplitude. This physical constraint requires the damping of the harvester to be adjusted for different excitation amplitudes, such that the relative displacement is controlled and maintained below the limit. For example, the damping can be increased to reduce the amplitude of the relative displacement. For high excitation amplitudes, the optimum damping is, therefore, dependent on the amplitude of the base excitation, and can be synthesised by a nonlinear function. In this paper, a nonlinear function in the form of a bilinear is considered to represent the damping model of the device. A numerical optimisation using Matlab is carried out to fit a curve to the amplitude-dependent damping in order to determine the optimum bilinear model. The nonlinear damping is then used in the time-domain simulations and the relative displacement and the average harvested power are obtained. It is demonstrated that the proposed nonlinear damping can maintain the relative displacement of the harvester at its maximum level for a wide range of excitation, therefore providing the optimum condition for power harvesting.

10:45 Smart Structures

Vibration reduction of a woven composite fan blade by piezoelectric shunted devices (2538)

O Thierry, O De Smet, J-F Deü

This study concerns the vibration reduction in the low frequency range of a composite fan blade of a turbojet engine with piezoelectric devices. The interest is to increase lifespan and avoid flutter phenomena by reducing the vibration amplitude. The solution considered in the work consists in using piezoelectric elements connected to a passive electric circuit usually called shunt. The use of woven composite materials for fan blades enables to plan on embedding piezoelectric materials, for instance in the form of patches inserted between the composite and the coating material. The work presented during this conference will illustrate the feasibility of a piezoelectric shunted device integrated in an industrial application that doesn't require electrical supply. For such a structure, it is shown that a purely passive resonant shunt can significantly reduce the level of vibration of the second bending mode and that a good correlation between experiments and simulations validates the best fitting finite element model.

10:45 Dynamics and Control of Multibody Systems I

Stochastic stability assessment of a semi-free piston engine generator concept (2310)

T N Kigezi, J A Gonzalez Anaya, J F Dunne

Small engines as power generators with low-noise and vibration characteristics are needed in two niche application areas: electric vehicle range extenders and domestic micro Combined Heat and Power systems. A recent semi-free piston design known as the AMOCATIC generator fully meets this requirement. The engine allows for high energy conversion efficiencies at resonance derived from having a mass and spring assembly. As with free-piston engines in general, stability and control of piston motion has been cited as the prime challenge limiting the technology's widespread application. Using physical principles, we derive in this paper two important results: an energy balance criterion and a related general stability criterion for a semi-free piston engine. Control is achieved by systematically designing a Proportional Integral (PI) controller using a control-oriented engine model for which a specific stability condition is stated. All results are presented in closed form throughout the paper. Simulation results under stochastic pressure conditions show that the proposed energy balance, stability criterion, and PI controller operate as predicted to yield stable engine operation at fixed compression ratio.

10:45 Uncertain Dynamical Systems

Quantifying the variability in stiffness and damping of an automotive vehicle's trim-structure mounts (2169)

A Abolfathi, D J O'Boy, S J Walsh, A Dowsett, S A Fisher

Small plastic clips are used in large numbers in automotive vehicles to connect interior trims to vehicle structures. The variability in their properties can contribute to the overall variability in noise and vibration response of the vehicle. The variability arises due to their material and manufacturing tolerances and more importantly due to the boundary condition. To measure their stiffness and damping, a simple experimental rig is used where a mass is supported by the clip which is modelled as a single degree of freedom system. The rig is designed in a way that it simulates the boundary condition as those of the real vehicle. The variability in clip and also due to the boundary condition at the structure side is first examined which is 7% for stiffness and 8% for damping. To simulate the connection of the trim side, a mount is built using a 3D printer. Rattling occurs in the response of the clips with loose connections, however by preloading the mount the effective stiffness increases and the rattling is eliminated. The variability due to the boundary condition at the trim side was as large as 40% for stiffness and 52% for damping.

10:45 Experimental techniques

Vibration Prediction Method of Electric Machines by using Experimental Transfer Function and Magnetostatic Finite Element Analysis (2254)

A Saito, M Kuroishi, H Nakai

This paper concerns the noise and structural vibration caused by rotating electric machines. Special attention is given to the magnetic-force induced vibration response of interior-permanent magnet machines. In general, to accurately predict and control the vibration response caused by the electric machines, it is inevitable to model not only the magnetic force induced by the fluctuation of magnetic fields, but also the structural dynamic characteristics of the electric machines and surrounding structural components. However, due to complicated boundary conditions and material properties of the components, such as laminated magnetic cores and varnished windings, it has been a challenge to compute accurate vibration response caused by the electric machines even after their physical models are available. In this paper, we propose a highly-accurate vibration prediction method that couples experimentally-obtained discrete structural transfer functions and numerically-obtained distributed magnetic-forces. The proposed vibration synthesis methodology has been applied to predict vibration responses of an interior permanent magnet machine. The results show that the predicted vibration response of the electric machine agrees very well with the measured vibration response for several load conditions, for wide frequency ranges.

Notes

11:00 Energy Harvesting I

Broadband vibratory energy harvesting via bubble shaped response curves (2237)

Z Q Lu, L Q Chen

This paper concerns an investigation into the characteristics of a linear-nonlinear coupled electromagnetic energy harvester. The nonlinear oscillator consists of a linear (mass-spring-damper) oscillator with two additional horizontal springs. It is assumed that the vibration is restricted to one direction of harvesting mass to which the parallel magnetic field is induced. Of interest here, however, is the bubble shaped response curves for the amplitude-frequency response, and its potential benefits on the energy harvesting. The Harmonic balance method is used to analysis the power amplitude-frequency response of the system. It is found that the linear and nonlinear resonances could interact with each other at moderate excitation levels, so bubble shaped response curves are formed. The benefits of the nonlinearity on the energy harvesting are achieved. The results are also validated by some numerical work. Then the averaged power under Gaussian white noise is also calculated numerically, the results demonstrate that the bubble shaped response curves design produces more power than other designs under random excitation.

11:00 Smart Structures

Active buckling control of an imperfect beam-column with circular cross-section using piezo-elastic supports and integral LQR control (2265)

M Schaeffner, R Platz

For slender beam-columns loaded by axial compressive forces, active buckling control provides a possibility to increase the maximum bearable axial load above that of a purely passive structure. In this paper, the potential of active buckling control of an imperfect beam-column with circular cross-section using piezo-elastic supports is investigated numerically. Imperfections are given by an initial deformation of the beam-column caused by a constant imperfection force. With the piezo-elastic supports, active bending moments in arbitrary directions orthogonal to the beam-column's longitudinal axis can be applied at both beam-column's ends. The imperfect beam-column is loaded by a gradually increasing axial compressive force resulting in a lateral deformation of the beam-column. First, a finite element model of the imperfect structure for numerical simulation of the active buckling control is presented. Second, an integral linear-quadratic regulator (LQR) that compensates the deformation via the piezo-elastic supports is derived for a reduced modal model of the ideal beam-column. With the proposed active buckling control it is possible to stabilize the imperfect beam-column in arbitrary lateral direction for axial loads above the theoretical critical buckling load and the maximum bearable load of the passive structure.

11:00 Dynamics and Control of Multibody Systems I

Active control of multi-input hydraulic journal bearing system (2365)

J C Chuang, C Y Chen, J Y Tu

Because of the advantages of high accuracy, high capacity, and low friction, the development of hydrostatic bearing for machine tool receives significant attention in the last decades. The mechanics and mechanical design of hydrostatic journal bearing with capillary restrictors has been discussed in literature. However, pragmatically, the undesired loading effects of cutting force tend to result in resonance and instability of the rotor and damage the shaft during operation. Therefore, multi-input, active flow control using state feedback design is proposed in this paper. To this purpose, the proportional pressure valves are added to the hydraulic system as active control devices, and the linearised models of the bearing and valve are discussed and identified. Simulation and experimental work is conducted to verify the proposed active control and parameter identification techniques. The results show that the unbalance responses of the rotor are reduced by the proposed state feedback controller, which is able to regulate the flow pressure effectively, thus enhancing the stability and accuracy of the hydraulic journal bearing.

11:00 Uncertain Dynamical Systems

Flexural Wave Propagation in Slowly Varying Random Waveguides Using a Finite Element Approach (2401)

A T Fabro, N S Ferguson, B R Mace

This work investigates structural wave propagation in waveguides with randomly varying properties along the axis of propagation, specifically when the properties vary slowly enough such that there is negligible backscattering. Wave-based methods are typically applied to homogeneous waveguides but the WKB (after Wentzel, Kramers and Brillouin) approximation can be used to find a suitable generalisation of the wave solution in terms of the change of phase and amplitude, but is restricted to analytical solutions. A wave and finite element (WFE) approach is proposed to extend the applicability of the WKB method to cases where no analytical solution is available. The wavenumber is expressed as a function of the position along the waveguide and a Gauss-

Legendre quadrature scheme is used to obtain the phase change while the wave amplitude is calculated using conservation of power. The WFE method is used to evaluate the wavenumbers at each integration point. The flexural vibration example is considered with random field proprieties being expressed by a Karhunen-Loeve expansion. Results are compared to a standard FE approach and to the WKB analytical solution. They show good agreement and require only a few WFE evaluations, providing a suitable framework for spatially correlated randomness in waveguides.

11:00 Experimental techniques

Fatigue Damage Spectrum calculation in a Mission Synthesis procedure for Sine-on-Random excitations (2379)

A Angeli, B Cornelis, M Troncossi

In many real-life environments, certain mechanical and electronic components may be subjected to Sine-on-Random vibrations, i.e. excitations composed of random vibrations superimposed on deterministic (sinusoidal) contributions, in particular sine tones due to some rotating parts of the system (e.g. helicopters, engine-mounted components, …). These components must be designed to withstand the fatigue damage induced by the "composed" vibration environment, and qualification tests are advisable for the most critical ones. In the case of an accelerated qualification test, a proper test tailoring which starts from the real environment (measured vibration signals) and which preserves not only the accumulated fatigue damage but also the "nature" of the excitation (i.e. sinusoidal components plus random process) is important to obtain reliable results. In this paper, the classic time domain approach is taken as a reference for the comparison of different methods for the Fatigue Damage Spectrum (FDS) calculation in case of Sine-on-Random vibration environments. Then, a methodology to compute a Sine-on-Random specification based on a mission FDS is proposed.

Notes

11:15 Energy Harvesting I

Application review of dielectric electroactive polymers (DEAPs) and piezoelectric materials for vibration energy harvesting (2280)

X Yuan, S Changgeng, G Yan, Z Zhenghong

This paper reviews recent advances in vibration energy harvesting with particular emphasis on the solutions by using dielectric electroactive polymers (DEAPs) and piezoelectric materials. These smart materials are in essence capable of converting wasted vibration energy in the environment to usable electrical energy. Much previous researches have been devoted to studying the technology of harvesting mechanical energy using piezoelectric materials. The recent introduction of the DEAPs that exhibits large displacements under electric activation has led to their consideration as promising replacement for conventional piezoelectric materials. The properties of the two materials are described in this paper together with a comparison of their performance in relation with energy harvesting. Finally comparisons are made in the applications of vibration energy harvesting using these two materials. This paper has been written with reference to a large number of published papers listed in the reference section.

11:15 Smart Structures

Parameter identification for active mass damper controlled systems (2313)

C C Chang, J F Wang, C C Lin

Active control systems have already been installed in real structures and are able to decrease the wind- and earthquake-induced responses, while the active mass damper (AMD) is one of the most popular types of such systems. In practice, an AMD is generally assembled in-situ along with the construction of a building. In such a case, the AMD and the building is coupled as an entire system. After the construction is completed, the dynamic properties of the AMD subsystem and the primary building itself are unknown and cannot be identified individually to verify their design demands. For this purpose, a methodology is developed to obtain the feedback gain of the AMD controller and the dynamic properties of the primary building based on the complex eigen-parameters of the coupled building-AMD system. By means of the theoretical derivation in state-space, the non-classical damping feature of the system is characterized. This methodology can be combined with any state-space based system identification technique as a procedure to achieve the goal on the basis of the acceleration measurements of the building-AMD system. Results from numerical verifications show that the procedure is capable of extracting parameters and is applicable for AMD implementation practices.

11:15 Dynamics and Control of Multibody Systems I

Design of passive interconnections in tall buildings subject to earthquake disturbances to suppress inter-storey drifts (2429)

K Yamamoto, M C Smith

This paper studies the problem of passive control of a multi-storey building subjected to an earthquake disturbance. The building is represented as a homogeneous mass chain model, i.e., a chain of identical masses in which there is an identical passive connection between neighbouring masses and a similar connection to a movable point. The paper considers passive interconnections of the most general type, which may require the use of inerters in addition to springs and dampers. It is shown that the scalar transfer functions from the disturbance to a given inter-storey drift can be represented as complex iterative maps. Using these expressions, two graphical approaches are proposed: one gives a method to achieve a prescribed value for the uniform boundedness of these transfer functions independent of the length of the mass chain, and the other is for a fixed length of the mass chain. A case study is presented to demonstrate the effectiveness of the proposed techniques using a 10-storey building model. The disturbance suppression performance of the designed interconnection is also verified for a 10-storey building model which has a different stiffness distribution but with the same undamped first natural frequency as the homogeneous model.

11:15 Uncertain Dynamical Systems

Random seismic response and sensitivity analysis of uncertain multi-span continuous beams subjected to spatially varying ground motions (2336)

Y Y Li, Y H Zhang

An analytical method is formulated for the seismic analysis of multi-span continuous beams with random structural parameters subjected to spatially varying ground motions. An earthquake-induced ground motion is modelled as a stationary random process defined by power spectral density function, and the spatial variation is considered. The physical parameters of the multi-span beams are random and modelled as continuous random Gaussian variables. The stationary random responses are determined as approximate explicit functions of the structural parameters. Direct differentiation of these functions with respect to the structural parameters provides analytical expressions of the sensitivities of the stationary responses. On the basis of Taylor expansion, the statistic moments of the random responses are obtained. Taking the four-span beam as an illustrative example, the mean value and standard deviation of the random responses are computed and compared with those from Monte Carlo simulation to demonstrate the accuracy of the proposed method. Results are illustrated for the influence of different structural parameters on the statistic moments of the random responses. It is found that randomness in Young's modulus and the mass per unit length has approximate equivalent and significant influence on the random responses, while that of damping is negligible.

11:15 Experimental techniques

Inferring unstable equilibrium configurations from experimental data (2385)

L N Virgin, R Wiebe, S M Spottswood, T Beberniss

This research considers the structural behavior of slender, mechanically buckled beams and panels of the type commonly found in aerospace structures. The specimens were deflected and then clamped in a rigid frame in order to exhibit snap-through. That is, the initial equilibrium and the buckled (snapped-through) equilibrium configurations both co-existed for the given clamped conditions. In order to transit between these two stable equilibrium configurations (for example, under the action of an externally applied load), it is necessary for the structural component to pass through an intermediate unstable equilibrium configuration. A sequence of sudden impacts was imparted to the system, of various strengths and at various locations. The goal of this impact force was to induce relatively intermediate-sized transients that effectively slowed-down in the vicinity of the unstable equilibrium configuration. Thus, monitoring the velocity of the motion, and specifically its slowing down, should give an indication of the presence of an equilibrium configuration, even though it is unstable and not amenable to direct experimental observation. A digital image correlation (DIC) system was used in conjunction with an instrumented impact hammer to track trajectories and statistical methods used to infer the presence of unstable equilibria in both a beam and a panel.

Notes

11:30 Energy Harvesting I

On the influence of nonlinearities on vibrational energy transduction under band-limited noise excitations (2320)

K Nakano, D Su, R Zheng, M Cartmell

Vibrational energy harvesters are often excited by band-limited noise excitations. In this paper, the influence of the stiffness nonlinearity on the transduction of the energy harvester and the relative performance of linear, monostable hardening-type and bistable energy harvesters are compared and investigated. The performance is experimentally compared under band-limited noise excitations of different levels, bandwidths, and centre frequencies at first. The rms output power delivered to the same load resistance is measured and compared under the same excitation levels, which indicts the constant electrical damping level. It is shown that the effect of nonlinearities is strongly dependent on the excitation parameters. Under a moderate excitation level it is shown that the monostable hardening-type oscillator performs worse than its linear counterpart under band-limited excitation. However, the results also illustrate that for the most part of the frequency and bandwidth range considered, the bistable harvester can outperforms the linear variant but for around the peak output area. Moreover, the comparison is also numerically conducted with the consideration of the optimised electrical damping level and the displacement constraint of the device. General conclusions are drawn based on the experimental observations.

11:30 Smart Structures

A broadband frequency-tunable dynamic absorber for the vibration control of structures (2319)

T Komatsuzaki, T Inoue, O Terashima

A passive-type dynamic vibration absorber (DVA) is basically a mass-spring system that suppresses the vibration of a structure at a particular frequency. Since the natural frequency of the DVA is usually tuned to a frequency of particular excitation, the DVA is especially effective when the excitation frequency is close to the natural frequency of the structure. Fixing the physical properties of the DVA limits the application to a narrowband, harmonically excited vibration problem. A frequency-tunable DVA that can modulate its stiffness provides adaptability to the vibration control device against non-stationary disturbances. In this paper, we suggest a broadband frequency-tunable DVA whose natural frequency can be extended by 300% to the nominal value using the magnetorheological elastomers (MREs). The frequency adjustability of the proposed absorber is first shown. The real-time vibration control performance of the frequency-tunable absorber for an acoustically excited plate having multiple resonant peaks is then evaluated. Investigations show that the vibration of the structure can be effectively reduced with an improved performance by the DVA in comparison to the conventional passive-type absorber.

11:30 Dynamics and Control of Multibody Systems I

Numerical and experimental comparison of the energy transfer in a parametrically excited system (2446)

A Fichtinger, H Ecker

This study is based on experimental results obtained from a test rig for a 2-DOF vibrational system. The main feature of this test rig is an electromechanical actuator which enables the variation of a mechanical stiffness parameter. The vibrational system is excited by this device, resulting in a parametrically excited system. In this study, the test rig is operated such that an initial deflection is applied to the masses, but no external excitation acts on the system. The actuator coils are driven by a current following a harmonic function defined by amplitude and frequency. The latter defines the parametric excitation frequency (PEF). When the mechanical system performs free vibrations, the parametric excitation may initiate an energy transfer between the two vibrational modes of the system. This transfer depends primarily on the PEF. For certain values of the PEF only one of the vibrational modes is affected. At other frequencies both modes are influenced and a continuous intermodal energy transfer is observed. A numerical model for the test rig was established and allows a comparison of experimental and numerical results. The total system energy as well as the modal energies are calculated from the measured and from the simulated signals. Interesting experimental observations are reported concerning the transfer of energy, and are in good agreement with simulated results.

11:30 Uncertain Dynamical Systems

Experimental investigation of the variability in the dynamics of connected structures (2352)

M R Souza, N S Ferguson

Hydraulic pipes and cable bundles attached to host structures are widely found in engineering. This paper explores how variability in the connection points between structures affects the coupled dynamics. One at a time, two different one-dimensional waveguides are attached to a thin plate through a different set of point connections. Measurements considering randomly spaced connections were made and the experimental results are presented and compared to previously developed models. When multiples attachments are considered, the structure accommodates standing-like waves between the attachments, amplifying its response. It was possible to see the variability due the random spacing and, in a frequency-averaged sense, good agreement between the experimental data and the models were obtained. A comparison of the spatial response of the experiment and the infinite system is also presented.

11:30 Experimental techniques

Sound power and vibration levels for two different piano soundboards (2414)

G Squicciarini, P M Valiente, D J Thompson

This paper compares the sound power and vibration levels for two different soundboards for upright pianos. One of them is made of laminated spruce and the other of solid spruce (tone-wood). These differ also in the number of ribs and manufacturing procedure. The methodology used is defined in two major steps: (i) acoustic power due to a unit force is obtained reciprocally by measuring the acceleration response of the piano soundboards when excited by acoustic waves in reverberant field; (ii) impact tests are adopted to measure driving point and spatially-averaged mean-square transfer mobility. The results show that, in the mid-high frequency range, the soundboard made of solid spruce has a greater vibrational and acoustic response than the laminated soundboard. The effect of string tension is also addressed, showing that is only relevant at low frequencies.

Notes

11:45 Energy Harvesting I

Adjustable Nonlinear Mechanism System for Wideband Energy Harvesting in Rotational Circumstances (2345)

Y Zhang, K Nakano, R Zheng, M P Cartmell

Nonlinear energy harvesters have already been exhibited to draw energy from ambient vibration owing to their particular dynamic characteristics, and are feasible to desirable responses for broadband excitations of bistable and monostable systems. This study proposes an energy harvester for rotational applications, in which a cantilever beam pasted piezoelectric film and magnets with the same polarity are comprised as a nonlinear vibrating system. As the rotationally angular velocity gradually increases, the tensile stress to the cantilever beam is also self-adjusted with the increscent centrifugal force, causing the potential barriers of bistable type become shallow, so that the cantilever beam has the ability to maintain the high energy orbit motion from bistable hardening type to monostable hardening behavior. From the implemented results, the valid bandwidth of angular frequency can be improved from 26 rad/s – 132 rad/s to 15 rad/s – 215 rad/s, under the case of the effect of centrifugal force on nonlinear vibrating behavior. It demonstrates that the centrifugal force can significantly promote the performance of nonlinear energy harvesters.

11:45 Smart Structures

Active load path adaption in a simple kinematic load-bearing structure due to stiffness change in the structure’s supports (2384)

C M Gehb, R Platz, T Melz

Load-bearing structures with kinematic functions enable and disable degrees of freedom and are part of many mechanical engineering applications. The relative movement between a wheel and the body of a car or a landing gear and an aircraft fuselage are examples for load-bearing systems with defined kinematics. In most cases, the load is transmitted through a predetermined load path to the structural support interfaces. However, unexpected load peaks or varying health condition of the system’s supports, which means for example varying damping and stiffness characteristics, may require an active adjustment of the load path. However, load paths transmitted through damaged or weakened supports can be the reason for reduced comfort or even failure. In this paper a simplified 2D two mass oscillator with two supports is used to numerically investigate the potential of controlled adaptive auxiliary kinematic guidance elements in a load-bearing structure to adapt the load path depending on the stiffness change, representing damage of the supports. The aim is to provide additional forces in the auxiliary kinematic guidance elements for two reasons. On the one hand, one of the two supports that may become weaker through stiffness change will be relieved from higher loading. On the other hand, tilting due to different compliance in the supports will be minimized. Therefore, shifting load between the supports during operation could be an effective option.

11:45 Dynamics and Control of Multibody Systems I

Stabilization and set-point regulation of underactuated mechanical systems (2533)

M Loccufier

Mechanical systems are referred to as underactuated if the number of independent actuators are fewer than the number of degrees of freedom, a general encountered problem in engineering applications. The considered mechanical systems belong to the class of Euler-Lagrange systems where both kinetic energy and potential energy are modeled in their most general form and energy dissipation is modeled according to the dissipation function of Rayleigh, i.e. viscous damping forces are assumed. The control objectives are stabilization and set-point regulation. The structure of the controller is a parallel combination of static output feedback with dynamic output feedback where nonlinear amplifiers are included. An energy based approach with Liapunov functions and the Kalman-Yacubovich-Popov main lemma yields alternative stability theorems. A number of conditions are introduced with respect to the controller’s structure in order to guarantee stability. However, sufficient design freedom is left to choose a proper tuning principle and obtain the specified control objectives such as fast convergence to a set-point combined with disturbance rejection. A restriction on the control input energy can be incorporated as well. The applicability of the method will be illustrated with planar manipulators. The main contribution is that a methodology is developed which incorporates many controllers and tuning facilities.

11:45 Uncertain Dynamical Systems

Uncertainties Quantification and Propagation of Multiple Correlated Variables with Limited Samples (2382)

Z Shen, X Chen, X Liu, C Zang

In order to estimate the reliability of an engineering structure based on limited test data, it is distinctly important to address both the epistemic uncertainty from lacking in samples and correlations between input uncertain variables. Both the probability boxes theory and copula function theory are utilized in proposed method to represent uncertainty and correlation of input variables respectively. Moreover, the uncertainty of response of interest is obtained by uncertainty propagation of correlated input variables. Nested sampling technique is adopted here to insure the propagation is always feasible and the response's uncertainty is characterized by a probability box. Finally, a numerical example illustrates the validity and effectiveness of our method. The results indicate that the epistemic uncertainty cannot be conveniently ignored when available samples are very limited and correlations among input variables may significantly affect the uncertainty of responses.

11:45 Experimental techniques

Experimental investigation on dynamic response of aircraft panels excited by high-intensity acoustic loads in thermal environment (2575)

Z Q Wu, H B Li, W Zhang, H Cheng, F J Kong, B R Liu

Metallic and composite panels are the major components for thermal protection system of aircraft vehicles, which are exposed to a severe combination of aerodynamic, thermal and acoustic environments during hypersonic flights. A thermal-acoustic testing apparatus which simulates thermal and acoustic loads was used to validate the integrity and the reliability of these panels. Metallic and ceramic matrix composite flat panels were designed. Dynamic response tests of these panels were carried out using the thermal acoustic apparatus. The temperature of the metallic specimen was up to 400℃, and the temperature of the composite specimen was up to 600℃. Moreover, the acoustic load was over 160 dB. Acceleration responses of these testing panels were measured using high temperature instruments during the testing process. Results show that the acceleration root mean square values are dominated by sound pressure level of acoustic loads. Compared with testing data in room environment, the peaks of the acceleration dynamic response shifts obviously to the high frequency in thermal environment.

Notes

12:00 Energy Harvesting I

Energy harvesting from the vibrations of a passing train: effect of speed variability (2357)

V G Cleante, M J Brennan, G Gatti, D J Thompson

This paper builds on a previous study which investigated the amount of energy that could be harvested from the vibration induced by a passing train using a trackside energy harvester. In that study, the optimum parameters of the device were determined for a train passing at a particular speed. However, the effect of the train speed variability on the amount of energy harvested was not explored. In this paper a study is thus undertaken to determine this effect using experimental data from train passages at a site in the UK. Furthermore, a model is developed to investigate the optimum design parameters of the energy harvester when trains pass by at slightly different speeds. This is then validated using the experimental data. It is found that, provided the variability in the train speed is less than about 1% from the nominal speed, then a harvester tuned so that its natural frequency matches one of the trainload dominant frequencies at the line speed is a reasonable design condition.

12:00 Smart Structures

Parallel kinematic mechanisms for distributed actuation of future structures (2551)

G Lai, A R Plummer, D J Cleaver, H Zhou

Future machines will require distributed actuation integrated with load-bearing structures, so that they are lighter, move faster, use less energy, and are more adaptable. Good examples are shape-changing aircraft wings which can adapt precisely to the ideal aerodynamic form for current flying conditions, and light but powerful robotic manipulators which can interact safely with human co-workers. A 'tensegrity structure' is a good candidate for this application due to its potentially excellent stiffness and strength-to-weight ratio and a multi-element structure into which actuators could be embedded. This paper presents results of an analysis of an example practical actuated tensegrity structure consisting of 3 ‘unit cells’. A numerical method is used to determine the stability of the structure with varying actuator length, showing how four actuators can be used to control movement in three degrees of freedom as well as simultaneously maintaining the structural pre-load. An experimental prototype has been built, in which 4 pneumatic artificial muscles (PAMs) are embedded in one unit cell. The PAMs are controlled antagonistically, by high speed switching of on-off valves, to achieve control of position and structure pre-load. Experimental and simulation results are presented, and future prospects for the approach are discussed.

12:00 Dynamics and Control of Multibody Systems I

Optimisation of shimmy suppression device in an aircraft main landing gear (2535)

Y Li, J Z Jiang, S Neild

In earlier publications of landing gear shimmy analysis, efforts have concentrated on predicting the onset of shimmy instability and investigating how to stabilise shimmy-prone landing gears. Less attention has been given to the improvements of shimmy performance for a gear that is free from dynamic instability. This is the main interest of this work. We investigate the effectiveness of a linear passive mechanical device that consists of springs, dampers and inerters on suppressing landing gear shimmy oscillations. A linear model of a Fokker 100 main landing gear and two configurations of candidate shimmy suppression device have been presented. Considering the physical shimmy motions, time-domain optimisation of the parameters in the shimmy suppression devices, using a cost function of maximum amplitude of gear torsional-yaw motion, has been carried out. The performance advantage of a shimmy suppression device incorporating inerter has been presented.

12:00 Uncertain Dynamical Systems

Vibration analysis of structure with uncertainty using two-level Gaussian processes and Bayesian inference (2389)

K Zhou, G Liang, J Tang

Vibration analysis of structure with uncertainty is computationally costly, especially when the finite element model involved has high dimensionality. In this research a combination of two-level Gaussian processes and Bayesian inference is employed to facilitate the development of an efficient and accurate probabilistic order-reduced model. We first employ the two-level Gaussian processes emulator to integrate together small amount of high-fidelity data from full-scale finite element analysis and large amount of low-fidelity data from order-reduced component mode synthesis (CMS) model to improve the response variation prediction. We then utilize the improved response variation prediction on modal characteristics to update the CMS model in the probabilistic sense. The effectiveness of this method is demonstrated through a case study.

12:00 Experimental techniques

Synchronization of dynamic response measurements for the purpose of structural health monitoring (2422)

K Maes, E Reynders, A Rezayat, G De Roeck, G Lombaert

This paper presents a technique for offline time synchronization of data acquisition systems for linear structures with proportional damping. The technique can be applied when direct synchronization of data acquisition systems is impossible or not sufficiently accurate. The synchronization is based on the acquired dynamic response of the structure only, and does not require the acquisition of a shared sensor signal or a trigger signal. The time delay is identified from the spurious phase shift of the mode shape components that are obtained from system identification. A demonstration for a laboratory experiment on a cantilever steel beam shows that the proposed methodology can be used for accurate time synchronization, resulting in a significant improvement of the accuracy of the identified mode shapes.

Notes

12:15 Energy Harvesting I

A numerical analysis of the electrical output response of a nonlinear piezoelectric oscillator subjected to a harmonic and random excitation (2141)

T L Pereira, A S Paula, A T Fabro, M A Savi

The renewable energy is in the focus of many researches in the last decades, and the use of piezoelectric material can be used to obtain one source of this renewable energy. In this case, energy harvesting explores mainly the source of ambient motion and the piezoelectric material convert mechanical energy, present in the ambient motion, into electrical energy. In the work, we present a nonlinear bistable piezomagnetoelastic structure subjected to harmonic and random base excitation. At first, harmonic excitation is of concern and then, the system subjected to random excitation is analysed. The goal of the numerical analysis is to present an investigation of the best electrical output response of the system given harmonic and random excitations.

12:15 Smart Structures

Exploring vibration control strategies for a footbridge with time-varying modal parameters (2621)

J M Soria, I M Díaz, E Pereira, J H García-Palacios, X Wang

This paper explores different vibration control strategies for the cancellation of human-induced vibration of a structure with time-varying modal parameters. The motivation of this study is an urban stress-ribbon footbridge (Pedro Gómez Bosque, Valladolid, Spain) that, after a whole-year monitoring, it has been obtained that the natural frequency of a vibration mode at approximately 1.8 Hz (within the normal range of walking) changes up to 20%, mainly due to temperature variations. Thus, this paper takes the annual modal parameter estimates (aprox. 14000 estimations) of this mode and designs three control strategies: a) a tuned mass damper (TMD) tuned to the aforementioned mode using its most-repeated modal properties, b) a semi-active TMD with an on-off control law for the TMD damping, and c) an active mass damper designed using the well-known velocity feedback control strategy with a saturation nonlinearity. Illustrative results have been reported from this preliminary study.

12:15 Uncertain Dynamical Systems

Variability analysis on the structural elastic properties of adhesively joined cylinders (2326)

K Van Massenhove, S Debruyne, D Vandepitte

Elastic structural adhesives have very attractive mechanical properties compared to brittle ones, especially in dynamically loaded structures and applications. They often combine an acceptable stiffness and bonding strength with excellent impact and vibration damping properties. Their viscoelastic nature involves some complexities however. For these adhesive types the apparent stiffness changes with time, temperature, frequency and amplitude of the applied mechanical load. Moreover, each bonding process involves variability that reflects on the (dynamic) mechanical behaviour of completed adhesively joined structures. This paper discusses part of an extensive research project on the uncertainty assessment of adhesive joint lifetime in case of fatigue loads. A first part of this paper deals with uniaxial quasi-static cyclic tests on nominally identical adhesively bonded samples, with a simple cylindrical geometry. The second part discusses dynamic measurements of a similar sample and identical load case, and identifies the effect of different load amplitudes. It also links the quasi-static measurements to the results of the dynamic measurements. Finally the paper concludes the research results and highlights the ongoing and planned activities.

Notes

13:30 Energy Harvesting II

Impulsive parametric damping in energy harvesting (2466)

M G Tehrani, T Pumhössel

In this paper, an electro-mechanical system with a time-varying damper, which is capable of changing the damping coefficient impulsively, is considered. The effect of the impulsive parametric damping to the modal energy content of the mechanical system is investigated analytically as well as numerically. First, the governing differential equation is presented and then the solution of the system's response is obtained through numerical integration. The energy dissipated by the damper is then calculated to investigate the amount of the energy that can be harvested, and the results are compared with the results from a system without parametric impulses. It is shown, that the amount of the harvested energy can be increased by introducing parametric impulses. Then, an analytical formulation is derived for the system using Dirac-Delta impulses and the analytical results are validated with numerical simulations. The device is subjected to an initial condition and therefore is vibrating freely without any base excitation. This could be used for applications such as harvesting energy from the passage of a train, where the train vibration can introduce an initial velocity to the harvester and the energy can then be extracted from the free vibration of the harvester.

13:30 Numerical methods

Reduced Order Models for Dynamic Behavior of Elastomer Damping Devices (2231)

B Morin, A Legay, J F Deü

In the context of passive damping, various mechanical systems from the space industry use elastomer components (shock absorbers, silent blocks, flexible joints...). The material of these devices has frequency, temperature and amplitude dependent characteristics. The associated numerical models, using viscoelastic and hyperelastic constitutive behaviour, may become computationally too expensive during a design process. The aim of this work is to propose efficient reduced viscoelastic models of rubber devices. The first step is to choose an accurate material model that represent the viscoelasticity. The second step is to reduce the rubber device finite element model to a super-element that keeps the frequency dependence. This reduced model is first built by taking into account the fact that the device's interfaces are much more rigid than the rubber core. To make use of this difference, kinematical constraints enforce the rigid body motion of these interfaces reducing the rubber device model to twelve dofs only on the interfaces (three rotations and three translations per face). Then, the superelement is built by using a component mode synthesis method. As an application, the dynamic behavior of a structure supported by four hourglass shaped rubber devices under harmonic loads is analysed to show the efficiency of the proposed approach

13:30 Dynamics and Control of Multibody Systems II

Digging Soil Experiments for Micro Hydraulic Excavators based on Model Predictive Tracking Control (2580)

T Tomatsu, K Nonaka, K Sekiguchi, K Suzuki

Recently, the increase of burden to operators and lack of skilled operators are the issue in the work of the hydraulic excavator. These problems are expected to be improved by autonomous control. In this paper, we present experimental results of hydraulic excavators using model predictive control (MPC) which incorporates servo mechanism. MPC optimizes digging operations by the optimal control input which is calculated by predicting the future states and satisfying the constraints. However, it is difficult for MPC to cope with the reaction force from soil when a hydraulic excavator performs excavation. Servo mechanism suppresses the influence of the constant disturbance using the error integration. However, the bucket tip deviates from a specified shape by the sudden change of the disturbance. We can expect that the tracking performance is improved by combining MPC and servo mechanism. Path-tracking controls of the bucket tip are performed using the optimal control input. We apply the proposed method to the Komatsu-made micro hydraulic excavator PC01 by experiments. We show the effectiveness of the proposed method through the experiment of digging soil by comparing servo mechanism and pure MPC with the proposed method.

13:30 System Identification and Inverse Problems

On a space-frequency regularization for source reconstruction (2087)

M Aucejo, O De Smet

To identify mechanical sources acting on a structure, Tikhonov-like regularizations are generally used. These approaches, referred to as additive regularizations, require the calculation of a regularization parameter from adapted selection procedures such as the L-curve method. However, such selection procedures can be computationally intensive. In this contribution, a space-frequency multiplicative regularization is introduced. The proposed strategy has the merit of avoiding the need for the determination of a regularization parameter beforehand, while taking advantage of one's prior knowledge of the type of the sources as well as the nature of the excitation signal. By construction, the regularized solution is computed in an iterative manner, which allows adapting the importance of the regularization term all along the resolution process. The validity of the proposed approach is illustrated numerically on a simply supported beam.

13:30 Analytical methods

Vibration analysis and optimization of sandwich composite with curvilinear fibers (2289)

S Honda, Y Narita

The present paper develops a shell element based on the refined zigzag theory (RZT) and applies it to the vibration analysis and optimization problem of the composite sandwich plate composed of CFRP skins and soft-cores. The RZT accepts large differences in layer stiffness, and requires less calculation effort than the layer-wise or three-dimensional theories. Numerical results revealed that the present method predicts vibration characteristics of composite sandwich plates with soft-core accurately. Then, shapes of reinforcing fibers in CFRP composite skins are optimized to maximize fundamental frequencies. As an optimizer, the particle swarm optimization (PSO) approach is employed since curvilinear fiber shapes are defined by continuous design variables. Obtained results showed that the composite sandwich with optimum curvilinear fiber shapes indicates higher fundamental frequencies compared with straight fibers.

Notes

13:45 Energy Harvesting II

Concept study of a novel energy harvesting-enabled tuned mass-damper-inerter (EH-TMDI) device for vibration control of harmonically-excited structures (2495)

J Salvi, A Giaralis

A novel dynamic vibration absorber (DVA) configuration is introduced for simultaneous vibration suppression and energy harvesting from oscillations typically exhibited by large-scale low-frequency engineering structures and structural components. The proposed configuration, termed energy harvesting-enabled tuned mass-damper-inerter (EH-TMDI) comprises a mass grounded via an in-series electromagnetic motor (energy harvester)-inerter layout, and attached to the primary structure through linear spring and damper in parallel connection. The governing equations of motion are derived and solved in the frequency domain, for the case of harmonically-excited primary structures, here modelled as damped single-degree-of-freedom (SDOF) systems. Comprehensive parametric analyses proved that by varying the mass amplification property of the grounded inerter, and by adjusting the stiffness and the damping coefficients using simple optimum tuning formulae, enhanced vibration suppression (in terms of primary structure peak displacement) and energy harvesting (in terms of relative velocity at the terminals of the energy harvester) may be achieved concurrently and at near-resonance frequencies, for a fixed attached mass. Hence, the proposed EH-TMDI allows for relaxing the trade-off between vibration control and energy harvesting purposes, and renders a dual-objective optimisation a practically-feasible, reliable task.

13:45 Numerical methods

Optimization of an installation angle of a root-cutting blade for an automatic spinach harvester (2338)

A Fujisawa, Y Chida

This paper presents an optimization of the installation angle of a root-cutting blade relative to the arm of an automatic spinach harvester. In the harvesting operation, the blade, which is a rigid body, moves under the planted rows in soil of powder consistency to cut the roots of the spinach and to harvest the spinach on a conveyor. Therefore, the interaction between a rigid body and powder is an important consideration. Experiments were conducted on the design of the harvester. The experiments revealed that a certain path of the blade is more favorable for both harvesting spinach easily and minimizing the amount of soil removed by the blade. In this paper, without revising the favorable path, the optimum installation angle of the blade is derived. To derive the installation angle, a nonlinear optimization problem is solved as an evaluation function consisting of the volume of soil pushed by the blade and the installation angle, which is a design parameter. The utility of the installation angle is confirmed by the Discrete Element Method (DEM), which analyzes the interaction between a rigid body and powder.

13:45 Dynamics and Control of Multibody Systems II

The dynamic research and position estimation of the towed array during the U-turn process (2581)

J X Yang, C G Shuai, L He, S K Zhang, S T Zhou

A dynamic model for estimating position of ship towed array during U-turn manoeuvre is introduced and developed. Based on this model, the influences of the parameters such as time step and segment length on the numerical simulation are analysed. The results indicate that decreasing the time step has little effect on the simulation accuracy but will increase the computational time. The selection of segment length has a great influence on the estimation of ship towed array position during U-turn manoeuvre. Reducing the segment length somewhat increases the computational complexity and significantly improves simulation precision.

13:45 System Identification and Inverse Problems

Wind load Identification of a guyed mast inversely from full-scale response measurement (2229)

A K Amiri, C Bucher

This paper presents a procedure for the wind load identification and the results of its practical application. The wind loads are inversely reconstructed in time domain from measured structural response by means of an augmented impulse response matrix. The inherent noise amplification arising from the ill-posed inverse problem is resolved through Tikhonov regularization. In order to increase the accuracy in solving the inverse problem along with the availability of the measured response just at a limited number of sensor locations, the problem is projected onto the modal coordinates. Consequently the modal wind loads are identified in modal subspace for several single degree of freedom systems, whose characteristic parameters are obtained by an operational modal analysis procedure. The structure under measurement is a 9.1 m (30 ft) tall guyed mast consisting of tubular elements. Since the direct wind pressure/load measurements on the structural members are almost impossible in full-scale testing, numerical simulation was also implemented to verify the results of experimental load identification by analogy. The load identification results are provided in time and frequency domain. Numerical simulation, where actual loads are available, confirm the capability of the method in identification of modal wind loads. Then based on the existing analogy between the simulation and practical application results, the identified loads from field measurements are validated.

13:45 Analytical methods

Governing equations of multi-component rigid body-spring discrete element models of reinforced concrete columns (2593)

P B Guan, E A Tingatinga, R E Longalong, J Saguid

During the past decades, the complexity of conventional methods to perform seismic performance assessment of buildings led to the development of more effective approaches. The rigid body spring-discrete element method (RBS-DEM) is one of these approaches and has recently been applied to the study of the behavior of reinforced concrete (RC) buildings subjected to strong earthquakes. In this paper, the governing equations of RBS-DEM planar elements subjected to lateral loads and horizontal ground motion are presented and used to replicate the hysteretic behavior of experimental RC columns. The RBS-DEM models of columns are made up of rigid components connected by systems of springs that simulate axial, shear, and bending behavior of an RC section. The parameters of springs were obtained using Response-2000 software and the hysteretic response of the models of select columns from the Pacific Earthquake Engineering Research (PEER) Structural Performance Database were computed numerically. Numerical examples show that one-component models were able to simulate the initial stiffness reasonably, while the displacement capacity of actual columns undergoing large displacements were underestimated.

Notes

14:00 Energy Harvesting II

A simulation of the performance of a self-tuning energy harvesting cantilever beam (2543)

J L Kaplan, P Bonello, M Alalwan

A vibration energy harvester is typically a cantilever beam made up of one or two layers of piezoelectric material that is clamped at one end to a vibrating host structure. The harvester is typically tuned to the frequency of the ambient vibration to ensure maximum power generation. One method to ensure that the system stays tuned in the presence of a varying frequency is to attach a mass to the cantilever and apply a control system to adjust its position along the cantilever according to the ambient frequency. This paper presents a simulation of the performance of such a system, based on a distributed parameter electromechanical model of the sliding-mass beam. A variety of control systems are used to adjust the position of the movable mass during operation and are compared for their efficacy in maintaining resonance over a varying excitation frequency. It was found that the resonance frequency of a bimorph cantilever VEH (Vibration Energy Harvester) could be successfully tuned over a wide frequency range. Moreover, it is also found that much of the voltage output reduction at higher frequencies could be compensated for by a separate control system used to adjust the capacitor load.

14:00 Numerical methods

A hybrid approach for modelling dynamic behaviours of a rotor-foundation system (2350)

Z G Zhang, Z Y Zhang, B Jing, H X Hua

A new hybrid approach is presented to study the dynamic behaviour of a rotor-foundation system, in which a shaft coupled with various discontinuities are connected to a flexible foundation via discrete spring subunits. By modelling the rotor with the modified transfer matrix method and describing the flexible foundation through the appropriate modal model, the proposed technique facilitates a computationally efficient modelling approach where a mixture of theoretical, numerical or experimental models can be incorporated into one overall numerical model. Particularly, the present model enables one to conveniently consider both the free and forced vibrations as well as effects of various combinations of discontinuities encountered in the rotor. Some results are compared with available results in previous publications and those from the finite element method to validate the model. Parametric studies are also performed to demonstrate the accuracy and versatility of the developed method for substructure coupling analysis.

14:00 Dynamics and Control of Multibody Systems II

Control of vibrations for a parallel manipulator with flexible links - concepts and experimental results (2591)

M Morlock, M Burkhardt, R Seifried

A comprehensive control approach is presented to reduce the vibrations of a parallel manipulator with a kinematic loop and two flexible links whereof the longer one can show significant oscillations. The control objectives are end-effector trajectory tracking and active vibration control. The system is modeled as a flexible multibody system and exact feedforward control based on the full dynamic flexible multibody system is applied to improve the end-effector trajectory tracking performance. Furthermore, the effect of different position control concepts for the two linear drives, such as gain scheduling for the utilized cascade control and a model based friction compensation, on the movers themselves as well as on the end-effector are discussed, which can be conflicting. Experimental results are presented illustrating the achievable accuracy of the end-effector tracking for different trajectories while showing significant error reductions for a feedforward control based on an elastic model in contrast to a rigid one. Finally, a model based curvature controller is utilized which actively controls the occurring oscillations of the parallel manipulator. Here, a proportional controller as well as a linear-quadratic regulator are applied and the impact of an additional curvature control on the end-effector tracking performance is investigated.

14:00 System Identification and Inverse Problems

Inverse characterisation of frequency-dependent properties of adhesives (2259)

L Rouleau, J F Deü, A Legay

Traditional damping treatments are usually applied to the vibrating structure by means of adhesive layers. Environmental parameters, such as frequencies of excitation, may influence the behaviour of the bonding layer and modify the damping efficiency of the treatment. Therefore it is desired to take into account the viscoelastic behaviour of the adhesive layer in the finite element model. The goal of this work is to present a procedure to characterise and model the adhesive layer. To that purpose, an experimental-numerical method for inverse characterisation of the frequency dependent properties of the adhesive layer is applied. The proposed inverse approach is based on a four-parameter fractional derivative model whose parameters are identified by minimising the difference between the simulated and the measured dynamic response of a multi-layered structure assembled by bonding. In the finite element model used for the optimisation, the adhesive layer is modelled by interface finite elements. The influence of the adhesive layer on the efficiency of a damping treatment is evidenced by performing dynamic testing on a sandwich structure with a viscoelastic core, assembled by bonding. The proposed approach is applied to the characterisation of a pressure-sensitive adhesive.

14:00 Analytical methods

Integration simulation method concerning speed control of ultrasonic motor (2340)

R Miyauchi, B Yue, N Matsunaga, S Ishizuka

In this paper, the configuration of control system of the ultrasonic motor (USM) from finite element method (FEM) model by applying the nonlinear model order reduction (MOR) is proposed. First, the USM and the FEM model is introduced. Second, FEM model order reduction method is described. Third, the result of comparing the computing time and accuracy of the FEM model and reduced order model is shown. Finally, nominal model for control is derived by system identification from reduced order model. Nonlinear model predictive control (NMPC) is applied to the nominal model, and speed is controlled. the controller effect is confirmed by applying the proposed reduced order model.

Notes

14:15 Energy Harvesting II

Design of an electromagnetic-transducer energy harvester (2697)

L Simeone, M G Tehrani, S J Elliott

This paper presents the design and the manufacturing of an electromagnetic-transducer energy harvester. The design considers the coupling between the mechanical vibrating behaviour, generated by a base excitation, and the electromagnetic conversion of energy, which is aimed to produce the voltage across a load resistance. The design is based on some constraints, which are related to the characteristics of the shaker and aimed to obtain the best performance of the device. Current tests show the presence friction at low input levels, which is associated with the gearbox. The output voltage and the harvested power of the device are studied experimentally for different values of load. By increasing the value of the load from zero (short circuit) to high values (open circuit) the swing angle increases, while the harvested power presents a peak associated with the electrical damping. Also, harmonic tests are run at resonance for different levels of excitation to demonstrate the effect of the nonlinearity on the voltage and the harvested power. A nonlinear load resistance, is then introduced as part of future work. The aim is to try to increase the harvested power with respect to the linear load, at low level of excitation.

14:15 Numerical methods

FEM Techniques for High Stress Detection in Accelerated Fatigue Simulation (2394)

M Veltri

This work presents the theory and a numerical validation study in support to a novel method for a priori identification of fatigue critical regions, with the aim to accelerate durability design in large FEM problems. The investigation is placed in the context of modern full-body structural durability analysis, where a computationally intensive dynamic solution could be required to identify areas with potential for fatigue damage initiation. The early detection of fatigue critical areas can drive a simplification of the problem size, leading to sensible improvement in solution time and model handling while allowing processing of the critical areas in higher detail. The proposed technique is applied to a real life industrial case in a comparative assessment with established practices. Synthetic damage prediction quantification and visualization techniques allow for a quick and efficient comparison between methods, outlining potential application benefits and boundaries.

14:15 Dynamics and Control of Multibody Systems II

Fast trajectory planning by design of initial trajectory in overhead traveling crane with considering obstacle avoidance and load vibration suppression (2146)

A Inomata, Y Noda

This paper is concerned with an advanced transfer trajectory planning method of 2-Dimensional transfer machine with vibrational element such as an overhead traveling crane. In the 2-D transfer machine, it is required to reach the target position in a short time, avoid the obstacles, and suppress the vibration. In recent years, the authors have proposed the trajectory planning method using the optimization problem with considering input and state constraints in the transfer system, obstacle avoidance and vibration suppression. However in the previous approaches, it takes a long time to derive the reference trajectory because of many variables in the optimization. Therefore in this study, we propose the fast solution for optimizing the transfer trajectory by giving a feasible initial trajectory. And, it is discussed how to give the cost function in the trajectory optimization with reducing the fluctuating cart motion. Moreover, we discuss the practical case that the proposed approach is applied to the large transfer space. The effectiveness of the proposed transfer trajectory planning method is verified by simulations of the overhead traveling crane.

14:15 System Identification and Inverse Problems

Vibration characteristics and optimization for panel elastically supported in mobile phone (2341)

Y Kaito, S Honda, Y Narita

In recent years, usage of smartphones and tablet terminals have spread around the world. These devices using touchscreen as a user interface are currently mainstream. Also, in order to let information of input or output surely know to users, there are some types of equipment having vibrational function in touchscreen. Here, the material of touchscreen consists of glass and the glass panel is fixed to a mobile phone's body by adhesive tapes along the edge of the panel. However, due to the difficulty of design of vibration, it needs investigation with a vast number of manufacturing prototypes. Moreover, the vibration characteristic of panels is not enough regarding intensity and a tactile impression. Therefore, in this study, the authors consider the vibration characteristic of glass panel elastically fixed by adhesive tapes along edges. First, they show modeling of adhesive tapes along edges of panel by using translational and rotational springs. Second, they show formulating vibration characteristic by using an energy method. Third, they optimize spring constants of translational and rotational springs by using Genetic

Algorithm(GA) from the obtained expression. Finally, they consider natural frequencies and eigenmodes which were acquired from experiments and simulations.

14:15 Analytical methods

A multiple-scales asymptotic approach for dynamic response analysis of piezoelectric laminated composites (2398)

G Kondagunta, M K Jain

A multiple-scales asymptotic theory is formulated for predicting the coupled electroelastic vibration characteristics of simply supported laminated piezoelectric plates composed of orthotropic layers. The equations of motion and charge equations are solved within the framework of three-dimensional piezoelectricity. The inhomogeneity is considered to be in the thickness direction. The equations are expressed in a non-dimensional form and the introduction of multiple scales in the formulation leads to a uniform expansion of the field variables in even powers of a plate thickness parameter. Two different laminate configurations are analyzed for the free vibration and electro-elastic response. The results obtained are compared with available exact solutions and numerical solutions from finite element analysis.

Notes

14:30 Energy Harvesting II

Global stabilization of high-energy response of a nonlinear wideband electromagnetic energy harvester (2609)

T Sato, S Kato, A Masuda

This paper presents a resonance-type vibration energy harvester with a Duffing-type nonlinear oscillator which is designed to perform effectively in a wide frequency band. For the conventional linear vibration energy harvester, the maximum performance of the power generation and its bandwidth are in a relation of trade-off. Introducing a Duffing-type nonlinearity can expand the resonance frequency band and enable the harvester to generate larger electric power in a wider frequency range. However, since such nonlinear oscillator may have coexisting multiple steady-state solutions in the resonance band, it is difficult for the nonlinear harvester to maintain the high performance of the power generation constantly. The principle of self-excitation and entrainment has been utilized to give global stability to the high-energy orbit by destabilizing other unexpected low-energy orbits by introducing a switching circuit of the load resistance between positive and the negative values depending on the response amplitude of the oscillator. In this paper, an improved control law that switches the load resistance according to a frequency-dependent threshold is proposed to ensure the oscillator to respond in the high-energy orbit without ineffective power consumption. Numerical study shows that the steady-state responses of the harvester with the proposed control low are successfully kept on the high-energy orbit without repeating activation of the excitation-mode.

14:30 Numerical methods

Local modes analysis of a rotating marine ship propeller with higher order harmonic elements (2670)

C Feng, C Yong, H Hongxing

An annular harmonic finite element for the computation of the local modes of a pretwisted ship propeller is developed. The elements take into account both the gyroscopic effect and centrifugal stiffening of the propeller blades. The displacement field is expressed by a truncated Fourier series along the angle and by polynomial shape functions in the radial direction. As an example, the dynamic behaviour, i.e. the nature frequency and local modes, of a ship propeller is studied, and compared with ANSYS, both of which have good consistency.

14:30 Dynamics and Control of Multibody Systems II

Modeling and control of a cable-suspended robot for inspection of vertical structures (2605)

N Barry, E Fisher, J Vaughan

In this paper, a cable-driven system is examined for the application of inspection of large, vertical-walled structures such as chemical storage tanks, large ship hulls, and high-rise buildings. Such cable-driven systems are not commonly used for these tasks due to vibration, which decreases inspection accuracy and degrades safety. The flexible nature of the cables make them difficult to control. In this paper, input shaping is implemented on a cable-driven system to reduce vibration. To design the input shapers, a model of the cable-driven system was developed. Analysis of the dominant dynamics and changes in them over the large workspace are also presented. The performance improvements provided by the input shaping controller are quantified through a series of simulations.

14:30 System Identification and Inverse Problems

A new method for the identification of the parameters of the Dahl model (2309)

I García-Baños, F Ikhouane

Friction is a nonlinear phenomenon that is present in many areas of science and engineering. It has static and dynamic characteristics. This paper deals with a dynamic model of friction, namely the Dahl model. More precisely, this paper proposes a new methodology for the identification of the parameters of the Dahl model. It is shown that, in the absence of noise, the identified parameters are equal to the real ones. Numerical simulations are carried out to illustrate the identification methodology.

14:30 Analytical methods

Milling Stability Analysis Based on Chebyshev Segmentation (2311)

J Huang, H Li, P Han, B Wen

Chebyshev segmentation method was used to discretize the time period contained in delay differential equation, then the Newton second-order difference quotient method was used to calculate the cutter motion vector at each time endpoint, and the Floquet theory was used to determine the stability of the milling system after getting the transfer matrix of milling system. Using the above methods, a two degree of freedom milling system stability issues were investigated, and system stability lobe diagrams were got. The results showed that the proposed methods have the following advantages. Firstly, with the same calculation accuracy, the points needed to represent the time period are less by the Chebyshev Segmentation than those of the average segmentation, and the computational efficiency of the Chebyshev Segmentation is higher. Secondly, if the time period is divided into the same parts, the stability lobe diagrams got by Chebyshev segmentation method are more accurate than those of the average segmentation.

Notes

14:45 Energy Harvesting II

Design, modelling and experimental characterization of a novel regenerative shock absorber with a ball-screw-based mechanical motion rectifier (2592)

Y Liu, X Lin, L Zuo

Energy-harvesting shock absorbers can effectively mitigate the vibration of vehicles while simultaneously harvesting the vibration energy otherwise dissipated by the conventional viscous damper. In this paper, we develop an innovative MMR-based energy-harvesting shock absorber using ball-screw mechanism. The proposed shock absorber is composed of three modules which are the ball-screw, the enclosed MMR gearbox and the generator. Due to two one-way clutches embedded in the transmission gears, the proposed shock absorber is able to convert the reciprocating vibration induced by the suspension vibration into the unidirectional rotation of the generator. Therefore, the proposed transmission system is named as Mechanical Motion Rectifier (MMR) which is in a similar sense as the electric voltage rectifier regulates an AC voltage. However, the MMR's advantages are well beyond the electric voltage rectifier. It can significantly increase the energy-harvesting efficiency by stabilizing the generator's rotational speed and improve the system reliability by reducing impact forces among transmission gears. In this paper, we also analyze the dynamics of the proposed MMR-based shock absorber. It is derived that the shock absorber acts as a fixed inerter in parallel with a controllable damper tuned by the external electrical loads of the generator. Moreover, we also derive the instants of one-way clutches engaging and disengaging from the transmission system, which allow us to predict the rotational speed of the generator and the corresponding generated voltage and power. The analysis presented in this paper can be extended to other types of energy harvesting shock absorbers involving clutches-embedded gear transmissions, not only limited to the proposed MMR-based shock absorber using ball-screw mechanism. In addition to the theoretical analysis, we also conduct the in-lab test to experimentally analyze and characterize the superior characteristics of the proposed shock absorber.

14:45 Numerical methods

Dynamic finite element model validation of an assembled aero-engine casing (2729)

Z Huang, C Zang, Y Jiang, X Wang

Structural dynamic model updating and validation of an aero-engine casing is critical to the design and development of an aircraft engine. It helps to identify the dynamic characteristics and reduce the response of the aero-engine. The modelling and parameter identification of joint are extremely difficult and important in structural dynamic analysis of the assembled aero-engine casing. In this paper, dynamic model validation technique was applied to update and validate the finite element model of an assembled aero-engine casing. First, modal test of individual casings and the assembled casing was performed by using the traditional acceleration sensors and a hammer. The modal frequencies and mode shapes were obtained by modal analysis tools. Second, the Inverse Eigen-sensitivity Method was used to correct frequency errors and MAC values of correlated mode pairs in the individual components to obtain validated models. Last, the bolt joints of two aero-engine casings were modelled by thin layer of shell elements. The material parameters or element properties of the thin-layer contact elements were updated to obtain reliable connection parameters. The results show that the errors of natural frequencies between the validated FE model of an assembled aero-engine casing and test data are within 7%, and the MAC values of main modes are above 70%, which can verify the feasibility and effectiveness of this approach.

14:45 Analytical Methods

A nonlinear cointegration approach with applications to structural health monitoring (2537)

H Shi, K Worden, E J Cross

One major obstacle to the implementation of structural health monitoring (SHM) is the effect of operational and environmental variabilities, which may corrupt the signal of structural degradation. Recently, an approach inspired from the community of econometrics, called cointegration, has been employed to eliminate the adverse influence from operational and environmental changes and still maintain sensitivity to structural damage. However, the linear nature of cointegration may limit its application when confronting nonlinear relations between system responses. This paper proposes a nonlinear cointegration method based on Gaussian process regression (GPR); the method is constructed under the Engle-Granger framework, and tests for unit root processes are conducted both before and after the GPR is applied. The proposed approach is examined with real engineering data from the monitoring of the Z24 Bridge.

Notes

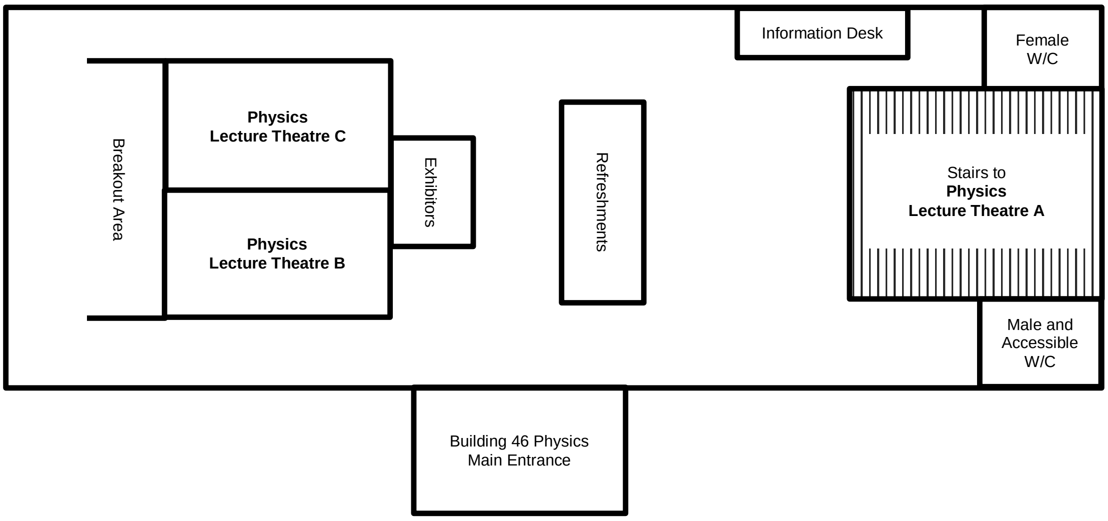
AUTHOR INDEX

AUTHOR INDEX

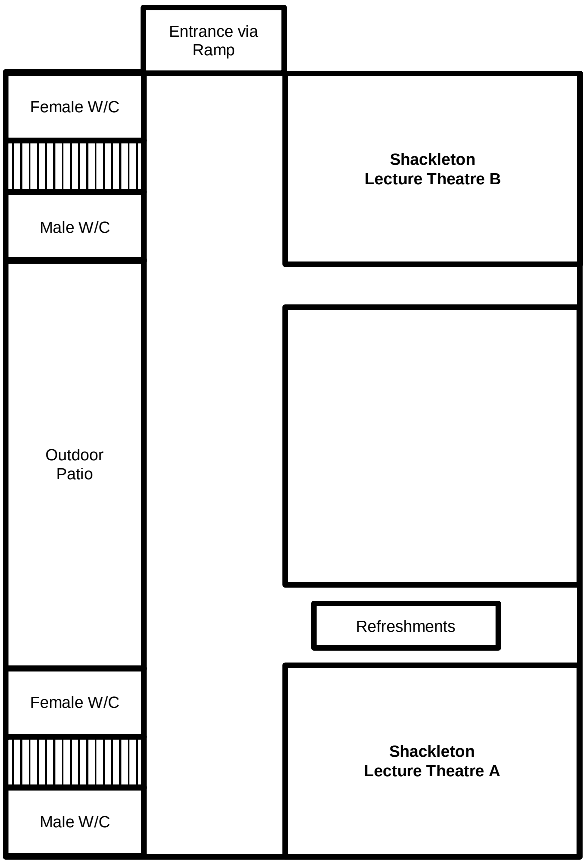
AUTHOR INDEX

Floor Plans

Building 46 (Physics)



Building 44 (Shackleton)



Campus Map

Boldrewood Campus
BURGESS ROAD
SALISBURY ROAD
UNIVERSITY ROAD
TO M3/M27
SOUTHAMPTON COMMON
CHAMBERLAIN ROAD
Valley Gardens
Coach Pick-Up and Drop-Off for Conference Dinner
Building 46 Physics
Building 44 Shackleton
Building 38 Garden Court
Venue for registration, lunches, reception and barbeque, poster session