Book of abstracts of ICoEV 2015 International Conference on Engineering Vibration

Ljubljana, 7 - 10. September

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FOREWORD

Welcome to ICoEV 2015 - an IFTOMM conference in Ljubljana, at the heart of Slovenia. Like with previous editions, this conference brings together a broad spectrum of scientists and researchers, who are focusing on Engineering Vibrations in a very broad sense.

The International Conference of Engineering Vibration (ICoEV) originated from a long-running series of events called the International Conference of Vibrational Problems (ICoVP), which was founded in India over 20 years ago. The last two conferences ICoVP were organised in Prague (2011) and Lisbon (2013), where the chair of the ICoVP event was heavily involved, and were very successful, attracting over 250 and 400 participants, respectively, from around the world.

This Ljubljana conference has attracted 200 participants from 31 countries; they include senior scientists, as well as master and PhD students.

The Steering and Organising Committees of the conference have made great efforts to maintain the high scientific standard of the papers. The conference is based on three and half days of technical presentations, structured into four parallel sessions. On each day of the conference there will be an invited lecture in the morning. The oral presentations are organized into 17 mini-symposia and eight other general topics.

The social programme includes a reception at Ljubljana Castle on Monday, which is free for everybody, a Tuesday afternoon trip to Bled and the conference dinner on Wednesday for the registered participants. We are confident that Ljubljana will provide interesting experiences for all participants, as it is well placed for reaching a wide variety of different attractions in a short time.

We express our gratitude to the Secretary of the Organizing Committee, Assoc. Prof. Janko Slavič, who has done an excellent job in making this conference a reality. Further thanks also go to the members of both the Scientific and Steering Committees, to our four invited speakers, to the organisers of the mini-symposia, to our sponsors and to all the contributing authors.

On behalf of the Steering and Organizing Committees we sincerely hope that you will all enjoy your time in Ljubljana during our conference.

Prof. Miha Boltežar
Chair of the Organizing Committee
University of Ljubljana, Slovenia

Prof. Marian Wiercigroch
Chair of the Steering Committee
University of Aberdeen, UK

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Faculty of Mechanical Engineering

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MINI SYMPOSIA

MS01 - Non-linear Dynamics and Dynamic Stability

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MS02 - Frequency-based spectral methods for vibration random fatigue

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Co-Organizer: **Assoc. Prof. Janko Slavič**
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MS03 - Vibration Problems in the Solids Systems With Dry Friction

Corresponding Organizer: **Prof. Alexander V. Karapetyan**
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MS04 - Optimization on Vibration Control of Seismic Structures

Corresponding Organizer: **Prof. S. Melih Nigdeli**
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Co-Organizer: **Prof. Gebrail Bekdas**
Istanbul University, Email: *bekdas@istanbul.edu.tr*

MS05 - Vibration Analysis of Steel and Steel-Concrete Composite Structures

Corresponding Organizer: **Prof. José Guilherme Santos da Silva**
State University of Rio de Janeiro, Email: *jgss@uerj.br*

MS06 - Vibration of Solids and Structures Under Moving Loads: Modelling and Analysis

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Cracow University of Technology, Email: *pkoziol@pk.edu.pl*
Co-Organizer: **Prof. Zuzana Dimitrovová**
Universidade Nova de Lisboa, Lisbon, Email: *zdim@fct.unl.pt*
Co-Organizer: **Prof. Miguel Matos Neves**
Universidade de Lisboa, Lisboa, Portugal, Email: *miguel.matos.neves@tecnico.ulisboa.pt*

MS07 - Nonlinear Dynamic Interactions and Phenomena: Emergent Methods and their Applications in Engineering and Science

Corresponding Organizer: **Prof. José Manoel Balthazar**

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MS08 - Influencing Vibrations by Dissipative Effects

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MS09 - Dynamics Drilling Deep Boreholes - Drillstring and Drillbit Vibrations

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MS10 - Inverse Problems and Uncertainty Quantification

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MS11 - Substructuring Techniques in Structural Dynamics

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MS12 - GRESIMO

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Co-Organizer: **Assoc. Prof. Janko Slavič**

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MS13 - Power-transformer noise

Corresponding Organizer: **Prof. Helmut PFÜTZNER**

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MS14 - The dynamics of an axially moving continuum

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MS15 - Engineering solutions for damping vibrations

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MS18 - Full Field Measurements for Advanced Structural Dynamics

Corresponding Organizer: **Dr. Alessandro Zanarini**

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MS19 - Non-smooth Dynamical Systems

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ICoEV 2015 PROGRAM

Sunday, September 6th

17:00 - 20:00	Registration

Monday, September 7th

8:00	Registration			
9:00	Opening			
9:15	Keynote: Professor Pol Spanos			
10:15	Coffee break			
	TP12	**MS13**	**TP09**	**MS07**
10:45	17	243	80	11
	18	278	113	14
	102	329	128	75
	149	340	261	83
	151	341	19	
12:30	Lunch			
	TP12	**MS13**	**MS15**	**MS07**
14:00	163	342	9	98
	172	346	87	111
	206	347	121	154
	210	363	143	180
	235		330	
15:40	Coffee break			
	TP12	**MS14**	**MS05**	**TP03**
16:10	238	20	73	106
	304	76	101	183
	327	168	112	323
	355	343		
19:00	**Welcome reception**			

Tuesday, September 8th

8:30	Keynote: Professor John E. Mottershead			
	MS11	**TP14**	**MS09**	**MS12-Gresimo**
9:15	150	94	5	79
	218	104	284	197
	325	144	320	204
10:15	Cofee break			
	MS11	**TP14**	**TP02**	**MS12-Gresimo**
10:45	270	164	114	269
	286	227	136	321
	302	232	138	322
		247	165	324
		145	199	326
12:30	Lunch			
13:30	E3: Gresimo closing event			
14:00	Optional tour to Bled			

Wednesday, September 9th

8:30	Keynote: Professor Gengkai Hu			
	TP05	**MS02**	**TP02**	**MS12-Gresimo**
9:15	108	10	281	336
	155	12	283	337
	157	90	305	338, 400
10:15	Cofee break + Poster session 1			
	99	142	161	176
	TP05	**MS02**	**MS04**	**TP10**
10:45	170	120	22	15
	207	167	23	21
	209	193	118	115
	245	282	169	166
	260	318	**DEWESOFT**	177
			NIKSIS	181
12:30	Lunch			
13:30	www.openmodal.com			
	TP05	**MS01**	**MS04**	**TP10**
14:00	264	85	230	228
	266	116	231	233
	362	205	351	288
	265	225	361	303
15:20	Coffee break + Poster session 2			
	299	315	317	349
	MS08	**MS01**	**MS06**	**MS18**
15:50	92	272	72	191
	100	293	126	251
	107	308	137	192
	77	97	273	196
			332	
19:30	Conference dinner			

Thursday, September 10th

8:30	Keynote: Professor Marian Wiercigroch			
	MS08	**MS10**	**MS19**	**MS03**
9:15	208	74	248	271
	279	125	259	289
	301	146	292	298
10:15	Cofee break			
	TP01	**MS10**	**MS19**	**MS03**
10:45	89	194	300	335
	109	214		344
	147	216		348
	258	221		
	307			
	215			
12:50	Closing of the conference			

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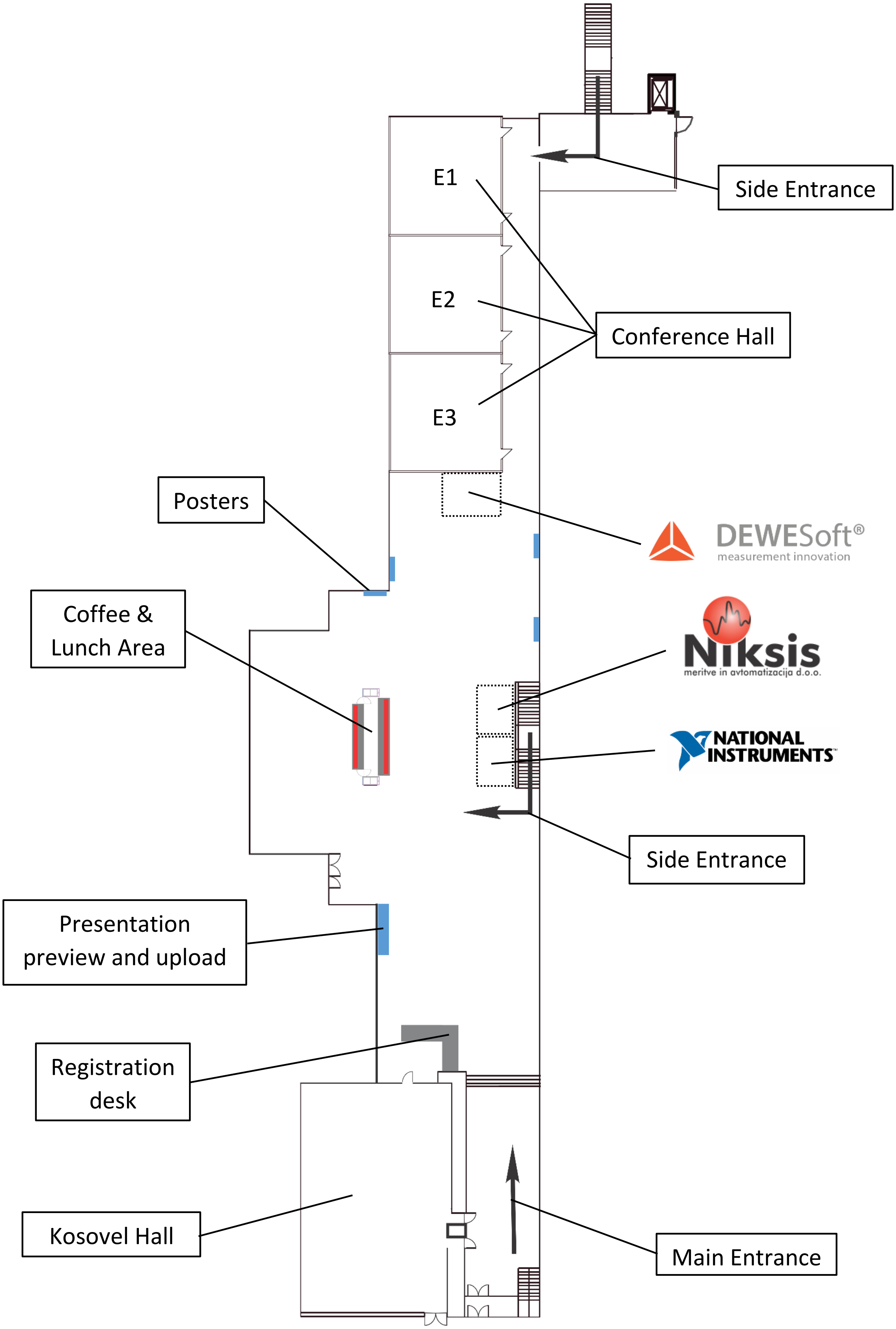

TECHNICAL PROGRAM

Sunday, September 6th, Afternoon

17:00 - 20.00 Registration

Monday, September 7^{th}, Morning

8:00	**Registration**			
9:00	**Opening**			
9:15	**Keynote:** Professor Pol Spanos			
10:15	**Coffee break**			
	Kosovel Hall - Session 1	Room E1 - Session 2	Room E2 - Session 3	Room E3 - Session 4
	TP12: Dynamics of Rotating Systems Chair: Professor Jaroslav Zapoměl	**MS13: Power-transformer noise** Chair: Ass. Professor Gregor Čepon	**TP09: Fluid-Structure Interactions** Chair: Professor Mike Jeffrey	**MS07: Nonlinear Dynamic Interactions and Phenomena...** Chair: Professor José M. Balthazar
10:45	**17 - Evaluation of the Dynamic Characteristics of the Three-Lobe Journal Bearing...** *Athanasios Chasalevris*	**243 - The Influence of Magnetic Anisotropy on Magnetostriction Forces and Vibration...** *Pawel Witczak*	**80 - Stabilization control of self-excited vibrations in a flexible fluid-conveying pipe** *X. Chen, H. Yabuno, K. Yamashita*	**11 - Forced Nonlinear Vibration Analysis of Cylindrical Panels** *H. A. R. Sattler, F. M. A. Silva, Z. J. G. N. Del Prado, P. B. Gonçalves*
11:05	**18 - Evaluation of the Floating Ring Bearing Characteristics Using Analytical Methods** *Athanasios Chasalevris*	**278 - A comparison between numerical and experimental modal parameters of transformer core** *M. Pirnat, P. Tarman, M. Nastran*	**113 - Investigation of Typical Section Aerodynamic Transfer Functions Using a Viscous...** *Rafael Ihi, Joao Luiz Azevedo*	**14 - Increasing Practical Safety of Von Mises Truss via Control of Dynamic Escape** *Diego Orlando, Paulo B. Gonçalves, Stefano Lenci, Giuseppe Rega*
11:25	**102 - Influence of the oil temperature of thrust bearings on the vibratory behavior...** *I. Chatzisavvas, A. Boyaci, P. Koutsovasilis, B. Schweizer*	**329 -Measurement and analysis of noise and vibration of 800kV converter transformers** *J. Pan, Y. Wang, X. H Du, Q.S Tang, H. Huang, M. Pei*	**128 - Transverse Seismic Response Analysis of Submerged Floating...** *Yiqiang Xiang, Chunfeng Cao*	**75 - Cubic Softening Nonlinear Elasticity Measurement of Magnetic Attraction...** *Yudai Tanaka, Hiroshi Yabuno*
11:45	**149 - Rotor Unbalance Estimation using a Single Machine Rundown...** *Sami Ibn Shamsah, Jyoti Sinha*	**340 - Spatial Distribution of Magnetostriction, Strain, Displacements and...** *G. Shilysashki, H. Pfützner, P. Hamberger, M. Aigner, A. Kenov, I. Matkovic*	**261 - CFD calibrated wake oscillator model for Vortex-Induced Vibrations** *Ekaterina Pavlovskaia, Andrey Postnikov, Marian Wiercigroch*	**83 - Parametric Study of a Macro-scale Tuning Fork Gyroscope** *Maryam Ghandchi Tehrani, Jose Manoel Balthazar, Marcos Silveira*
12:05	**151 - Dynamics of a rotating hub-blade structure with nonideal energy source** *Jerzy Warminski, Jaroslaw Latalski, Zofia Szmit*	**341 - Numerical MACC-Modelling of Local Peak-to-peak Magneto...** *G. Shilyashki, H. Pfützner, P. Hamberger, M. Aigner, E. Gerstbauer, G. Trenner*	**19 - Investigation on cavitation bubble near an elastic sphere** *B.H.T. Goh, S.W. Gong, E. Klaseboer, S.W. Ohl, B.C. Khoo*	
12:30	**Lunch**			

Monday, September 7^{th}, Afternoon

	Kosovel Hall - Session 5	Room E1 - Session 6	Room E2 - Session 7	Room E3 - Session 8
	TP12: Dynamics of Rotating Systems Chair: Professor Jaroslav Zapomĕl	**MS13: Power-transformer noise** Chair: dr. Shilyashki Georgi	**MS15: Engineering solutions for damping vibrations** Chair: Professor Zuzana Dimitrovová	**MS07: Nonlinear Dynamic Interactions and Phenomena: Emergent Methods...** Chair: Professor Paulo Batista Goncalves
14:00	**163 - Analizing the stiffness of a rotor with triangular cross fracture** *Homero Jiménez, Benjamín Vázquez, Gilberto Alvarez*	**342 - Development of numerical model for computation of power transformer noise** *Gregor Čepon, Miha Nastran, Miha Boltežar*	**9 - Tuned mass damper use for structural improvement behaviour in some...** *Nicola Longarini, Marco Zucca, Giuseppe Silvestro*	**98 - On energy transfer between vibration modes and frequency-varying...** *J.L.P. Felix, R. Bianchin, A. Almeida, J. M. Balthazar, R. T. Rocha, R.M.L.R.F Brasil*
14:20	**172 - Dynamics of the rotor with foil bearings at an elevated temperature** *Grzegorz Zywica, Pawel Baginski, Slawomir Banaszek*	**346 - Acoustic field inside the oil-filled transformer tank model and its consequence...** *Michal Kozupa, Grzegorz Kmita, Karolina Kolber*	**87 - Stiffness and loss factor of unbonded, multi-strand beams under flexural deformation** *Haval Asker, Jem Rongong, Charles Lord*	**111 - Dynamical vibration absorber by using shape memory materials** *V. Piccirillo, J. M. Balthazar, A. Tusset, D. Bernardini, G. Rega*
14:40	**206 - Vibration of a two degree of freedom air bearing-rotor system with asymmetric...** *Abdurrahim Dal, Tuncay Karaçay*	**347 - Vibroacoustic behavior of 120 MVA power transformer** *Michal Kozupa, Michal Swiatkowski, Grzegorz Kmita*	**121 - Nonlinear Dynamic Absorber to Reduce Vibration in Hand Held Impact Machines** *Hans Lindell, Viktor Berbyuk, Mattias Josefsson, Snaevar Leó Grétarsson*	**154 - Nonlinear discontinous phenomena in atomic force microscopy** *Laura Ruzziconi, Mohammad Younis, Stefano Lenci*
15:00	**210 - Effects of a Journal Bearing Clearance on Rotordynamics of Turbocharger** *Luboš Smolík, Michal Hajžman, Miroslav Byrtus*	**363 - The behaviour of vibration, near- and far-field noise of ultrahigh...** *C. M. Pei, Y.X Wang, X.H. Du, Q.S. Tang, H. Huang, J. Pan*	**143 - Ehrlich-Aberth iteration for vibrational systems** *Peter Benner, Jonas Denißen*	**180 - Dynamics of Beams and Plates under Coupled Thermo-Mechanical Loading** *Anna Warminska, Emil Manoach, Jerzy Warminski*
15:20	**235 - A numerical investigation into the effect of the supports on the vibration...** *Azrul Abidin Zakaria, Emiliano Rustighi, Neil Ferguson*		**330 - Structural optimization of a material exhibiting negative stiffness** *Jan Heczko, Zuzana Dimitrovová Helder Rodrigues*	
15:40	**Coffee break**			

Monday, September 7^{th}, Afternoon (Cont.)

	Kosovel Hall - Session 9	Room E1 - Session 10	Room E2 - Session 11	Room E3 - Session 12
	TP12: Dynamics of Rotating Systems Chair: Professor Ekaterina Pavlovskaia	**MS14: The dynamics of an axially moving continuum** Chair: Professor Lionel Manin	**MS05: Vibration Analysis of Steel and Steel-Concrete Composite Structures** Chair: Professor Americo Barbosa da Cunha Junior	**TP03: Computational Methods** Chair: Dr. Joseph Paez Chavez
16:10	**238 - Structural dynamics of a wind turbine drive train high speed subsystem:...** *Saeed Asadi, Viktor Berbyuk, Hakan Johansson*	**20 - Modelling the belts - envelope interactions during the postal mail conveying...** *Lionel Manin, Stefan Braun, Damien Hugues*	**73 - Vibration analysis of steel-concrete composite multi-storey buildings** *Vinicius Calazans Morais, Rafael Rangel Barboza, José Guilherme Santos da Silva*	**106 - Application of the Wave Based Method to steady-state vibrations of thick plates** *Michael Klanner, Katrin Ellermann*
16:30	**304 - Modelling of magnetorheological oils in rotordynamic damping devices...** *Jaroslav Zapomel, Petr Ferfecki, Jan Kozánek*	**76 - Experimental Analysis of Nonlinear Response in Simply Supported Beam Subjected...** *Naoto Araumi, Hiroshi Yabuno*	**101 - Human comfort analysis of concrete pedestrian footbridges using biodynamic models** *Gilvan Lunz Debona, José Guilherme Santos da Silva*	**183 - The Helmholtz Equations by the Null-field and the Interior Field Methods...** *Ming-Gong Lee, Zi-Cai Li, Hung-Tsai Huang, Kun-Ming Yu*
16:50	**327 - Investigation of high vibration on large fan motor** *Keri Elbhbah, Ian Andrew, Jyoti Sinha, Wolfgang Hahn, Erfan Asnaashari*	**168 - The Natural Frequencies of an Axially Moving Beam Supported by an Intermediate Spring,** *F. Köstekci, A. K. Banik*	**112 - Vibration control and human comfort evaluation of steel-concrete composite floors under aerobics** *Cássio Marques Rodrigues Gaspar, José Guilherme Santos da Silva*	**323 - Contact Situations in Rigid Body Dynamics** *Luka Skrinjar, Janko Slavič, Miha Boltežar*
17:10	**355 - Evaluation of the Dynamic Response of High-Speed Systems Using an...** *Athanasios Chasalevris*	**343 - Rotational response and slip prediction of serpentine belt drives using...** *Gregor Čepon, Miha Boltežar*		
19:00	**Welcome reception**			

Tuesday, September 8^{th}, Morning

8:30	**Keynote:** Professor John E. Mottershead			
	Kosovel Hall - Session 13	Room E1 - Session 14	Room E2 - Session 15	Room E3 - Session 16
	MS11: Substructuring Techniques in Structural Dynamics Chair: Professor Daniel J. Rixen	**TP14: Vibration Control and Isolation** Chair: Professor Przemyslaw Perlikowski	**MS09: Dynamics Drilling Deep Boreholes - Drillstring...** Chair: Professor Hans Ingo Weber, Professor Marian Wiercigroch, Professor Ian Forster	**MS12: Gresimo** Chair: Dr. Jan Rejlek
9:15	**150 - Selection of internal DoFs to replace hard-to-measure coupling DoFs in...** *Walter D'Ambrogio, Annalisa Fregolent*	**94 - On the removal of break squeal by tuned mass dampers** *Rolf Steinbuch, Simon Gekeler, Oskar Glück, Srivastava Ashish*	**5 - Axial Excitation Tool String Modelling** *Ian Forster*	**79 - Dynamic response of laminated structures using a Refined Zigzag Theory...** *Alessandra Treviso, Domenico Mundo, Michel Tournour*
9:35	**218 - Adaptive Feedforward Cancellation for Realtime Hybrid Testing with...** *Andreas Bartl, Johannes Mayet, Daniel J. Rixen*	**104 - Technique to overcome piezo stack actuator saturation using parallel stiffness...** *Ahmad Zhafran Ahmad Mazlan, Zaidi Mohd Ripin*	**284 - Localizing the Excitation Source of High Frequency Torsional Oscillations** *Mathias Tergeist, Hanno Reckmann, Michael Neubert, Georg-Peter Ostermeyer*	**197 - Surface impedance prediction using phased geometrical acoustics...** *Matthew Boucher, Bert Pluymers, Wim Desmet*
9:55	**325 - Effects of Interface Loading in Dynamic Substructuring** *Andreas Linderholt, Maren Scheel, Anders Johansson*	**144 - A contribution to the reduction of self-excited vibrations of dynamical...** *Thomas Pumhoessel*	**320 - Propagation of Torsional Vibrations in Drillstrings: How Borehole Geometry...** *Roman Shor, Can Pehlivanturk, Behcet Acikmese, Eric van Oort*	**204 - On the effects of damping on wave propagation in periodic vibro-acoustic meta-materials** *Alireza Nateghi, Claus Claeys, Elke Deckers, Bert Pluymers, Wim Desmet*
10:15	**Coffee break**			

Tuesday, September 8th, Morning (Cont.)

	Kosovel Hall - Session 17	Room E1 - Session 18	Room E2 - Session 19	Room E3 - Session 20
	MS11: Substructuring Techniques in Structural Dynamics Chair: Professor Daniel J. Rixen	**TP14: Vibration Control and Isolation** Chair: Professor Przemyslaw Perlikowski	**TP02: Experimental Techniques** Chair: Professor Stefano Lenci	**MS12: Gresimo** Chair: Dr. Marco Pierini
10:45	**270 - Comparison between primal and dual Craig-Bampton substructure reduction...** *Fabian M. Gruber, Johannes B. Rutzmoser, Daniel J. Rixen*	**164 - Fractional pid controller to an active image stabilization system** *Sergio A. David, Carlos A. Valentim, Rafael V. Sousa, Lucas R. Trevisan, Leonardo P. Magalhaes, José M. Balthazar*	**114 -Vibration of aerosols in the tubes** *Damir Gubaidullin, Rinat Zaripov, Liudmila Tkachenko*	**269 - NVH performances of automotive car bodies with different structural contrasts** *M. Nobou Dassi, A. Gaudin, Z. Abbadi, L. Gagliardini, C. Pezerat, F. Gautier*
11:05	**286 - A Comparison on Model Order Reduction Techniques for Geometrically Nonlinear...** *Johannes Rutzmoser, Fabian Gruber, Daniel J. Rixen*	**227 - Vibration protection of object with help of thin-layered rubber-metal elements** *Svetlana Polukoshko, Vladimirs Gonca*	**136 - Introducing Shaper-Based Filters for the improvement of the load cell response in...** *Dario Richiedei, Alberto Trevisani*	**321 - On variable screening and optimization of car body structures subject to ...** *Ramses Sala, Niccolo Baldanzini, Marco Pierini*
11:25	**302 - An interface force measurements-based substructure identification** *Tadej Kranjc, Janko Slavič, Miha Boltežar*	**232 - Effectiveness of seismic-tuned passive tuned mass dampers accounting...** *Jonathan Salvi, Fabio Pioldi, Egidio Rizzi*	**138 - Influences of external vibration on precision machines - theoretical and...** *Isabel Husung, Erik Gerlach, Bernd Fiedler, Klaus Zimmermann*	**322 - The Impact of the Structural Non-linearity on the Vibration Fatigue...** *Uroš Proso, Janko Slavič, Miha Boltežar*
11:45		**247 - A methodology to decouple the tonal noise sources of a compressor system** *Roberto Faventi, Adrien Gomar*	**165 - Axial behavior of self-compacting, self-stressing and high-strength Concrete...** *Xu Lihua, Gu Yushan, Chi Yin*	**324 - Equivalent material modelling of sandwich beam assemblies: propagating...** *Sophie de Rijk, Eugene Nijman*
12:05		**145 - Active suspension lq control for improving riding comfort** *Francesco Cosco, Ion Borozan, Stefano Candreva, Domenico Mundo*	**199 - Effects of center distance and microgeometry on the dynamic behaviour...** *S. Shweiki, A. Palermo, A. Toso, D. Mundo, W. Desmet*	**326 - An inverse methodology for low-frequency Transmission Loss characterization...** *Vittorio D'Ortona, Eugene Nijman*
12:30	**Lunch**			
13:30	**E3: Gresimo closing event**			
14:00	**Optional tour to Bled**			

Wednesday, September 9th, Morning

8:30	**Keynote:** Professor Gengkai Hu			
	Kosovel Hall - Session 21	Room E1 - Session 22	Room E2 - Session 23	Room E3 - Session 24
	TP05: Structural Dynamics Chair: Professor Hiroshi Yabuno	**MS02: Frequency-based spectral methods for vibration random fatigue** Chair: dr. Turan Dirlik	**TP02: Experimental Techniques** Chair: Professor Stefano Lenci	**MS12: Gresimo** Chair: Dr. Jan Rejlek
9:15	**108 - Masing rule motivated local discrete modelling of contact interfaces to...** *Anuj Sharma, Wolfgang Mueller-Hirsch, Sven Herold, Tobias Melz*	**10 - Derivation of Equivalent Power Spectral Density Specifications for Swept...** *Tom Irvine*	**281 - A Benchmark for Tip Timing Measurements of Forced Response in...** *Giuseppe Battiato, Christian Firrone, Teresa Berruti*	**336 - The Finite Element Analysis assessment of structure properties for...** *Roman Pawel Jedrzejczyk, Thomas Jost*
9:35	**155 - Risk Assessment of Safety Analysis of NPP Structures due to Earthquake Evens** *Juraj Králik*	**12 - Fatigue Assessment of Non Gaussian Random Vibrations by using Decomposition...** *Peter Wolfsteiner*	**283 - Experimental research of the kinematics and contact conditions of the brush...** *Aleš Turel, Janko Slavič, Miha Boltežar*	**337 - A sampling criterion for acoustic radiation problems: practical applications** *Giorgio Veronesi, E. J. M. Nijman*
9:55	**157 - Deterministic and Probabilistic Analysis of the Accidental Torsion Effect...** *Juraj Králik*	**90 - An analytical approach to measure the accuracy of various definitions of the...** *Denis Benasciutti*	**305 - Investigating the application of guided wave propagation for ice detection...** *Siavash Shoja, Viktor Berbyuk, Anders Boström*	**338 - Determining vibration sources in solid media using time reversal technique** *Amr Abboud, Eugene Nijman* **400 - Simultaneous optimization of composite structures with shunted piezoceramics** *Rogério Salloum, Oliver Heuss, Dirk Mayer*
10:15	**Coffee break + Poster session 1:**			
	99	142	161	176

Wednesday, September 9^{th}, Morning (Cont.)

	Kosovel Hall - Session 25	Room E1 - Session 26	Room E2 - Session 27	Room E3 - Session 28
	TP05: Structural Dynamics Chair: Professor Hiroshi Yabuno	**MS02: Frequency-based spectral methods for vibration random fatigue** Chair: Professor Denis Benasciutti, Assoc. Professor Janko Slavič	**MS04: Optimization on Vibration Control of Seismic Structures** Chair: Professor S. Melih Nigdeli	**TP10: Identification and Modal Analysis** Chair: Professor Rafał Rusinek
10:45	**170 - Design and optimization of a compact high-frequency electromagnetic shaker** *Leonardo Bertini, Paolo Neri, Ciro Santus*	**120 - Simulation of the whole wind-induced fatigue life of a slender steel structure,** *Maria Pia Repetto*	**22 - Optimization of TMDS for seismic structures considering near field ground motion sets** *Gebrail Bekdaş Sinan Melih Nigdeli*	**15 - Application of Equivalent Material Properties in Free Vibration Analysis...** *K.-H. Jeong, M.-J. Jhung, J.-W. Kim*
11:05	**207 - Reduced thin-layer element model for joint damping** *Christian Ehrlich, André Schmidt, Lothar Gaul*	**167 - Shaker testing simulation of non-Gaussian random excitations with the fatigue...** *B. Cornelis, A. Steinwolf, M. Troncossi, A. Rivola*	**23 - A robust optimum design approach of tmds considering structural uncertanity** *Sinan Melih Nigdeli, Gebrail Bekdaş*	**21 - High-frequency control of the slow motions** *Eugen Kremer*
11:25	**209 - Numerical and experimental investigations into mass, stiffness and damping...** *Sharad Pradhan, S.V. Modak*	**193 Full field experimental modelling in spectral approaches to fatigue predictions** *Alessandro Zanarini*	**118 - Effect of eccentricity on active control of seismic structures** *Sinan Melih Nigdeli, M. Hasan Boduroglu*	**115 - Strategy for identification of damping ratio using Morlet Wave Damping...** *Ivan Tomac, Željan Lozina, Damir Sedlar*
11:45	**245 - A parametric analysis of the nonlinear response of...** *L. Fernando Paullo M., P. Gonçalves, R. Silveira, A. Silva*	**282 - Experimental comparison of multi-axial criteria in frequency-domain** *Matjaž Mršnik, Janko Slavič, Miha Boltežar*	**169 - Multi objcetive optimization of double tuned mass dampers considering...** *Sinan Melih Nigdeli, Gebrail Bekdaş*	**166 - Biomechanical model of a smart middle ear prosthesis** *R. Rusinek, K. Kozik, M. Szymanski, J. Warminski*
12:05	**260 - Direct damping identification methods in frequency domain** *Matija Brumat, Janko Slavič, Miha Boltežar*	**318 - A Review and Comparison of Cycle Identification Methods for Fatigue...** *Curtis Larsen, Tom Irvine*	**DEWEsoft**	**177 - Numerical transfer path analysis for the assessment of air-borne noise...** *Antonio Acri, Guenter Offner, Eugene Nijman, Roberto Corradi*
12:25			**Niksis**	**181 - Fast online monitoring and system identification for the application...** *G. Jeličić J. Schwochow, Y. Govers, A. Hebler, M. Böswald*
12:30	**Lunch**			
13:30	**www.openmodal.com**			

Wednesday, September 9^{th}, Afternoon

	Kosovel Hall - Session 29	Room E1 - Session 30	Room E2 - Session 31	Room E3 - Session 32
	TP05: Structural Dynamics Chair: Professor Hiroshi Yabuno	**MS01: Non-linear Dynamics and Dynamic Stability** Chair: Professor Jiří Náprstek	**MS04: Optimization on Vibration Control of Seismic Structures** Chair: Professor Gebrail Bekdas	**TP10: Identification and Modal Analysis** Chair: Professor Rafał Rusinek
14:00	**264 - Damage identification in beam structure using mode shape data: from spatial...** *R. Janeliukstis, S. Rucevskis, M. Wesolowski, A. Chate, A. Kovalovs*	**85 - Quasi-periodic response types of a single non-linear dynamic system in resonance...** *Jiří Náprstek, Cyril Fischer*	**230 - Controlling of the full vehicle model using sliding model control optimized by...** *Alaattin Sayin, Hasan Omur Ozer*	**228 - Industrial use of methods for modal analysis of small and light structures** *Domen Rovšček, Janko Slavič, Miha Boltežar, Vitoslav Bratuš, Tomaž Mlakar*
14:20	**266 - Biodynamic Based Experimental Validation of a Human Finger Model** *Luka Knez, Janko Slavič, Miha Boltežar*	**116 - Influence of shear deformability and axial/rotational inertia in...** *Stefano Lenci, Giuseppe Rega*	**231 - Suppression of structural vibrations using dynamic absorber** *Hasan Omur Ozer, Nurkan Yagiz, Yuksel Hacioglu*	**233 - FDD modal identification from earthquake response data with evaluation of...** *Fabio Pioldi, Jonathan Salvi, Egidio Rizzi*
14:40	**362 - Structural model updating based on measured response** *Samson Cooper, Dario DiMaio, Arnlado DelliCarri*	**205 - Multi-mode solutions in a periodic array of coupled nonlinear pendulums under...** *Diala Bitar, Najib Kacem, Noureddine Bouhaddi*	**351 - Seisimc analysis on multi-level supported pressure retaining components in npps...** *Gangsig Shin, Jinseong Kim*	**288 - Assessment of damping properties of large 2-stroke marine diesel engines** *Thomas Secall Wimmel, Dominic Müller, Jürg Meier*
15:00	**265 - Stochastic model for thermorheologically simple materials using fractional...** *William Pinto Hernandez, Daniel Alves Castello, Flavia Borges, Ney Roitman, Carlos Magluta*	**225 - A parametric study of the non-linear response of plane frame structures under...** *Luis Fernando Paullo Munoz, Paulo Gonçalves, Ricardo Silveira, Andréa*	**361 - Adaptive inertial shock-absorber for vibration damping** *Rami Faraj, Jan Holnicki-Szulc*	**303 - Dynamic tests and design of a vibration-based shm system for prompt...** *Danilo Gargaro, Carlo Rainieri, Giovanni Fabbrocino*
15:20	**Coffee break + Poster session 2:**			
	299	315	317	349

Wednesday, September 9th, Afternoon (Cont.)

	Kosovel Hall - Session 33	Room E1 - Session 34	Room E2 - Session 35	Room E3 - Session 36
	MS08: Influencing Vibrations by Dissipative Effects Chair: Professor Utz von Wagner, Professor Alexander Fidlin	**MS01: Non-linear Dynamics and Dynamic Stability** Chair: Professor Jiří Náprstek	**MS06: Vibration of Solids and Structures Under Moving Loads: Modelling and Analysis** Chair: Professor Piotr Koziol, Professor Zuzana Dimitrovová	**MS18: Full Field Measurements for Advanced Structural Dynamics** Chair: Ass. Professor Alessandro Zanarini
15:50	**92 - Preliminary study investigating the capability of Eulerian- and . . .** *Philipp Wahl, Sebastian Ihrle, Pascal Ziegler, Peter Eberhard*	**272 - Numerical and experimental investigation of an underplatform damper test rig** *Luca Pesaresi, Christoph W. Schwingshackl, Loic Salles, Robert Elliott, Adrian Jones, J.S. Green*	**72 -Multipoint contact model for dynamic interaction analysis of high-speed train and. . .** *Makoto Tanabe, Masamichi Sogabe, Hajime Wakui, Yasuko Tanabe*	**191 - Comparative studies on Full Field FRFs estimation from competing optical instruments** *Alessandro Zanarini*
16:10	**100 - Numerical and experimental investigation of the effect of a fluid pipe on systems. . .** *Georg Jehle, Alexander Fidlin*	**293 - A Rotating Pendulum with Irrational Nonlinearity** *Ning Han, Qingjie Cao*	**126 - An ABAQUS numerical method to predict ground vibrations induced. . .** *Yanmei Cao, Fuxing Wang, Ying Wang*	**251 - Determining subpixel full-field displacements from videos by using optical flow** *Jaka Javh, Janko Slavič, Miha Boltežar*
16:30	**107 - On the Influence of Damping in Brake Vibrations** *Nils Graebner, Holger Goedecker, von Wagner Utz*	**308 - Discontinuity induced bifurcations in higher dimension Filippov systems** *B Santhosh, C Padmanabhan, S Narayanan*	**137 - Energy harvesting from moving loads on a beam with elastic foundation** *Maryam Ghandchi Tehrani, Mohammed Hussein*	**192 - Accurate FRF estimation of derivative quantities from different full field measuring technologies** *Alessandro Zanarini*
16:50	**77 - Excitation Techniques for the Sound Analysis of Electric Guitars** *Pascal Bestle, Michael Hanss, Peter Eberhard*	**97 - Interaction of frictional and regenerative mechanism of chatter vibrations** *Rafal Rusinek, Marian Wiercigroch*	**273 - Analytical modelling of railroad dynamics** *Piotr Koziol*	**196 - Model updating from full field optical experimental datasets** *Alessandro Zanarini*
17:20			**332 - Uniformly moving load on a beam supported by a foundation with finite depth** *Zuzana Dimitrovová*	
19:30	**Conference dinner**			

Thursday, September 10^{th}, Morning

8:30	**Keynote:**z Professor Marian Wiercigroch			
	Kosovel Hall - Session 37	Room E1 - Session 38	Room E2 - Session 39	Room E3 - Session 40
	MS08: Influencing Vibrations by Dissipative Effects Chair: Professor Utz von Wagner, Professor Alexander Fidlin	**MS10: Inverse Problems and Uncertainty Quantification** Chair: Professor Daniel A. Castello, Professor Thiago Gamboa Ritto	**MS19: Non-smooth Dynamical Systems** Chair: Professor Marian Wiercigroch, Professor Qingjie Cao, Dr. Joseph Paez Chavez	**MS03: Vibration Problems in the Solids Systems With...** Chair: Ass. Professor Alexey A. Kireenkov
9:15	**208 - On the effect of the distributed friction in the arc spring on the dynamic...** *Alexander Fidlin, Phillip Mall*	**74 - Identification of uncertain boundary condition of a beam model using the...** *Thiago Ritto, Rubens Sampaio, Romulo Aguiar*	**248 - Hidden dynamics of dry-friction oscillators** *Mike Jeffrey*	**271 - On Vibrational Smoothing of Dry Friction and its Application to Revolute Joints** *Simon Kapelke, Wolfgang Seemann*
9:35	**279 - A Mechanical Model for the Dynamical Contact of Elastic Rough Bodies with...** *Frank Schulte, Jan Neuhaus, Walter Sextro*	**125 - Robust optimization of horizontal drillstring rate of penetration through...** *Americo Cunha Jr, Christian Soize, Rubens Sampaio*	**259 - Modelling the non-smooth dynamics of windscreen wipers** *Giovanni Lancioni, Stefano Lenci, Ugo Galvanetto, Giammichele Cocchi*	**289 - Identification strategies for friction laws: a numerical study** *Andrew McKay, Jim Woodhouse, Thibaut Putelat*
9:55	**301 - Synchronization via discontinuous coupling** *Piotr Brzeski, Ekaterina Pavlovskaia, Tomasz Kapitaniak, Przemyslaw Perlikowski*	**146 - Stability of Transverse vibrations of a rotating uniform wind turbine blade...** *S. Mohsen Forghani, Tiago G. Ritto*	**292 - The stick-slip chaotic motions of an archetype self-excited SD oscillator...** *Zhixin Li, Qingjie Cao*	**298 - Influence of contact characteristics on the dynamic behavior of rubbing structures** *M.-A. Douville, B. Faverjon, G. Jacquet-Richardet*
10:15	**Coffee break**			

Thursday, September 10^{th}, Morning (Cont.)

	Kosovel Hall - Session 41	Room E1 - Session 42	Room E2 - Session 43	Room E3 - Session 44
	TP01: Mathematical Modelling Chair: Jerzy Warminski	**MS10: Inverse Problems and Uncertainty Quantification** Chair: Professor Daniel A. Castello, Professor Thiago Gamboa Ritto	**MS19: Non-smooth Dynamical Systems** Chair: Professor Marian Wiercigroch, Professor Qingjie Cao, Dr. Joseph Paez Chavez	**MS03: Vibration Problems in the Solids Systems With...** Chair: Ass. Professor Alexey A. Kireenkov
10:45	**89 - Energy harvesting from transverse galloping using a flexible crank-rod** *Felix Sorribes-Palmer, Angel Sanz-Andres, Gustavo Alonso*	**194 - Partial eigenstructure assignment in vibrating systems through homotopy optimization** *Roberto Belotti, Ilaria Palomba, Dario Richiedei, Alberto Trevisani*	**300 - Multiple Buckling and High Co-dimension Analysis of a Novel Smooth...** *Qingjie Cao, Yanwei Han, Marian Wiercigroch*	**335 - On the Dynamics of the Symmetrical Solids on a Vibration Rubbed...** *Alexey Kireenkov*
11:05	**109 -Modelling of Heavy Vehicle Transmission Synchronizer using...** *M. Irfan, V. Berbyuk, H. Johansson*	**214 - Comparison between multi-objective genetic algorithm and Bayesian...** *A. Rezende, N. Tyminski, H. de Castro*		**344 - Falling Motion of a Circular Cylinder Interacting Dynamically with a...** *Sergei Sokolov*
11:25	**147 - Mathematical modeling of the mechanical system of the vibrating table...** *K. Bissembayev, Z. Iskakov*	**216 - Damage Identification under Modelling Uncertainties** *Daniel Castello, Jari Kaipio*		**348 - Experimental Investigation on squeal-noise of disk-brakes for...** *M. C. De Simone, D. Guida*
11:45	**258 - Response Statistics and Bifurcation Analysis in Stochastic Vibro-Impact System** *Pankaj Kumar, S Narayanan, Sayan Gupta*	**221 - Deterioration of tensile strength and stiffness of elastic structural...** *Korneel Van Massenhove, Dirk Vandepitte, Stijn Debruyne*		
12:05	**307 - Force field separation of vibrofluidized granular materials, mathematical...** *K. Ivanov, I. Demidov, L. Vaisberg, A. Mezenin, S. Dmitriev, A. Murachev*			
12:25	**215 - Modelling and automatic control for a scan eagle simulator** *J. C. R. Medina, D. Hernandez, F. C. Pinto, W.Hernandez, D. Castello, D. Godoy*			
12:50	**Closing of the conference**			

ABSTRACTS

Invited Speakers

EMERGING JOINT TIME-FREQUENCY ANALYSIS TECHNIQUES FOR VIBRATIONS APPLICATIONS

Pol D. Spanos
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Traditional Fourier analysis has been an important tool in scientific and engineering applications for many years. However, it does not readily capture non-stationary and local features, which are inherently present in many dynamic phenomena. The lecture will focus on modern time-frequency analysis techniques for capturing localized effects and evolutionary frequency content by using wavelets and other related techniques. These techniques can be construe as "mathematical microscopes" and allow representation of complex problems with gradually increasing degree of detail and resolution. These techniques will be presented with a historical perspective and in context with several engineering applications; they will be used for analyzing both recorded ground accelerograms and linear/nonlinear seismic responses of benchmark structures. However, they are applicable as well to a plethora of other themes. Related general topics and options for non-local analysis in vibration problems via non-integer order differential calculus will be also discussed.

NOTES:

IMAGE ANALYSIS FOR FULL-FIELD VIBRATION AND STRAIN MEASUREMENTS

John E. Mottershead[1], **Weizhuo Wang**[2]
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Full-field measurement of vibration and strain data, using techniques such as digital image correlation, automated photoelasticity, electronic speckle pattern interferometry, thermoelastic stress analysis and scanning laser vibrometry are now widely used in university and industrial research laboratories. Subsequent processing of this data for the purposes of determining frequency response functions, finite element model updating, damage detection or the estimation of residual life, requires efficient data storage with noise rejection and minimal loss of information. Techniques from the image processing community, based on moment descriptors, provide the scientific basis of the work. For example, moment descriptors based on Zernike polynomials may be used for the decomposition of plane circular images, whereas Legendre polynomials provide kernels for rectangular images. Engineering structures, however, often have complicated three-dimensional shapes with irregular boundaries. In that case the classical basis functions (e.g. Zernike and Legendre polynomials) are no longer suitable and it becomes necessary to design structure-specific moment descriptors. Adaptive moment descriptors (AGMDs) are based on monomials, subsequently processed using Gram-Schmidt ortho-normalisation to make them suitable for engineering structures of arbitrary shape. In the case of three-dimensional structures, surface parameterization (typically conformal mapping) may be applied to produce an equivalent plane surface, allowing the application of AGMDs. Applications include full-field modal analysis of a car-bonnet liner, finite element model updating of composite structures used in space probes and uncertainty analysis of assembled car wheels.

NOTES:

ELASTIC METAMATERIALS AND WAVE STEERING

Gengkai Hu
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Elastic metamaterials are composites with special properties not easily found in nature materials, such as negative effective bulk modulus, mass density and shear modulus. They may have a great potential in controlling low-frequency elastic waves. In this talk, we will explain how to realize these elastic metamaterials by exploring the microstructure of materials. The principle will be first illustrated by simple mass-spring models, and the negative effective material parameters for a composite with coated inclusion are then related to monopole, dipole and quadruple resonances of the coated inclusion. A more compact design for an elastic metamaterial with simultaneous negative effective bulk modulus and mass density is also discussed with help of chiral lattice with resonant inclusion, the negative refraction of this type of metamaterial is predicted and confirmed by experiment. Three possible applications are explained as examples for the use of these materials, the first one is the design of metamaterials for low frequency sound isolation, the second is a metacomposite beam for low-frequency vibration alleviation and the last one is steering elastic wave based on transformation technique.

NOTES:

GRAZING INDUCED BIFURCATIONS: INNOCENT OR DANGEROUS?

Marian Wiercigroch
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In this lecture I will examine nature of subtle phenomenon such grazing bifurcations occurring in non-smooth systems. I will start with linear oscillators undergoing impacts with secondary elastic supports, which have been studied experimentally and analytically for near-grazing conditions [1]. We discovered a narrow band of chaos close to the grazing condition and this phenomenon was observed experimentally for a range of system parameters. Through stability analysis, we argue that this abrupt onset to chaos is caused by a dangerous bifurcation in which two unstable period-3 orbits, created at "invisible" grazing collide [2].
The experimentally observed bifurcations are explained theoretically using mapping solutions between locally smooth subspaces. Smooth as well as non-smooth bifurcations are observed, and the resulting bifurcations are often as an interplay between them. In order to understand the observed bifurcation scenarios, a global analysis has been undertaken to investigate the influence of stable and unstable orbits which are born in distant bifurcations but become important at the near-grazing conditions [3]. A good degree of correspondence between the experiment and theory fully justifies the adopted modelling approach.
Similar phenomena were observed for a rotor system with bearing clearances, which was analysed numerically [4] and experimentally [5]. To gain further insight into the system dynamics we have used a path following method to unveil complex bifurcation structures often featuring dangerous co-existing attractors.

REFERENCES:

[1] Ing, J., Pavlovskaia, E.E., Wiercigroch, M. and Banerjee, S. 2008 Philosophical Transactions of the Royal Society - Part A 366, 679-704. Experimental study of impact oscillator with one sided elastic constraint.

[2] Banerjee, S., Ing, J., Pavlovskaia, E., Wiercigroch, M. and Reddy, R. 2009 Physical Review E 79, 037201. Invisible grazing and dangerous bifurcations in impacting systems.

[3] Ing, J., Pavlovskaia, E., Wiercigroch, M. and Banerjee, S. 2010 International Journal of Bifurcation and Chaos 20(11), 3801-3817. Complex dynamics of bilinear oscillator close to grazing.

[4] Páez Chávez, J. and Wiercigroch, M. 2013 Communications in Nonlinear Science and Numerical Simulation 18, 2571-2580. Bifurcation analysis of periodic orbits of a non-smooth Jeffcott rotor model.

[5] Páez Chávez, J., Vaziri Hamaneh, V. and Wiercigroch, M. 2015 Journal of Sound and Vibration 334, 86-97. Modelling and experimental verification of an asymmetric Jeffcott rotor with radial clearance.

NOTES:

Mathematical Modelling (TP01)

89 - ENERGY HARVESTING FROM TRANSVERSE GALLOPING USING A FLEXIBLE CRANK-ROD

Felix Sorribes-Palmer, Angel Sanz-Andres, Gustavo Alonso
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In this paper a coupled fluid-structure model of a flexible crank-rod connected to an electrical generator is analyzed and compared with other ways to extract energy from transverse galloping. One of the problems of energy harvesting is the conversion of linear oscillatory motion to a type of motion more compatible with an energy conversion device. One possibility is to transform the linear motion into a rotational one. The model considers a two degree-of-freedom galloping oscillator where fluid forces are described resorting to a quasi-steady condition by using a quasi-steady aerodynamics model. Transverse galloping is a dynamic instability in which IDR/UPM (Instituto de Microgravedad "Ignacio Da Riva", Universidad Politécnica de Madrid) has a large interest. This instability can be used for energy extraction. One possible application could be as a damping system for pressure waves in high speed railway tunnels. The wind speed induced by a pressure waves generated by a high speed train during its transit through a railway tunnel can surpass 5 m/s, and the train wake can induce speeds over 25 m/s. Due to the nature of the excitation and with a proper location for the device in the tunnel, these can be an optimal emplacement for devices based on aeroelastic instabilities such as transverse galloping.

109 - MODELLING OF HEAVY VEHICLE TRANSMISSION SYNCHRONIZER USING CONSTRAINED LAGRANGIAN FORMALISM

Muhammad Irfan, Viktor Berbyuk, Håkan Johansson
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The demands for decreasing vehicle emissions, particularly for heavy vehicles, have led to higher demands on drive train components; by lower engine speed the gearbox must sustain higher torque, more torque vibrations and more frequent and faster shifts to keep engine running as close as possible to optimal speed. In order to design new synchronizers meeting these demands, simulation tools to study gearbox synchronizer performance are needed. The gear synchronizer mechanism in its traditional design has the purpose that during released clutch, a new gearwheel is engaged by reducing the speed difference between outgoing shaft and gearwheel to be engaged using a sleeve. This involves frictional contact between conical surfaces, and a design such that the sleeve is not engaged until the speed difference between sleeve and gearwheel is sufficiently small. In this contribution, a mechanical system with 5 degrees of freedom modeling a generic synchronizer consisting of sleeve, blocker ring and gearwheel is considered. Due to the design of the different components and their interactions the synchronizing process is in the literature described in terms of different steps or phases. To study the whole process in a unified manner, Constrained Lagrangian Formalism turns out to be a suitable method in which the interactions between components (sleeve, blocker ring and gearwheel) are described by unilateral or/and bilateral constraints imposed on generalized coordinates of the system during different phases which results in a system of differential-algebraic equations. Mathematical and computational models are developed to study the synchronizer mechanism performance with respect to principal structural parameters relevant to heavy trucks. The resulting system is solved numerically using the Adams-Bashforth predictor corrector method. This model is used to find the feasible modes of synchronizer function considering the effect of varying principal structural parameters (e.g. cone angle, chamfer angle, oil properties and coefficient of dry friction) and imposed loads (e.g. rate of applied sleeve force).

147 - MATHEMATICAL MODELING OF THE MECHANICAL SYSTEM OF THE VIBRATING TABLE WITH ORTHOGONAL MOVEMENT AND HYDRAULIC TURBINE WITH INCLINED BLADES

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Functioning of many important and crucial vibrating machines and mechanisms is based on the use of different energy sources. If the energy source has an ideal excitation, i.e. it has an unlimited power; the inverse effect of oscillatory system upon excitation source of oscillations is neglected. However, on practice, there are frequent situations, when power consumed of the oscillating load is comparable on value with power of exciter oscillations. In such cases, using of the "ideal" mathematical models can lead to gross errors in dynamics description both the oscillatory system, so and excitation source of oscillations. The present work is devoted to the research of interaction of link mechanism of vibrating table with orthogonal movement and stimulating element of its oscillation with hydraulic turbine without dams with inclined blades and a limited power. Relatedness of processes of the link mechanism with orthogonal movement and energy source, i.e. hydraulic turbine leads to the qualitatively new effects in their dynamics, which cannot be detected by investigating the problem in the formulation of ideal excitation. The special attention is paid to the research of influence of parameters of the link mechanism with orthogonal movement to movement modes of the hydraulic turbine. It is established that a equation of system movement is significantly non-linear and has a big parameter of non-linearity under the first derivative, the angular speed of the hydraulic turbine (driving member) is oscillated about its average value, the coefficient of movement non-uniformity of the hydraulic turbine (driving member) depends on parameters of link mechanism and hydraulic turbine. The patterns of change of angular speed amplitude of the driving member were determined depending on parameters of the link mechanism with orthogonal movement and hydraulic turbine. The results of research can be successfully used by projecting of the vibrating table on the basis of the link mechanism with orthogonal movement with non-ideal energy source, i.e. by the hydraulic turbine without dams.

215 - MODELLING AND AUTOMATIC CONTROL FOR A SCAN EAGLE SIMULATOR

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Unmanned aircrafts are very useful nowdays because of their great performance and the ability to perform different kinds of tasks without the direct presence of humans. The Scan Eagle is one of the most versatile aircrafts available on the market, therefore it is necessary to train pilots to accomplish with the different missions assigned, due to this, a simulator was developed to train those pilots to fly these kind of aircrafts. The simulator allows the pilots to be trained in different situation very close to the reality of the flight. To achieve a real flight description, a dynamic model of the Scan Eagle and automatic control was developed and will be presented in this document. The Scan eagle has a special configuration, that doesn't use a tail to achieve its stability, instead it uses two elevons placed on the wings to regulate the total lift force of the plane, also has two winglets on the outside tip of the wings on vertical position with elevons that make a variation of the thrust allowing the rotation of the aircraft along its Z axis. This paper will first describe the development of the equations of motion, establishing different frames to describe the movements, as a second step the model of forces and torques is developed, finally the deduction of the aerodynamic forces and coefficients using specialized software for airfoil design and analysis as XFLR5 is discussed. Having the complete dynamic model an automatic control is developed that allows the system to be on a stable state over the whole flight. The automatic control will allow the control tracking of the of the controlled states to make smooth filghts and follow predetermined trajectories. Some test were made, implementing the model on Matlab-Simulink, to verify the correct behavior of the model and controller.

258 - RESPONSE STATISTICS AND BIFURCATION ANALYSIS IN STOCHASTIC VIBRO-IMPACT SYSTEM

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This paper investigates the stationary response probability density function (pdf), bifurcation, and stability analysis of Duffing Van der Pol (DVDP) oscillator with impact under additive and multiplicative Gaussian white noise excitations. The original discontinuous vibro impact system is mapped on to a continuous phase plane by the Zhuravlev non-smooth coordinate transformation. The mod, and Dirac-delta functions which are discontinuous and which appear in the resultant equation of motion are approximated using suitable arc tangent and Gaussian distribution functions respectively. The Fokker-Planck (FP) equation corresponding to the transformed and approximate equation of motion of the nonlinear oscillator is solved using the finite element(FE) method. Damping coefficient and coefficient of restitution are considered as the bifurcation (control) parameters. The FE solutions are validated with Monte Carlo simulation (MCS) results with good agreement between the two. Stochastic bifurcation and stability analyses are carried out in terms of the largest Lyapunov exponent (LLE) which is computed using the Wedig algorithm and the Nordmark construction of the local Poincare' map. From the results it is observed that P-bifurcation and D-bifurcation need not occur in same parameter regimes.

307 - FORCE FIELD SEPARATION OF VIBROFLUIDIZED GRANULAR MATERIALS, MATHEMATICAL MODEL AND PRACTICAL APPLICATIONS

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Water is a resource of rapidly growing importance. Rational use of water in minerals processing presents both environmental and economic benefits. Water is often used as the disperse media for granular materials. In some cases, the dispergation effect could be obtained by using vibration instead of watering. Thus, minerals are being treated in the so-called state of vibrofluidization.
This work presents a technology for force field (electrostatic and electromagnetic) separation of granular materials in vibrofluidized layers and also a mathematical model for the process. The model is developed in assumption of low content of the extracted minerals thuswise allowing considering separately the dynamics of the vibrofluidized layer and individual particles of the extracted minerals within the layer.

Experimental Techniques (TP02)

114 - VIBRATION OF AEROSOLS IN THE TUBES

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In the present work, longitudinal oscillations of a small-dispersed aerosol in tubes are considered. Experimental investigations oscillations of an aerosol were carried out for different length of tubes with various geometry on the end in the shock-wave and the shock-free modes in the vicinity of the resonance frequencies equal to the first eigenfrequency and the frequency that is twice lower than the first eigenfrequency (subharmonic resonance). Di-ethyl-hexyl-sebacate is used as the working fluid to generate aerosol. Numerical concentration of aerosol droplets for all experiments monotonously decreases with time. In the case of a closed tube, this process is defined by the coagulation of aerosol and deposition of droplets on the tube walls. In a half-open tube, the discharge of aerosol to the environment is observed in addition to the coagulation of aerosol and deposition of droplets on the tube walls. The dependence of the time scale of the coagulation and deposition of aerosol and the time scale of the clearing of aerosol on the excitation frequency likewise exhibits a nonmonotonic pattern. With increase of intensity of the oscillations, the caused increase of excitation amplitude, and decrease of the tube length these times decreases. Nonlinear dependence of the time of coagulation of droplets is established at nonlinear oscillations of an aerosol in a tube from initial number concentration of an aerosol. It is established, that presence of a flange slows down process of the clearing of aerosol. Reduction of internal diameter of a flange results in increase in the time scale of the clearing of aerosol. In so doing, the time scale of the clearing of aerosol in the case of a half-open tube is reduced by a factor of 1.5 and more compared to the time scale of the coagulation and deposition of aerosol in a closed tube. The time scale of the coagulation and deposition of aerosol in the closed tube by 2-4 times and time scale of the clearing of aerosol in a half-open tube by 6-12 times lower than at natural depositing.

136 - INTRODUCING SHAPER-BASED FILTERS FOR THE IMPROVEMENT OF THE LOAD CELL RESPONSE IN DYNAMIC WEIGHING SYSTEMS

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A novel model-based signal filtering technique is proposed in this work to compute accurately and rapidly the value of the measurand by taking advantage of the idea of the Input Shaping (IS), which has been developed for the optimal planning of command position references in flexible systems. The typical IS application is the manoeuvring of overhead cranes. The litera-ture on IS has shown that less residual vibrations of crane suspended loads are obtained whenever IS is adopted to synthesize the motion reference. Following such a theory, this paper proposes an effective technique for performing high-speed filtering of load cell measurements, capable of reducing the time the filtered signal requires to settle down (i.e. to get and remain within a specified standstill range). The digital filters obtained, referred to as Shaper-Based Filters (SBF), are based on the convolution of the load cell signal with a sequence of a few impulses (typically from 2 to 5). The amplitudes and the instants of application of such impulses are computed through the system dynamic model by imposing the level of admissible residual oscillation in the steady-state filtered signal and by requiring the desired sensitivity of such an outcome. The inclusion of robustness specifications also allows effectively tackling uncertainty and variability on the load cell dynamic model parameters, i.e. frequency and damping. The effectiveness of the SBFs is proved experimentally by applying them to industrial load cells and by comparing their performances with those provided by other filters most widely employed both in industries and in literature.

138 - INFLUENCES OF EXTERNAL VIBRATION ON PRECISION MACHINES - THEORETICAL AND EXPERIMENTAL INVESTIGATIONS

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The investigations in the paper concern optimal setup of high precision machines, working in nanometer dimensions. Current and future high technologies demand increasing ranges of motion, extreme precision and high positioning velocities. The objective is the optimization of the complete system in terms of dynamical behavior, stability and robustness, especially in the case of external vibrations. Methods of multi-body system dynamics may be used for parameter estimation and for the analysis of the dynamics of the machine and their modules, respectively. To guarantee optimal working conditions, environmental influences (e.g. vibrations, airflow, temperature variations) acting on the machines need to be minimized. Besides a systematic analysis of the problems of active and passive vibration isolation, the occurring vibrations, induced from the environment to the machine, are in the focus of investigations. The results of measurements (machines at different locations) of the vibration velocity are introduced for selected measuring points from the ground to the top of the machine. The identified amplitudes of the vibration velocity at the laboratory floor are mostly larger than permitted by the vibration criteria for nanotechnology facilities, which were defined in NIST A from the U.S. National Institute of Standards and Technology. The design of most devices to mount a machine (machine feet, vibration isolators, dampers) focuses on the vertical-direction and neglects the effects of vibrations in the horizontal plane, while ponderable vibrations in this plane are traceable. To fulfill the requirements for high dynamic positioning and measuring machines, the conditions at the place of installation need to be considered.

165 - AXIAL BEHAVIOR OF SELF-COMPACTING, SELF-STRESSING AND HIGH-STRENGTH CONCRETE FILLED STEEL TUBE

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The concrete filled steel tube (CFST) components are gaining increasing applications in practical engineering. However, the difficulties in tamping after pouring, and the decrease of straining force caused by concrete creep and shrinkage are needed to be solved. The proposed composite structure of self-compacting, self-stressing and high strength CFST is aimed at this problem. This paper attempts to explore the mechanical performance of self-stressing CFST short columns under axial compression. The expanding agent was added to form the self-compacting, self-stressing and high strength CFST columns. The influence of the self-stress on the axial behavior of CFST short columns was addressed. The main variables considered were the self-stress value, the strength of concrete as well as the thickness of steel tube. The results showed that the ultimate strengths of all the CFST columns were invariably improved due to the contribution of self-stress, high strength of concrete and thick steel tube. The ductility of self-compacting, self-stressing and high strength CFST short columns can also be enhanced by high confining factor. Subsequently, predictive equations for ultimate bearing capacity of self-compacting, self-stressing and high strength CFST short columns were developed, which can serve as a reference for further analytical study of CFST and provide a foundation for real practical applications.

199 - EFFECTS OF CENTER DISTANCE AND MICROGEOMETRY ON THE DYNAMIC BEHAVIOUR OF A SPUR GEAR PAIR

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Quietness and reliability, together with efficiency and lightweight design, are key requirements to compete in current mechanical industry. Within the latter, gearboxes play an important role as the usual choice to transmit mechanical power with high power density, especially when using cylindrical involute gears. Noise and

vibration performance are strongly dominated by tooth microgeometry modifications. Typical modifications are applied along the profile and at the lead of the teeth. Profile modifications mainly compensate for tooth deflections, while lead modifications mainly compensate for angular misalignments. Both modification types yield optimal performance at a given operating condition (e.g. nominal transmitted torque under ideal alignment), minimizing the meshing excitation. One key operating condition for the gear pair is represented by the instantaneous center distance between the gears. Center distance variations affect mainly the pressure angle for the transmitted contact force, the total contact ratio and the active tooth height. Furthermore after a change in center distance, the contacting surfaces on the tooth flanks shift with respect to each other, which yields a mismatch with respect to the theoretical start for the tooth profile modifications. A precision gear test rig, where operating conditions can be varied and tightly controlled, is used in this paper to evaluate the effects of center distance variations on the dynamic behaviour of a spur pair of identical spur gears. The dynamic behaviour is analysed by measuring the Static Transmission Error (STE). Spectral analysis of the STE provides an indication of the internal excitation generated by gear meshing.

281 - A BENCHMARK FOR TIP TIMING MEASUREMENTS OF FORCED RESPONSE IN ROTATING BLADED DISKS

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The Blade Tip Timing is a well known noncontact measurement technique for the identification of the dynamic properties of rotating bladed disks. Even if it is an industry-standard technique its reliability has still to be proved for the different operation conditions by comparison with other well established measurement techniques. Typically a strain gauges system in conjunction with radio telemetry is used as reference. This paper aims at evaluating the accuracy of a last generation tip-timing system on two different bladed dummy disks characterized by different geometrical, structural and dynamical properties. The first dummy disk has the simple geometry of a flat plate and it is characterized by blade bending vibration modes along the axial direction well separated by the other modes. The second dummy disk was designed to simulate a dynamic behavior closer to a real turbine disk where the blades are connected each other at the tips by an outer ring as in the case of shrouded blades. The so called beam shutter method was adopted for the tip timing system. Due to the presence of shrouds a particularly set up of the probes was chosen in order to avoid that the probes look radially inward at the blade tips as in the most common configurations. The probes are optical laser sensors pointing at leading and trailing edges locations where the blade experiences the greatest magnitude of displacement. The presence or absence of the blades during the rotation is detected thanks to a tape reflecting the laser beam toward the sending-receiving sensor. Both disks were tested into a spinning rig where a fixed number of permanent magnets, equally spaced around the casing, excite a synchronous resonance vibration with respect to the rotor speed. The amplitude and frequency values obtained by the tip-timing system are compared with the ones obtained by the strain gauge measurements. The paper shows that the agreement of the measured frequencies by the two techniques is satisfactory while the comparison in terms of vibration amplitude is more challenging. An analysis of the measurement accuracy for the different modes amplitude is presented and discussed.

283 - EXPERIMENTAL RESEARCH OF THE KINEMATICS AND CONTACT CONDITIONS OF THE BRUSH AND SLIP-RING

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To increase the reliability and to extend the lifetime of alternators the dynamics of the brush and the slip-ring are essential. The dynamics of the brush and the slip-ring is highly dependent on the contact situations between the slip-ring with the brush, the brush with the brush-holder, and the brush with the spring. For validated numerical and experimental modeling it is required to have good experimental insight into the dynamics and contact situations of the researched system. For this reason, the electrical, thermal, and kinematical details of the contact between the slip-rings with the brush were experimentally researched. A special test bench, where

individual parameters (e.g.: rotational speed, temperature, electrical current) can be researched with regards to the kinematics and contact conditions. Besides the newly introduced experimental approach, the results of this study are also the experimentally identified influences of the rotational speed and electrical current on the dynamics, contact conditions and consequently to wear. The presented experimental approach can also be used for model validation and updating.

305 - INVESTIGATING THE APPLICATION OF GUIDED WAVE PROPAGATION FOR ICE DETECTION ON COMPOSITE MATERIALS

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Wind turbines operating in cold regions face icing problems. At the same time these regions are one of the best places to install the wind turbines. To minimize this problem and optimize the de-icing system it is very important to have an efficient ice detection system. Application of guided wave propagation has been previously considered in aircraft industries. To study this application for wind turbines, guided wave propagation should be investigated in composite materials. In the current work, first the guided wave propagation in multi-layered anisotropic materials is mathematically modelled and dispersion curves were obtained. Moreover the composite plate was homogenized to an anisotropic plate in order to simplify the calculations. Comparison of dispersion curves shows changes in group velocity when a second layer as ice is added on top of the first layer. Next, a finite element model was made to observe the effects of ice accretion on top of a composite plate. An experimental set-up was also developed at a cold climate lab on a composite test object used in wind turbine industry. The guided wave propagation was studied experimentally to see the effect of temperature and ice on the material and measurement data was obtained to validate the computational model. Both numerical and experimental results show that a patch of ice on top of a composite plate reflects the propagated guided waves with an amplitude that raises by increasing the thickness of the ice layer. Furthermore, ice accumulation affects the group velocity of the guided waves and it proves that the use of guided waves is a promising method to detect ice on turbine blades.

Computational Methods (TP03)

106 - APPLICATION OF THE WAVE BASED METHOD TO STEADY-STATE VIBRATIONS OF THICK PLATES

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The numerical simulation of low frequency harmonic responses of plates is usually carried out with deterministic methods, especially with the Finite Element Method (FEM), while for high frequencies statistical methods are used like the Statistical Energy Analysis (SEA). In the so-called mid-frequency region, the computational load of FEM is generally too high for practical simulations, while the assumptions of SEA are not meet. The applicability of a deterministic method called Wave Based Method (WBM) can be extended to the mid-frequency range due to a higher computational efficiency. The WBM is an indirect Trefftz method and uses exact solutions of the governing equations to approximate the unknown field variables. The method has already been developed for thin plates using the Kirchhoff plate theory, which neglects the shear deformation and rotatory inertia. A first order shear deformation theory, the Mindlin plate theory, accounts for the shear deformation and rotatory inertia and is used to extend the applicability of the WBM to thick plates. A numerical example is shown for a non-convex plate domain under point force excitation, which requires the decomposition into convex subdomains to ensure convergence. The convergence rate and computational efficiency of the WBM is compared to the FEM.

183 - THE HELMHOLTZ EQUATIONS BY THE NULL-FIELD AND THE INTERIOR FIELD METHODS ON CIRCULAR DOMAINS

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The null-field method (NFM) is applied to the Helmholtz equation $\Delta u + k^2 u = 0$, and the explicit algebraic equations are derived. The field nodes may be pushed to the domain boundary, to give the interior field method (NFM). There must exist the unique solutions when $k^2 \neq \lambda$, where λ is the eigenvalue of $\Delta u + \lambda u = 0$. However, the NFM and the IFM fail to solve the the Helmholtz equation when k^2 being the spurious eigenvalues. On the other hand, for eigenvalue problems the NFM and the IFM will produce those extra-spurious eigenvalues, which need to identify from numerical solutions and to recover the real approximate eigenvalues. Although a great deal of efforts have been paid to this kind of identification by many researchers, the NFM and the IFM are still inefficient in real application, because the spurious eigenvalues are so many, and because the computational work of identification is exhausted, which is unnecessary if other methods are chosen. New modification of the IFM is explored in this paper, to bypass all spurious eigenvalues, but it falls into the Trefftz methods. Hence, the collocation Trefftz methods are strongly recommended for both Helmholtz and eigenvalue problems.

323 - CONTACT SITUATIONS IN RIGID BODY DYNAMICS

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Rigid body dynamics highly depends on the contact situations. The goal of this research is to simulate the dynamics of a system of rigid bodies with kinematic joints and contact situations, which correspond to the imperfections that can be observed at experiment. The basic theory of dynamics describes kinematic joints and impacts as ideal, but in reality, there are always imperfections present, such as clearance of the kinematic joints, surface roughness, friction, lubricated contact and surface wear. In this approach, the numerical simulation of dynamics of multibody system is based on the theory of Absolute Nodal Coordinate Formulation (ANCF) and event-driven algorithm for contact detection, while numerical integration is done with Runge-Kutta method. Real conditions like clearance and dry friction are included in a revolute joint with a goal to evaluate the effect on the dynamics of multibody system. The approach is presented with a test case of a subassembly in mechanism of a circuit breaker. A custom designed measurement rig was built to evaluate the applied force on a subassembly component and to evaluate contact parameters. The presented experimental and numerical approach showed as appropriate for research of rigid body dynamics of kinematic joins and contact situations with imperfections.

Structural Dynamics (TP05)

108 - MASING RULE MOTIVATED LOCAL DISCRETE MODELLING OF CONTACT INTERFACES TO PREDICT DYNAMICAL BEHAVIOUR OF JOINTED STRUCTURES

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Assembled structure use various joints to fasten different sub-parts. Due to these joints, assembled structure experience local non-linearity near the regions of the jointed sections. Although the joints are sources of local non-linearity, they do influence the global dynamical properties - like the resonance frequency and damping of the assembled structure. This paper presents an equivalent quasi-linearised contact model with use of local discrete elements at the contact interface. The discrete elements are characterized through the Kelvin-Voigt elements. The normal contact behaviour is formulated based on the modified Greenwood- Williamson surface roughness model. The tangential contact behaviour is formulated based on the Hyperbolic constitutive laws in conjecture with Masing rules for visco-elastic systems. The non-linear contact forces are disintegrated into equivalent contact stiffness and damping, which are explicitly defined based on the modifications of the governing normal and tangential contact constitutive laws. The conventional time domain method or the family of harmonic balance methods are computationally time in-efficient for large systems, with difficulties in obtaining convergent solutions. The proposed new model utilizes local linearisation to retain the advantages of linear systems, while the non-homogeneous description over contact interface accounts for the non-linear behaviour. A double layered beam structure fastened using four bolted joints is used for the validation of the proposed model. A random-force controlled white noise excitation with varying excitation level is used to obtain the FRF-mobility curve and utilized for the comparison with simulation model. A very good match between the experiment and simulation results confirms the robustness of the proposed model, to capture the effects from the bolted joints for moderately non-linear systems.

155 - RISK ASSESSMENT OF SAFETY ANALYSIS OF NPP STRUCTURES DUE TO EARTHQUAKE EVENS

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This paper gives the results of the risk-based safety analysis of the seismic resistance of the NPP (Nuclear Power Plants) in Slovakia. The probabilistic assessment of NPP safety analysis is presented. On the base of the geophysical and seismological monitoring of locality the peak ground acceleration and the uniform hazard spectrum of the acceleration was defined for the return period 10 000 years using the Monte Carlo simulations. There is showed summary of calculation models and calculation methods for the probability analysis of the structural safety considering load, material and model uncertainties. The numerical simulations were realized in the system ANSYS. The results from the reliability analysis of the NPP structures are presented.

157 - DETERMINISTIC AND PROBABILISTIC ANALYSIS OF THE ACCIDENTAL TORSION EFFECT TO SEISMIC RESISTANCE OF MULTI-STOREY BUILDINGS

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This paper presents the results from the deterministic and probabilistic analysis of the accidental torsional effect of reinforced concrete tall buildings due to earthquake even. The core-column structural system was considered with various configuration in plane. The methodology of the seismic analysis of the building structures in Eurocode 8 and JCSS 2000 is discussed. The possibilities of the utilization the LHS method to analyze the extensive and robust tasks in FEM is presented. The influence of the various input parameters (material, geometry, soil, masses,...) is considered. The deterministic and probability analysis of the seismic resistance of the structure was calculated in the ANSYS program.

170 - DESIGN AND OPTIMIZATION OF A COMPACT HIGH-FREQUENCY ELECTROMAGNETIC SHAKER

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Dynamic characterization and resonances prediction of mechanical structures is a crucial issue in industry. Performing experimental modal analysis and harmonic response requires an excitation source able to operate in a wide frequency range, depending on the analyzed structure. In the present paper, the optimization and the design of an electromagnetic shaker is presented. This device has been engineered for a test bench to investigate the vibrational dynamics of centrifugal compressor bladed wheels. A really compact solution is needed since the final test bench provides up to 20 shakers on the circumference hoop, one for each blade, and the excitation frequency ranges from 1 to 10 kHz. Different stinger solutions are proposed and compared in the paper, in order to monitor the stinger effects on the dynamic response of the analyzed structure. The investigated solutions are: a beam stinger (diameter 1 mm), a wire stinger (diameter 0.2 mm), and a ball stinger (diameter 3 mm) which was tested with two different contact solutions. Experimental tests were performed on a shaker prototype to verify the vibrational loads applied by the device and to compare the different stinger solutions.

207 - REDUCED THIN-LAYER ELEMENT MODEL FOR JOINT DAMPING

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Damping properties of assembled structures are largely influenced by frictional damping between joint interfaces. Therefore, these effects must be considered during the modelling process. Applying thin-layer elements (TLEs) with a linear, orthotropic material model on mechanical interfaces to incorporate joint damping has shown good agreement with experimental modal analysis in previous work. In the TLE model, constant hysteretic damping is assumed. The damping and stiffness parameters for the TLEs are experimentally identified on an isolated lap joint. Imprecisions caused by model simplifications and parameter uncertainty are addressed by model updating or uncertainty analysis. This requires multiple evaluations of systems that are equivalent besides their TLE parametrization. In this work, a model reduction technique for the thin-layer element modelling approach is presented which significantly reduces computational cost for the re-calculation of eigenvalues after joint parameters are changed. The reduction is based on an eigensensitivity analysis and results in a single, linear equation for each eigenvalue. The presented approach is applied to a model updating example. Here, the model reduction allows for a larger number of design variables. Therefore, experimental results can be reproduced more accurately.

209 - NUMERICAL AND EXPERIMENTAL INVESTIGATIONS INTO MASS, STIFFNESS AND DAMPING MATRIX UPDATING THROUGH A TWO-STAGE FRAMEWORK

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Finite element model updating techniques are used to update a structural dynamic FE model so as to obtain an accurate representation of a structure in terms of mass, stiffness and damping matrix. Some of the existing updating methods update all the three matrices simultaneously using either complex FRF or modal data. These methods, however, are faced with numerical problems in practical implementation due to large difference in the magnitude of stiffness and mass matrix elements and damping matrix elements. Recently, two novel approaches, one for updating mass and stiffness matrix and the other for updating damping matrix have been developed. These two approaches provide a theoretically consistent formulation for updating mass and stiffness matrix and damping matrix respectively. These two approaches have been independently validated through numerical studies. However, for updating all the three matrices, these two approaches need to be used in a sequential manner in a two-stage framework. Updating in a sequential manner couples the performance of the damping matrix updating in the second stage to mass/stiffness matrix updating in the first stage. Inaccuracies in the updated matrices in first stage may have an adverse impact on the performance of the second stage and this coupling of the performances needs to be investigated. The incompleteness of the reference or measured data and any noise in it also plays a role in making the second stage performance dependent on the first stage. The performance of the two-stage updating framework in the presence of actual experimental data also needs to be assessed. These are the issues, related to mass, stiffness and damping matrix updating through a two-stage framework, which form the subject matter of this paper. The paper undertakes numerical and experimental studies with the objective of analyzing above issues. A numerical study of a fixed-fixed beam structure is first presented followed by an experimental study of an F shape structure. A new method called "hybrid" method to deal with data incompleteness in the context of two-stage updating is suggested. Effect of equivalent updating parameters on performance of two-stage updating is studied. The results of the investigations carried out in this paper would be helpful in proper implementation and application of two stage updating method in practice.

245 - A PARAMETRIC ANALYSIS OF THE NONLINEAR RESPONSE OF STEEL FRAMES UNDER BASE EXCITATION IN FREQUENCY DOMAIN

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The dynamic response of large structures in the main resonance regions is a topic of great importance in the analysis of structures under time varying loads. In complex problems, the determination of the response in the frequency domain, characterized by the resonance curves is, in some cases, indirectly obtained through a series of analyses in time domain, which leads to huge computational effort when analyzing structures with a large number of degrees of freedom. In nonlinear cases, the response in the frequency domain becomes even more cumbersome because of the possibility of multiple solutions for certain forcing frequencies. Those solutions can be stable and unstable, and bifurcations can appear, in particular saddle-node bifurcation at the turning points along the resonance curves. In this work, an incremental technique for direct calculation of the nonlinear dynamic response in frequency domain of nonlinear plane frame systems discretized by the finite element method and subjected to base excitation is proposed. The transformation of discretized equations of motion, in the finite element method context, to the frequency domain is made here through the classical harmonic balance method in conjunction with the Galerkin method. The resulting system of nonlinear equations in terms of the modal amplitudes and forcing frequency is solved by the Newton-Raphson method together with an arc-length procedure to obtain the nonlinear resonance curves. Suitable examples are presented, and the influence of the frame geometric parameters and base motion on the nonlinear resonance curves is investigated.

260 - DIRECT DAMPING IDENTIFICATION METHODS IN FREQUENCY DOMAIN

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Damping combined with mass and stiffness represents dynamic properties of a structure. Standard procedure is to assign proportional damping in physical coordinates which does not reflect true damping distribution. Direct damping methods were developed to improve identification of damping distribution with direct identification of damping from measured signals without transformation to modal coordinates. Four methods for direct damping identification in frequency and one in time domain will be compared on the identified damping from measured responses of real beam and plate with and without added passive damping elements. Measuring mesh density and uniformity of mesh spacing influence on damping identification are also discussed.

264 - DAMAGE IDENTIFICATION IN BEAM STRUCTURE USING MODE SHAPE DATA: FROM SPATIAL CONTINUOUS WAVELET TRANSFORM TO MODE SHAPE CURVATURE METHODS

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Different modern engineering structures, including but not limited to buildings, bridges, dams, stadiums, tunnels, automotive and aerospace facilities have to maintain their integrity and functionality under prolonged exploitation and severe environmental conditions. Failure of these structures may lead to tragic consequences and therefore costly and time-consuming inspections must be carried out on regular basis. As a result, non-destructive structural health monitoring (SHM) methods have become an important research area in civil, mechanical and aerospace communities. Numerous methods in the area of vibration-based damage detection are proposed. These methods are based on the fact that dynamic characteristics, namely, natural frequencies, mode shapes and damping are directly related to the stiffness of the structure. Therefore, changes in natural frequencies or mode shapes will also indicate changes in stiffness. Many studies have shown that mode shapes and corresponding mode shape transformations are highly sensitive to damage and can be used for damage detection and quantification. However, the major drawback of those methods is a need for the data of healthy structure, which sometimes can be difficult or even impossible to obtain. To overcome this shortcoming, wavelet transform technique is suggested as one of solutions. It originated in 1980's and was mainly used for signal singularity detection, signal denoising, image compression to name a few. Later in 1990 wavelet transform technique was used on vibrational data for damage detection for the first time. Wavelet transform is a mathematical tool to transform the original signal into a different domain where additional data analysis becomes possible, therefore damage-affected signal portion is revealed. In this paper a method based on wavelet transform technique for damage detection and localization in beam structure is described and compared to well-known mode shape curvature method. The basic idea of the proposed mode shape curvature method is that the mode shape curvature of a healthy structure has a smooth surface and it can be approximated by polynomial. Damage index is defined as the absolute difference between the measured curvature of the damaged structure and smoothed polynomial representing the healthy structure. Applicability and effectiveness of the proposed algorithms are demonstrated experimentally on aluminum beams containing mill-cut damage.

266 - BIODYNAMIC BASED EXPERIMENTAL VALIDATION OF A HUMAN FINGER MODEL

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Mechanical models have been used to predict the biodynamic responses of the human body and hand exposed to vibration but there has been little research on finger modeling. A detailed model is necessary to get an accurate response at the fingers but such a model often leads to coupled equations which prove difficult to solve. To overcome this problem a new approach is proposed in this study, which uses explicit instead of the usual implicit calculation of the dynamic response of the finger model. The multi-degree-of-freedom model parameters were identified from the biodynamic responses and forces measured on the index finger exposed to single-axial broadband excitation (5 to 500 Hz, 10 m/s^2). To measure the responses a special measuring handle equipped with a force transducer and an accelerometer was used. Reasonable agreement was achieved between the measurements and the model predicted results and the study also confirmed that the proposed finger model is acceptable for further biodynamic studies of the finger. More importantly the proposed procedure enables a systematic approach to modeling, which helps the researchers solve more detail and complex mechanical models.

362 - STRUCTURAL MODEL UPDATING BASED ON MEASURED RESPONSE

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Model updating is an important aspect of structural engineering as a result of its regular application in structural vibration control and structural health monitoring, finite element method (FEM) has become one of the most common approach of understanding and representing the dynamic characteristics of various engineering structures. However, the present FEM is not able to provide acceptable finite element (FE) models which are in adequate agreement when compared with measured results. To narrow the gap between the output of the finite element model and the output of a measured response, model updating technique has been introduced and used widely to update or correct the analytical FE models using measured modal data. Identification of modal frequencies and mode shapes using output-only data has been in existence in conjunction with many other consistent modal identification methods. In this paper, a differential method for updating the mass and stiffness matrices of a structural model to repli-cate the measured frequency of the structure is proposed. As an initial simplified step, only the first eigen mode of the structure is considered, the updating process is carried out by applying the orthogonality conditions for the eigenvector. The technique is then generalized to assess scenarios where the first few eigen modes of the structure are measured. To validate the efficiency of the proposed method, numerical simulation based on a Cantilever beam test structure is presented. The result obtained demonstrated that the differential updating method can be used to simultaneously update the analytical mass and stiffness of the model using measured vibration data. The advantage of the presented model is its simplicity and precision in computation, it can also be applied to structures with large degrees of freedom.

265 - STOCHASTIC MODEL FOR THERMORHEOLOGICALLY SIMPLE MATERIALS USING FRACTIONAL DERIVATIVE OPERATORS

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The dynamic properties of thermorheological materials are highly frequency- and temperature-dependent. Numerical methods of structural systems require the mathematical model for these dependencies. The present work is a natural continuation of the research work concerning modeling and parameter identification of thermorheologically simple materials. The material behavior is modeled according to a fractional derivative operators model and it also considers a nonlinear relationship for the temperature dependence of the material. Shear complex modulus data for several temperatures of a material are obtained by dynamic tests in an experimental set-up. The goal of the present work is to propose a model calibration strategy for thermorheologically simple

materials using the Bayesian Framework, where the parameter identification was performed using Markov Chain Monte Carlo (MCMC) approach. The utilized MCMC method enables us to generate a stochastic model for the thermorheologically simple material with frequency and temperature dependency.

Fluid-Structure Interactions (TP09)

19 - INVESTIGATION ON CAVITATION BUBBLE NEAR AN ELASTIC SPHERE

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This paper explores the interaction between a spark-generated cavitation bubble and an elastic sphere experimentally and numerically. The experiments are conducted by creating a cavitation bubble at various distances horizontally away from a suspended elastic sphere, in which the elastic sphere is made of silicone rubber or super absorbent polymer while the bubble is induced using a low-voltage spark discharge method. Numerical simulations are also performed using a boundary element method (BEM) coupled with a finite element solver and show good comparisons with experimental data. The results show that the pronounced deformation and elongation of the elastic sphere when the spark-bubble is generated very close to the sphere with a small modulus of elasticity and a small size ratio R' between the bubble and the elastic sphere. The results also reveal the influences of elasticity, the size ratio R' as well as stand-off distance H' on both the elastic sphere and the bubble dynamics. From the results obtained, some insights to the problem of a cavitation bubble near an elastic sphere are deduced. Keywords: cavitation bubble, elastic sphere, boundary element, finite element.

80 - STABILIZATION CONTROL OF SELF-EXCITED VIBRATIONS IN A FLEXIBLE FLUID-CONVEYING PIPE

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This paper presents a theoretical and experimental investigations of stabilization control of self-excited vibrations of a pipe conveying fluid due to non-conservative force. There is a long history of studies on the unstable phenomena of a flexible fluid-conveying pipe. In contrast with the studies on the mechanisms of the unstable phenomena, there are few studies on the stabilization control method for the flexible fluid-conveying pipe. Because most control methods do not take into account the non self-adjointness and employ the eigenmodes of the pipe without fluid flow, the unstable mode is approximated by the linear combination of them. Therefore, many sensors are required and neglected higher modes can cause the spillover. On the other hand, in this study, we try to directly derive the unstable eigenmode by using power series. By using this unstable mode, it is possible to carry out the stabilize control without spillover using one sensor. In this presentation, we derive the method of the unstable eignemode and discuss an experimental result of destabilized a flexible fluid-conveying pipe. A stabilization control method of self-excited vibrations of a fluid-conveying pipe is proposed based on the velocity feedback of the pipe displacement. Then, according to the proposed feedback rule, a bending moment on the top end of the pipe is applied by a piezo actuator. The validity of the proposed stabilization control method is experimentally confirmed.

113 - INVESTIGATION OF TYPICAL SECTION AERODYNAMIC TRANSFER FUNCTIONS USING A VISCOUS CFD FORMULATION

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The fluid-structure interaction problem plays an important role in many industrial applications of engineering systems. In aeronautics, for instance, it is a crucial item to be considered, since this interaction generates vibrations, which in turn can cause structural fatigue and even aeroelastic phenomena, such as buffeting, aileron

reversal, or flutter, for example. These problems are often very complex, involving the coupling effects of the fluid flow interacting with a moving structure. Recent advances in computational performance and in computational fluid dynamics (CFD) techniques have made the numerical approach to this problem feasible in an industrial setting. Nevertheless, there is still considerable room for improvement in this research area. In this context, the present work addresses the use of high-fidelity CFD formulations in the construction of the aerodynamic operator for aeroelastic stability analyses. In particular, the work is concerned with studying the effects of the inclusion of the viscous terms in the aerodynamic formulation, as compared to previous inviscid results. Hence, the flows of interest are assumed to be adequately modeled either by the 2-D Euler equations or the 2-D Reynolds-averaged Navier-Stokes (RANS) equations with appropriate turbulence closures. All turbulent results included in the present paper have used the Spalart-Allmaras turbulence model. The dynamic system is represented by the NACA 0012 airfoil typical section with two degrees of freedom, namely, plunge and pitch. The purely aerodynamic test cases considered for the airfoil, in the transonic regime, include steady cases and harmonically prescribed motions. Indicial aerodynamic responses of the airfoil, with the current flow solver formulation, are compared to purely inviscid calculations. These responses are used to construct aerodynamic transfer functions, which then allow for aeroelastic analyses in state space format. The comparison of viscous and inviscid results presents the expected trends.

128 - TRANSVERSE SEISMIC RESPONSE ANALYSIS OF SUBMERGED FLOATING TUNNEL CONSIDERING BOUNDARY SOIL PROPERTY

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Analysis of seismic response of submerged floating tunnel(SFT) is important task for ensuring the safety of this new structure. But existing researches often neglected impact of the real connection form between revetment structures and SFT tube, and only simplified the constraint supports simple or fixed support in calculation. In this paper, the seismic response characteristics of SFT in the lateral earthquake were studied by considering the impact of the geotechnical properties around the revetment structures. The transverse displacement, bending moment and torque of tube and cables tension of SFT were calculated by using large mass method, in the case of the seabed geotechnical condition in the South Sea of China and the Messina Strait SFT design scheme. The parametric study was finished for the revetment struc-ture length Lsh and cohesive soil shear modulus G. The results showed that the maximum dis-placement and bending moment of tube appeared at the mid-span, the maximum torque arised at both ends, and the maximum incremental of cable tension occurred in the shortest cables. The elastic support of SFT considering the impact of the practical geotechnical properties around the revetment structures was conducive to reduce the forces of the tube segment struc-ture, but not to control some of cables tension. The seismic response characteristics of SFT were significantly influenced by the revetment structure length Lsh and cohesive soil shear modulus G. But the impact was complicated, which may be related to the dynamic character-istics of SFT structure and the parameters of the seismic waves exerted on SFT.

261 - CFD CALIBRATED WAKE OSCILLATOR MODEL FOR VORTEX-INDUCED VIBRATIONS

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In this study we investigate vortex-induced vibrations of elastically supported cylinders capable of moving in cross-flow and in-line directions. Two approaches are adopted to analyse the considered system. First the amplitudes of cross-flow and in-line vibrations under variation of the fluid flow velocity are calculated using CFD for various mass ratio. Analysis is performed initially for a cylinder restricted to move in cross-flow direction only and then for the cylinder capable of moving in both directions. It is shown that when a light cylinder is moving in the fluid flow (mass ratio is low), the in-line motion becomes significant resulting in the increase of the cross-flow displacement amplitudes, thus confirming the presence of the "supper-upper" branch earlier obtained in the experimental studies. In the second part of the paper, a new two degrees-of-freedom wake oscillator model is proposed where vortex-induced lift and drag are modelled with two nonlinear self-excited oscillators of

van der Pol type. Total hydrodynamic force is obtained here as a sum of lift and drag forces, which are defined as being proportional to the square of the magnitude of the relative flow velocity around the cylinder. The two van der Pol type oscillators are then used to model fluctuating drag and lift coefficients. As the relative velocity around the cylinder depends both on the fluid flow velocity and the velocity of the cylinder, the equations of motions of the cylinder in cross-flow and in-line directions become coupled through the fluid forces. It is shown that such approximation of the fluid forces allows to obtain the well known low dimensional models in the limit case and the model proposed by Facchinetti et al. (2004) to describe the cross-flow vibrations is used an example. The CFD results are utilised to calibrate the proposed wake oscillator model and to compare of the cross-flow displacement amplitudes obtain by CDF and using new wake oscillator model for different mass ratios. Some insight into the influence of main coefficients of the wake oscillators and fluid forces coefficients on the cross-flow displacement amplitudes are also presented.

Identification and Modal Analysis (TP10)

15 - APPLICATION OF EQUIVALENT MATERIAL PROPERTIES IN FREE VIBRATION ANALYSIS OF A PARTIALLY PERFORATED PLATE WITH TRIANGULAR PENETRATION PATTERN

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An analytical analysis for free vibration of a perforated square or rectangular plate with a triangular penetration pattern is suggested. The natural frequencies of the perforated plate gradually decrease with the hole size, because the structural stiffness of the perforated plate is reduced severely than mass inertia according to the hole size. In the study, the natural frequencies of the perforated square plate are obtained as a function of ligament efficiency using commercial finite element analysis code, ANSYS. The results are used to extract the effective modulus of elasticity under the assumption of constant Poisson's ratio. The effective modulus of elasticity of the fully perforated square plate is applied to modal analysis of a partially perforated rectangular plate using a homogeneous finite element analysis model. The natural frequencies and the corresponding mode shapes of the homogeneous model are compared with the results of the detailed full finite element analysis model of the partially perforated rectangular plate in order to check the validity of the effective modulus of elasticity. In addition, analytical method based on the Rayleigh-Ritz method to calculate the natural frequencies of a partially perforated rectangular plate is suggested.

21 - HIGH-FREQUENCY CONTROL OF THE SLOW MOTIONS

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A non-linear system with essentially different time scales is considered. It is well known, that slow motions in non-linear systems are generally dependant on the high-frequency excitation, which can modify the characteristics of the system with respect to slow motions. This effect is a central issue in the concept of the vibrational mechanics by Prof. I.I.Blekhman. This concept is developed here further on the base of multi-scale asymptotic technique. It was succeeded to obtain the equations describing only the slow motions in a rather general case of analytical systems. It enables us to analyze how the structure of the original equations effects the structure of the equations for the slow motions. These results give a possibility for constructing a high-frequency control to provide requested properties of the the system relating to slow motions. For example, a high-frequency excitation transforms a non-linear friction in a controlled linear friction with essential bigger damping ratio, as it was in original system without exitation. The theoretical results are verified by comparison with numerical simulations.

115 - STRATEGY FOR IDENTIFICATION OF DAMPING RATIO USING MORLET WAVE DAMPING IDENTIFICATION METHOD

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A strategy for the identification of damping ratios in structures with a Morlet Wave Damping Identification method is proposed. Generally, this method is based on extracting damping ratios for a given natural frequency from only two wavelet coefficients. The considerable sensitivity of the identified values is noticed even for a small change of the parameters of the wavelet functions. To raise a certainty in the identified values we propose identification of damping ratio for the whole range of feasible wavelet functions parameters. Decision criteria

are based on lowest fluctuation of the identified damping ratio. This strategy resulted in the raising the level of automation and reducing the operator interaction. Method is tested on the simulated responses and the experimentally measured responses. In both cases, the results of the damping ratios identification are compared with numerous independent traditional methods. Traditional identification methods applied in comparative analysis were available as in house code or commercial software.

166 - BIOMECHANICAL MODEL OF A SMART MIDDLE EAR PROSTHESIS

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The human middle ear is a biomechanical system which consists of the tympanic membrane, three ossicles (i.e. malleus, incus and stapes) connected each other and with temporal bone by means of ligaments and tendons. In this system sound is transformed from the tympanic membrane to the stapes as mechanical vibrations. Some middle ear dysfunctions need to use prosthesis in order to improve hearing process. In clinical practice a variety of middle ear prostheses are available, although each of them should be adjusted to individual needs of patients. Therefore, we propose to design the smart prosthesis made of shape memory alloy (SMA), which would be able to adjust its size and angulation to requirements in a specific medical case. The piston - stapes prostheses (NiTiBOND) made of Nitinol are known in the literature and sold by medical concerns. Clinical tests prove that the acousto-mechanical properties of such self-crimping prostheses are better and less variable because of better sound transmission properties at the incus-prosthesis. Here a new model of PORP (Partial Ossicular Replacement Prosthesis) made of smart material is built and analysed by means of Finite Element Method (FEM). Interesting dynamical behaviour of the prosthesis is produced by nonlinear properties of SMA material and geometry of the prosthesis as well. The paper focuses on dynamic response of the prosthesis under acoustic pressure. Acknowledgement The work is financially supported under the project of National Science Centre (Poland) no. 2014/13/B/ST8/04047.

177 - NUMERICAL TRANSFER PATH ANALYSIS FOR THE ASSESSMENT OF AIR-BORNE NOISE IN INTERNAL COMBUSTION ENGINES

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Noise legislation and the increasing customer demands determine the NVH (Noise Vibration and Harshness) development of modern commercial vehicles. In order to meet the stringent legislative requirements for the vehicle noise emission, more accurate understanding of all vehicle noise sources and their acoustic behavior is required. Transfer Path Analysis (TPA) is a fairly well established technique for estimating and ranking individual low-frequency noise or vibration contributions via the different transmission paths. Transmission paths from different sources to target points of interest and their contributions can be analyzed by applying TPA. This technique is applied on test measurements, which can only be available on prototypes, at the end of the designing process. In order to overcome the limits of TPA, a Numerical Transfer Path Analysis (NTPA) method, based on numerical simulation, is proposed in this paper. The main target of NTPA methodology is to get information of noise source contribution and noise transmission paths, starting from the first steps of the designing process. The structure-borne noise is computed with a multi-body dynamic model and the results are used to compute the acoustic radiation in the far field with the Wave Based Technique (WBT). In this paper, a short introduction on NTPA will be provided. Then, the investigated model, a 4-cylinder internal combustion engine, will be described. Finally, the relationships between forces and responses are computed with NTPA methodology and the main noise contributions are identified and analyzed. The aim of this work is to identify and rank main noise sources of an engine, showing the advantages and benefits of the proposed methodology.

181 - FAST ONLINE MONITORING AND SYSTEM IDENTIFICATION FOR THE APPLICATION IN THE FIELD OF AEROELASTICITY

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During the development of new aircraft wind tunnel testing of 2D and 3D aerofoils or even complete aircraft is essential. The structural integrity of the wind tunnel model needs to be assured for the test campaign because a failure can cause severe damage on the wind tunnel facility and means the loss of the costly model itself. To enhance the level of safety, a detection of the flutter stability while testing is desirable. This new development utilizes ex-perimental and operational modal analysis methods for fast and reliable online identification of a system's eigenvalues and eigenvectors. The developed code presented here uses efficient and novel implementations of signal processing and system identification algorithms coupled with new ones for mode selection and tracking, to achieve a computation time in the order of seconds, thus allowing a responsive temporal tracking of varying parameters. The code de-veloped at the Institute of Aeroelasticity at the German Aerospace Centre (DLR) is written in MATLAB, is hardware-agnostic and its performance has been assessed with different models. The main focus of the discussion is the time efficiency of various algorithms which enable the online monitoring of system parameters, with an overlook of the influence on speed of various parameters along with presentation of results of a flutter test conducted in the Transonic Wind tunnel in Göttingen.

228 - INDUSTRIAL USE OF METHODS FOR MODAL ANALYSIS OF SMALL AND LIGHT STRUCTURES

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When dealing with small and light structures, difficulties occur when measuring the modal parameters. The resonant frequencies are usually relatively high and therefore a wide frequency range is needed for the measurement. Furthermore, the mass that is added to the structure by the sensors causes structural modifications. Three innovative procedures for the experimental modal analysis of small and light structures were developed in this study and the most appropriate of them was used for the modal analysis of an industrial product. The procedure that was used involves a measurement of the excitation force, which was performed by a piezo strain-gauge. The main advantage of this sensor in comparison to other devices used for force measurements is that it adds a very small mass to the measured structure ($\approx$ 0.4 gram) but at the same time enables an accurate measurement of the modal parameters in a wide frequency range (up to 20 kHz). This makes it suitable for the measurement of the frequency-response functions of light structures that have high resonant frequencies. Consequently, an experimental modal analysis of the aforementioned structures with free-free support can be performed. The results of the modal analysis were used to validate the numerical model of the product. The development and functioning of the numerical model is also presented in this study.

233 - FDD MODAL IDENTIFICATION FROM EARTHQUAKE RESPONSE DATA WITH EVALUATION OF SOIL-STRUCTURE INTERACTION EFFECTS

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"Non-parametric" system identification via a refined FDD (rFDD) algorithm is developed to evaluate current modal properties of civil engineering buildings subjected to earthquake excitation. Innovatively, the algorithm operates in an OMAX (Operational Modal Analysis with eXogenous input) environment on base-excited buildings, to detect also potential Soil-Structure Interaction (SSI) effects. At first, the identification technique is explored analytically, dealing with a variable stiffness and damping foundation system. The OMAX condition comes from the use of base excitation records, which are employed as exogenous input. The standard fixed-base

condition may simulate well the response to ambient loading or weak seismic excitations; rather, the flexible-base model shall deal with more realistic seismic responses of buildings, which may embed interactions between soil and structure. The developed analyses are performed on synthetic response signals, which are computed from a benchmark structure. Simulated signals are generated prior to dynamic identification, by adopting a given seismic input with variable foundation properties. The method demonstrates its full effectiveness, also for the detection of close modes and for the identification of high modal damping ratios. Issues pertaining to earthquake record processing are specifically addressed. The present work proves a necessary condition for the effectiveness of the present rFDD algorithm as a robust method to inspect current flexible-base strong ground motion modal parameters. This shall help in identifying possible variations of structural features and SSI effects along experienced seismic histories, and providing an effective tool towards Earthquake Engineering and Structural Health Monitoring purposes.

288 - ASSESSMENT OF DAMPING PROPERTIES OF LARGE 2-STROKE MARINE DIESEL ENGINES

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When simulating the vibration behaviour of large 2-stroke marine diesel engines the damping properties are an important parameter to be considered. Simulations only allow determining realistic vibration amplitudes if the engine's damping characteristic is known. Modal damping ratios of reciprocating engines vary depending on which parts of the engine interact during oscillation and on how energy is dissipated while vibrating. Therefore different damping ratios can be expected for different engine mode shapes.
For determining typical modal damping ratios of a diesel engine a methodology for an automated analysis of vibration measurement data was developed: After identifying N resonance peaks in a measured vibration spectrum a spectral curve corresponding to a simple mass-spring-damper system with N degrees of freedom is automatically fitted onto the measured curve by parameter optimization. At the end of this iterative process the damping properties of the substituting mass-spring-damper-system, whose curve adjusts most precisely to the measured spectrum, are attributed to the measured resonances. In addition to determining modal damping ratios and eigenfrequencies the procedure allows separating overlapping resonance peaks.
The analysis process was applied on vibration measurement results of a series of different marine diesel engines and characteristic modal damping ratios could be determined for the engine's principal mode shapes. Considering the determined modal damping properties when performing forced response simulations of the engine by modal superposition in the frequency domain allowed to achieve a higher accuracy in the calculated vibration amplitudes.

303 - DYNAMIC TESTS AND DESIGN OF A VIBRATION-BASED SHM SYSTEM FOR PROMPT POST-EARTHQUAKE ASSESSMENT OF AN ITALIAN HOSPITAL

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Health facilities play a primary role in post-earthquake emergency management. They are required to be fully operational after frequent earthquakes and ensure safety and support to the rescue operations in the case of strong motion. A number of structural monitoring programs have been recently issued in the United States, aimed at assessing the health of the structure after earthquakes. Other research programs are also focusing the attention on the condition assessment of non-structural components, equipment and installations. This paper describes the dynamic identification tests carried out on the building of the Main Hospital in Foggia (Southern Italy), that houses the maternity department. The building con-sists of three adjacent structural bodies and it is representative of typical layouts of existing facilities. In such conditions, the first objective of the tests was the analysis of the expected dynamic interactions. The obtained results have been also used to define an opportune sensor layout for continuous vibration-based Structural Health Monitoring of the structure for rapid condition assessment after earthquakes.

Dynamics of Rotating Systems (TP12)

17 - EVALUATION OF THE DYNAMIC CHARACTERISTICS OF THE THREE-LOBE JOURNAL BEARING WITH FINITE LENGTH USING ANALYTICAL METHODS

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A recent analytical solution for the lubrication problem of the plain cylindrical journal bearing is applied in this paper in the three-lobe journal bearing geometry that is commonly applied in the large scale rotational machinery. The aim of this paper is to present the procedure of the analytical solution of the Reynolds equation for each one of the lobes of the bearing that is considered to be of finite length and to present results for static and dynamic characteristics of the journal bearing. Charts for eccentricity ratio and equilibrium locus are presented comparing analytical numerical and experimental results. Additionally, stiffness and damping coefficients are evaluated under the analytical solution and compared with the literature.

18 - EVALUATION OF THE FLOATING RING BEARING CHARACTERISTICS USING ANALYTICAL METHODS

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The floating ring bearings widely used in turbosystems are usually incorporated in rotordynamic algorithms under short bearing approximation or by using numerical solutions. As an effort to improve both evaluation time and accuracy of the pressure distribution in a floating ring, a recent achievement of an analytical solution for the plain cylindrical journal bearing is applied to the floating ring bearing model. After the procedure of exact and approximate analytical solution of the Reynolds equation for the floating ring bearing, the static characteristics are evaluated and compared with the corresponding results under short bearing approximation and numerical methods. Design characteristics and operational parameters such as ring seed ratio, inner and outer eccentricity, and friction coefficient are presented and compared.

102 - INFLUENCE OF THE OIL TEMPERATURE OF THRUST BEARINGS ON THE VIBRATORY BEHAVIOR OF SMALL TURBOCHARGERS

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In this contribution, the effect of thrust bearings on the nonlinear oscillations of small turbocharger rotors is investigated. The oil-film forces from each pad of a thrust bearing are calculated using the Reynolds equation. The oil-temperature, which is determined with an appropriate energy equation, affects the pressure distribution and thereby the hydrodynamic forces from the thrust bearing. The Reynolds and the energy equation are coupled. In general, the two equations should be solved simultaneously at each time integration step of a transient simulation. The immense computational effort for the solution of these equations can be relaxed using a well-established simplified form of the energy equation. This simplification allows the decoupling of the energy equation from the Reynolds equation. Run-up simulations are performed with isothermal and thermohydrodynamic thrust bearing models, where the pressure fields from the thrust bearing are calculated. Moreover, the influence of the thrust bearing on the rotordynamic system is investigated in transient simulations.

149 - ROTOR UNBALANCE ESTIMATION USING A SINGLE MACHINE RUN-DOWN WITH REDUCED NUMBER OF SENSORS

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Earlier proposed methods in the literature on the rotor unbalance estimation using a single machine run-down data have used vibration measurements at all bearing pedestals in both lateral and vertical orthogonal directions. It is generally believed that the measurement in both directions provides the bigger picture of machine dynamical behaviour. However, in the present study the concept of the earlier method is used again but with reduced number of sensors. Instead of using 2 vibration sensors at a bearing pedestal in both lateral and vertical directions, just a single sensor is used at each pedestal, hence reducing the number of sensor by 50%. The sensor is mounted in the radial direction (45 degree to both lateral and vertical directions) so that the measured vibration data will have significant content of vibration behaviour from both directions. The concept is applied to a simple simulated rig of a rotor having a balance disc and supported on either side through ball bearing on flexible foundation. The paper presents the modelling details and comparison of several unbalance estimations in the simulated rig example.

151 - DYNAMICS OF A ROTATING HUB-BLADE STRUCTURE WITH NON-IDEAL ENERGY SOURCE

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The paper presents dynamics of a rotating structure composed of two nominally identical flexible thin-walled beams attached to a rigid hub. The structure is excited by a DC motor which may be considered as an ideal or a non-ideal energy source. Both beams are made of unidirectional composite material with reinforcing fibers skewed with respect to their longitudinal axis. The applied lamination pattern in cross-sections flanges and webs results in circumferentially asymmetric stiffness (CAS) property, thus vibrating beams exhibit combined flapwise bending-shear-twisting mode. The equations of motion of the structure are derived according to Hamilton's least action principle. These are supplemented by an additional equation incorporating characteristics of the driving DC motor. The Galerkin method is used to convert continuous differential equations to a discrete problem. Finally, the dimensionless form of the governing equations is given. Vibrations of individual beams and hub are analysed. An influence of the energy source output considered as an ideal and non-ideal one on rotor dynamics is demonstrated. The results of numerical simulation show that the oscillations of the beams and the hub are fully synchronized. This phenomenon is observed either for the ideal and the non-ideal system cases. Although, in the case of non-ideal system both beams are been synchronized after passing a certain transient domain. Moreover, ani-resonance phenomena is observed.

163 - ANALIZING THE STIFFNESS OF A ROTOR WITH TRIANGULAR CROSS FRACTURE

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In this work, the stiffness of a rotor with triangular cross fracture in the middle part, within its elastic range, in static condition, simply supported at its ends and middle concentrated load is determined. The functional relationship for the variation of second area moment of their different cross sections is deduced. It was calculated the slope and deflection by numerical integration double obtaining its elastic curve and the frequency range in which the fractured rotor resonates. Additionally the numerical solution to the critical orientation of the fracture was obtained. The calculated values for the rotor fractured are compared with corresponding values to the rotor without fracture, including the comparison the result of the numerical solution. The above parameters were calculated based on the angle of orientation of the fracture with respect to the normal line. From the values obtained it is concluded that, given the geometry of the rotor and of the fracture, the load applied, the

support conditions and physical properties of the material and considering the birth and growth of the fracture; there are some frequencies of resonance for the rotor with fracture, in relation with the rotor without fracture, where the last one just have one resonance frequency. The variation between the first resonance frequency of the rotor with fracture and the value of the frequency of the rotor without fracture is of the order of a quarter for the same conditions.

172 - DYNAMICS OF THE ROTOR WITH FOIL BEARINGS AT AN ELEVATED TEMPERATURE

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Foil bearings ensure stable operation for high-speed rotors even at high ambient temperatures. In comparison with other types of slide bearings, such bearings are characterized by very good vibration damping properties. This is due to their construction since they contain a set of thin, appropriately shaped foils that dissipate energy of vibrating shaft. Bearing geometry and materials are thus especially adapted to a specific machine and operating conditions. The article presents the works on foil bearings that are intended to be used in the steam microturbine of 3 kWe. These bearings were tested at room temperature, and then, at elevated temperatures on the test bench designed for this purpose. The object under test was rigid rotor with two foil bearings. The following dynamic characteristics, except of temperatures of individual bearing components, were investigated: vibration amplitudes and vibration trajectories of the rotor, vibrations of bearing supports. Maximum rotational speed was 24 krpm. Studies carried out made it possible to determine the speed, above which fluid friction was present in the bearing where the top foil and the journal were separated from each other by an air layer. The experimental value of rotor resonant speed was also obtained. Research results have proven that the dynamic characteristics of the rotor with foil bearings are very much dependent on the ambient temperature. That clearly illustrates that ambient temperature is a particularly critical factor which should be taken into consideration in the design process of foil bearings. Higher ambient temperature caused reduction in stiffness of the set of foils, which resulted in lowering of resonant speed and increasing of vibration amplitude. This characteristic is crucial in case of the microturbines, where at high vibration amplitudes occurring in the bearings there is a need to increase the blade clearance which is the cause of reduced flow system efficiency. When designing foil bearings for the microturbines we should, therefore, strive for obtaining the lowest possible vibration amplitudes across the entire speed range; it permits the design of high-efficiency machines.

206 - VIBRATION OF A TWO DEGREE OF FREEDOM AIR BEARING-ROTOR SYSTEM WITH ASYMMETRIC SUPPLY PRESSURE

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In externally pressurized air lubricated bearing, air is generally supplied with constant pressure by orifices. Radial loads (rotor mass or external forces on rotor) make a relative eccentricity between bearing and rotor. And the relationship between the load and the eccentricity is nonlinear due to compressibility of air. Increase in the eccentricity may reach to a critical value, if the rotor is close to the bearing wall. Because the air film thickness may not be sufficient to carry applied load. In order to avoid high value of eccentricity, the load carrying capacity of the bearing must be increased. In this study, in order to increasing the stiffness (load carrying capacity) of the bearing directionally, the supply pressure of the orifices, which are opposite to the loading direction, are increased. However, in this approach although air consumption is lower than the increasing pressure in all orifices, the asymmetric stiffness of the bearing along the orthogonal direction will affect the dynamics of the rotor. In order to investigate the dynamics behaviour of the rotor, the air bearing is analyzed numerically. The bearing-rotor system is modeled in two degree of freedom and it is simulated for different asymmetric supply pressure.

210 - EFFECTS OF A JOURNAL BEARING CLEARANCE ON ROTORDYNAMICS OF TURBOCHARGER

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In the recent years, turbocharged engines have become more common because of better power-to-weight ratio (and thus lower consumption and emission of air pollutants). However, the better performance comes at a price because turbochargers operate on high speeds - usually hundreds of thousands revolutions per minute - and tend to be fatigue and stability prone. For this reason a turbocharger rotor have to be designed carefully with respect to its dynamic properties. The influence of a bearing clearance on stiffness and damping of a single-film journal bearing is well known and documented. Turbochargers, however, are often supported by floating journal bearings, which have two oil films linked by oil feedholes. Such a bearing have two bearing clearances - between journal and floating ring and between floating ring and housing - which are determined by different temperatures of oil films and also dimensional tolerances. The following paper deals with differences between nominal (cold) and operational (hot) bearing clearances. The influence of the dimensional tolerances on the values of bearing clearances and turbocharger dynamics is also discussed.

235 - A NUMERICAL INVESTIGATION INTO THE EFFECT OF THE SUPPORTS ON THE VIBRATION OF ROTATING SHAFTS

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Vibration is typically encountered by rotating equipment during its start-up, running operation and shutdown. The severity of the oscillation, which depends on the critical speed and natural frequencies of the system, could cause serious malfunction of the device and affect its operating performance. A simplified lumped parameter model of a rotor system is typically used for the study of the shaft dynamics of a single rotor on bearing supports. Bearing supports are the means of connecting a device between the rotor and supporting structure, which are of different forms and designs. They can be a simple bushing, rolling-element or journal types for light, medium and large load applications respectively. Particularly in this work, flexible supports made of rubber are considered by implementing viscoelastic material into the rotor bearing system. Viscoelastic material is well known to be a good choice for use within isolation systems, due to it being easily available and possessing high damping characteristics over a wide temperature and frequency range. However, the change of mechanical properties with frequency and temperature makes it difficult to design a viscoelastically device that works over a large range of operating conditions. Thus numerical analysis, which focuses on the simple rotor model supported on a range of different flexible supports, will be presented and compared.

238 - STRUCTURAL DYNAMICS OF A WIND TURBINE DRIVE TRAIN HIGH SPEED SUBSYSTEM: MATHEMATICAL MODELING AND VALIDATION

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The paper studies the dynamics of a wind turbine drive train high speed subsystem, both by modelling and experiments with focus on system torsional vibration and transient events which can reduce fatigue life of functional components (gearbox, bearings, shafts, couplings, others). A scaled down drive train high speed shaft test rig has been developed. Main components of the test rig are six-pole motor with variable frequency drive controller (up to 1000 rpm), shafts' disk coupling and flexible mounting structure representing gearbox housing with output high speed bearing. The test rig is equipped with measurement system comprising a set of accelerometers and displacement sensors, strain gauges and telemeter system, data acquisition hardware and software (SKFWindCon3.0). Mathematical and computational models of the test rig have been developed and went through validation tests. The system dynamic response is studied for different operational scenarios and

structural parameters (run-shut down case with and without eccentric mass). The ultimate goal of the test rig is to get insight into interaction between internal dynamics of drive train mechanical and electrical functional components and to develop novel methods to detect, predict and prevent faults and failures in wind turbine drive trains arising due to misalignments and transient external loads.

304 - MODELLING OF MAGNETORHEOLOGICAL OILS IN ROTORDYNAMIC DAMPING DEVICES BY BILINEAR MATERIAL

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Lateral vibrations of rotors induced by unbalance of rotating parts can be reduced by adding damping devices to the rotor supports. To achieve their optimum performance their damping effect must be controllable. This is offered by magnetorheological squeeze film dampers whose damping force is produced by squeezing a thin layer of magnetorheological fluid between two concentric rings. The damping device is equipped with an electric coil that generates magnetic flux passing through the lubricating oil. As its resistance against the flow depends on magnetic induction, the change of the current can be used to control the damping force.

The developed mathematical model is based on assumptions of the classical theory of lubrication except that for the lubricant. Magnetorheological oils belong to the class of liquids with a yielding shear stress and therefore, they are usually represented by Bingham fluids. The pressure distribution in the damper gap is then desribed by a modified Reynolds equation. The experience shows that because of strong nonlinear character of the damping force the computational procedures for analysis of the steady state and transient vibrations of rotor systems can stop to converge. This was a motivation to derive the equation for the pressure distibution in the lubricating layer based on bilinear theoretical material. Its flow curve is continuous unlike the Bingham fluid which can contribute to reducing the nonlinear character of the problem.

In the performed analyses the rotor was supported by magnetorheological squeeze film dampers on both its ends. The computational simulations showed that the change of magnetic induction in the lubricating film could adapt the damping force to the current operating conditions and thus to reduce amplitude of the rotor vibrations. The computations confirmed that the new model of the damping device increased the numerical stability of the applied computational procedures.

327 - INVESTIGATION OF HIGH VIBRATION ON LARGE FAN MOTOR

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The West Burton power plant (a subsidiary of EDF Company) commissioned between 1967 and 1969 is a 2000 MW capacity power station consists of four similarly Boiler and Turbo Generator (TG) sets (generating unit). Each of the generating units is made up of several turbine stages (i.e. high pressure (HP) turbine; an intermediate pressure (IP) turbine and three low pressure (LP) turbines), in addition to a generator and an exciter. Along with the main generating units' assets, there are number of auxiliary equipment such as; condenser; air ejector; feed water pumps and primary air (PA) fans. Each boiler has two primary air (PA) fans, used for supplying primary air to the mills and conveying pulverised fuel into the boiler unit. As part of operational performance enhancement strategies, two of the boilers' (unit 1 & 4) PA-fans have been retrofitted with new electric motors, while the other two boilers (units 2 & 3) still possess their original electric motors. High levels of vibration readings were recorded on unit 3 PA-fan-B' electric motor' bearings on both; drive and non-drive ends. Hence a number of vibration measurements were conducted on this machine to find out the root cause of the increase on the machine vibration.

355 - EVALUATION OF THE DYNAMIC RESPONSE OF HIGH-SPEED SYSTEMS USING AN ANALYTICAL MODEL FOR THE FLOATING RING BEARINGS OF FINITE LENGTH

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The paper presents a model of a high-speed rotor-bearing system consisting of a rigid rotor mounted on nonlinear floating ring journal bearings of finite length that are incorporated using a recently developed analytical solution for the Reynold's equation. The analytical solution for the floating ring bearing of finite length offers the ability of introducing the bearing forces to the rotordynamic algorithm using closed form expressions. The paper aims to the investigation of the dynamics and stability of high-speed systems under an analytical nonlinear-dynamic model that focuses on the influence of the nonlinear fluid film forces. The evaluated response and the developed ecccentricities in the fluid films during a transient start-up of the system covers the majority of the results. Time-frequency decompositions and bifurcation maps of the system's transient response support this investigation of the fundamental dynamic effects that appear in high-speed systems with floating ring bearings. The results are compared to those obtained using numerical methods for the simulation of floating ring bearings and to those obtained using infinitely short bearing approximation. Additionally, a comparison on the evaluation time regarding the different methods of floating ring bearing simulation is discussed.

Vibration Control and Isolation (TP14)

94 - ON THE REMOVAL OF BREAK SQUEAL BY TUNED MASS DAMPERS

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Break squeal is one of the most disruptive noises produced especially by upper class vehicles. The non-symmetric contact between pads and disc excites resonant frequencies of the disc, producing a shrill sound which is unacceptable to most drivers. Methods for reducing break squeal without major alterations to the axis geometry must reduce the stiffness and the forces acting on the vibration system. However, these reductions severely decrease brake performance. Tuned Mass Dampers are a broadly accepted tool to reduce unwanted vibrations. The addi-tional masses of the Tuned Mass Dampers are coupled via a defined stiffness to the vibrating system, such that excited parts will transmit their energy to the damper. To reduce the break squeal problem the masses must be applied to the rotating disk without contacting the pads. As many modern break discs are supplied with cooling channels the dampers could be placed into some of them. A set of such dampers could be designed to cover the range of critical fre-quencies over the lifetime of the disc. A problem of this design lies in the limited mass of dampers able to be placed into the cooling channels. Furthermore, the reduction of the flow of air through the channels may cause local deformations. The basic principle is outlined, design proposals are demonstrated and applications shown. The idea may help to reduce break squeal, or even remove it entirely.

104 - TECHNIQUE TO OVERCOME PIEZO STACK ACTUATOR SATURATION USING PARALLEL STIFFNESS COMBINATION FOR AN ACTIVE SUSPENDED HANDLE

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This paper presents a technique to overcome piezo stack actuator saturation using parallel stiffness combination (PSC) based on the deflection shape of an active suspended handle. Three types of stiffness are designed at the center, center-end and at the end of the lower handle structure to strengthen the active area of piezo stack actuator. The combination of these stiffness show a significant improvement of the structure by shifting the modes of the structure outside of the operating frequency range of an active suspended handle. The PSC is realized in the form of material modification for the actual active suspended handle with an equal total stiffness value. Experimental modal analysis is carried out to validate the model of the modified active suspended handle. A real-time proportional-integral-derivative (PID) controller is developed to provide a counter voltage for the active vibration control (AVC) system. Using this technique, the effective frequency range of isolation is improved and reduced the vibration transmissibility of the handle. The modified active suspended handle is then attached to a die grinder to prove its effectiveness.

144 - A CONTRIBUTION TO THE REDUCTION OF SELF-EXCITED VIBRATIONS OF DYNAMICAL SYSTEMS BY IMPULSIVE PARAMETRIC EXCITATION

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In this paper, the possibilities of reducing self-excited vibrations of dynamical systems by using stiffness excitation of impulsive type are investigated. The self-excitation mechanism is modeled by a linearized Rayleigh approach, describing self-excited vibrations which originate from fluid flows with constant velocity, for example. A stiffness element, which is capable of changing its stiffness value is introduced to affect the dynamical behav-

ior of the mechanical system in a targeted manner. The proposed approach for the reduction of vibrations is based on the theory of impulsive parametric excitation. Therewith, the effect of parametric impulses of Dirac delta type to the modal energy content of mechanical systems can be investigated analytically. Self-excited vibrations result in an increasing energy content of a mechanical system. It is shown in this contribution that a proper impulsive parametric excitation, applied in a state-dependent manner, allows to shift kinetic energy from lower, to higher modes of vibration. As higher modes possess enhanced damping properties compared to lower ones, the damping properties of the mechanical system are utilized more effectively. In the theoretical case of applying parametric impulses of Dirac delta type, it is shown that certain states of the mechanical system exist, which allow a modal energy transfer to higher modes where no external energy is required, i.e. the total energy content of the mechanical system remains unchanged. This may results in a stabilization of the otherwise unstable system, which is demonstrated with a numerical example with three degrees of freedom, where the stiffness impulses of Dirac delta type are replaced by rectangular shaped ones.

145 - ACTIVE SUSPENSION LQ CONTROL FOR IMPROVING RIDING COMFORT

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The purpose of this research is to improve the perceived comfort in passenger's cars, by means of a properly tuned optimally controlled active suspension, exploiting conceptual human body models as a tool for virtually sense human body vibrations. Canonical approaches achieve comfort performance by reducing vehicle body accelerations. Complimentary, our ap-proach aims to reduce also human body vibrations, taking into account their estimation by means of a simplified human body model. In order to assess whether and to what extent the proposed approach improves comfort, we defined a case study where just vertical vibrations are considered. In this scenario, several conceptual human body models are available in literature, specifically designed for capturing the vertical vibrational behaviour of the driver while in the seated position. By coupling such a two DOFs human body model with a standard two DOFs quarter car model we get a four DOFs driver-car system on which the linear quadratic optimal control design was performed to obtain the optimally controlled behaviour. For validating the approach, we derived also the optimal control of the active suspension in a canonical sense (i.e. by aiming at reducing vehicle body vibrations) which we adopted as the reference model. By use of numerical simulations, we fi-nally compared the proposed active suspension optimal control highlighting the main differ-ences w.r.t. the reference model in terms of head vibrations (vertical accelerations), vehicle body vibrations, suspension travel, and tire deflection. In particular, we considered two differ-ent scenarios: one where the vehicle travels just over the planar straight road roughness at a constant speed of 72km/h, and the other one where the vehicle pass over a sinusoidal bump with a frequency of 2 Hz. Numerical results demonstrate that the proposed controller is able to reduce the driver head's vibrations in both situations more than the standard approach, leading this way to an improvement of comfort.

164 - FRACTIONAL PID CONTROLLER TO AN ACTIVE IMAGE STABILIZATION SYSTEM

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Applications involving machine vision in agriculture has been researched in recent decades mainly for non-destructive measurement, visual navigation and behavioural surveillance. The development of autonomous agricultural vehicles or mobile robots for different kinds of applications depends on the development of such technologies. However, there are still significant challenges to overcome to enable commercial agricultural technologies both for processing and for the image acquisition system. One of these challenges corresponds to the vibrations of the machines themselves that harm the acquisition of images. Vibrations of parts of machinery

can lead to blurry images that have a negative impact on the accuracy of measurement applications for the machine vision system. Furthermore, continuous vibration can damage the electronics components of this system. In this context, active image stabilization (AIS) has interests in areas such as robotics to eliminate or reduce unwanted fluctuations in the acquired images. The unintentional movements are identified by inertial sensors and a controller determines commands to an active stabilizing mechanism. Advanced control methods have been researched to improve accuracy AIS systems. In this paper we considered a system involving an oscillatory mechanical platform that can be used, for instance, in image acquisition on the field through a camera on the top of a vehicle (a mobile robot), which moves in a rough ground. However, the impact caused by irregularities on the ground during displacement of the platform provokes oscillations, interfering with the precision of any activity performed by the camera, hence reducing the video or image quality. Therefore, may be convenient or even necessary a better attenuation or suppression of these vibrations. Thus, a Fractional Order PID (FOPID) controller was proposed. Different excitations inputs were considered and some parameters such as overshoot, stabilization time, peak time were analyzed in order to understand what would be the implications of this type of fractional controller on the system.

227 - VIBRATION PROTECTION OF OBJECT WITH HELP OF THIN-LAYERED RUBBER-METAL ELEMENTS

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Rubber and rubber-metal (RM) elements are successfully used as bearing, joints, compensating devices, vibration and shock absorbers in civil engineering and machine building because of rubber and rubberlike materials (elastomers) have a capability of absorbing input energy much better than other construction materials. The elastic properties of rubber in such supports allows reverse backward to its original position under dynamic load action. Along with the immediate elastic deformation these materials exhibit a retarded elastic deformation, viscous flow (creep) and relaxation. The mechanical properties of rubber which are necessary for the optimal design of antivibration devices are next: bulk modulus of compression, dynamic and static shear modulus, energy dissipation factor. To describe the relationship between the compressive (or shear) stress $\sigma(t)$ and strain $\varepsilon(t)$ the creep and relaxation kernels, taking into account the viscoelastic properties of the rubber, are used. In this paper the flat-type RM absorber with kinematic harmonic excitation is considered. For the accounting of dissipative properties of the rubber Rabotnov's kernel is used, the energy loss during one oscillation period is calculated. Damping properties are expressed by the ratio of amplitude of the driving vibration to the amplitude of the forced oscillations of object.

232 - EFFECTIVENESS OF SEISMIC-TUNED PASSIVE TUNED MASS DAMPERS ACCOUNTING FOR SOIL-STRUCTURE INTERACTION

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Tuned Mass Damper (TMD) devices are generally considered as valuable means for reduction and control of undesired vibrations and excessive dynamic responses of structural systems. The expectable level of performance of TMDs in the framework of earthquake engineering, a research topic widely studied and still debated, doubtlessly plays an important role, since TMDs may represent a convenient intervention solution for both aseismic structural design and seismic retrofitting of existing structures. The present paper is placed within such a research context, aiming at investigating the potential effectiveness of an optimum passive TMD in reducing the structural response to strong-motion earthquakes of a given set of MDOF shear-type frame structures. One of the most relevant features of this study is the proposal of a seismic-tuned TMD, optimised through an innovative numerical method, apt to provide the optimum configuration of the control device for a given combination of host structure and seismic event. A further important aspect is the consideration, within the structural and dynamic model, of Soil-Structure Interaction (SSI) effects, which looks crucial for a comprehensive analysis of the whole context. Moreover, being SSI embedded within the tuning process, an influence on both optimum TMD parameters and achievable TMD performance is recorded and quantified. The obtained results, focussing

on the relations between all considered features (including soil parameters) and arising TMD effectiveness in terms of reduced seismic response, also for post-tuning trials, provide crucial information towards the final evaluation of TMDs as possible useful control devices in earthquake engineering applications.

247 - A METHODOLOGY TO DECOUPLE THE TONAL NOISE SOURCES OF A COMPRESSOR SYSTEM

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Fans and compressors generate noise which can be split into two main components: aerodynamic and structure borne noise. In the case of a small compressor for domestic appliances, the aerodynamic noise governs the broadband signature and dictates the overall sound power level, but also exhibits tonal content. Structure borne noise also contributes to the sound power level, but it originates from the vibration generated due to rotating unbalance and therefore has a predominately tonal characteristic that is detrimental to the sound quality. To control the structure borne noise the motor mount must adequately isolate the vibration generated.
In this paper a methodology is proposed to experimentally decouple the aerodynamic and structure borne tonal noise. Experimentation has been performed on a compressor that is mounted with different schemes, ranging from a rigidly coupled to a soft mounted system. For each of these schemes the contribution of the structure borne and aerodynamic tonal content is evaluated and compared with the ideal tonal noise floor represented by the broadband level. The broadband signature is defined using a median filter, which replaces each data point with the median of its neighbouring values, thus removing the tonal content from the power spectrum.
Using this technique, it was found that the soft mount scheme suitably isolated the vibration and thus minimised the structure borne contribution. Furthermore the technique outlined has been used to categorise and weight the different transmission paths contribution to the the noise. This information, which dictates the appropriate noise control solution, is valuable to improve the sound quality of such compressor systems.

Non-linear Dynamics and Dynamic Stability (MS01)

85 - QUASI-PERIODIC RESPONSE TYPES OF A SINGLE NON-LINEAR DYNAMIC SYSTEM IN RESONANCE AND OUT OF RESONANCE DOMAINS

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The exact coincidence of external excitation and basic eigen-frequency of a single degree of freedom (SDOF) non-linear system produces stationary response with constant amplitude and phase shift. When the excitation frequency differs from the system eigen-frequency, various types of quasi-periodic response occur having a character of a beating process. The period of beating changes from infinity in the resonance point until a couple of excitation periods outside the resonance area. The shape of the response amplitude envelope within one quasi-period changes dramatically with increasing frequency distance from the resonance. The above phenomena have been identified qualitatively in many papers. Nevertheless investigation of internal structure of a quasi-period and its dependence on the difference of excitation and eigenfrequency is still missing. Authors cover this gap using qualitative analytical methods and numerical procedures. Combinations of harmonic balance and small parameter methods are used for qualitative analysis of the system in mono- and multi-harmonic versions. They lead to non-linear differential and algebraic equations serving as a basis for qualitative analytic estimation or numerical description of characteristics of quasi-periodic system response. Zero, first and second level perturbation techniques are used. Appearance, stability and neighbourhood of limit cycles is evaluated. Numerical phases are based on simulation processes and numerical continuation tools. Parametric evaluation and illustrating examples are presented.

97 - INTERACTION OF FRICTIONAL AND REGENERATIVE MECHANISM OF CHATTER VIBRATIONS

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This paper presents new model of frictional chatter extended with regenerative effect due to modulation of cutting depth. These both chatter mechanisms interact each other giving interesting effect of nonlinear dynamics. Nonlinear behaviour is examined with the help of bifurcation diagrams where cutting velocity is chosen as the bifurcation parameters.

116 - INFLUENCE OF SHEAR DEFORMABILITY AND AXIAL/ROTATIONAL INERTIA IN THE NONLINEAR FREE VIBRATIONS OF BEAMS WITH DIFFERENT BOUNDARY CONDITIONS

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Nonlinear free oscillations of elastic beams have been investigated in the past aimed at highlighting the effects of kinematical and dynamical assumptions under different boundary conditions. Yet, open issues still occur as regards the influence of the various assumptions (concerned with axial inertia, rotational inertia, shear deformability, and nonlinear curvature) in variable geometrical situations. This paper aims at comparatively highlighting their importance via a unified treatment of the nonlinear free vibrations of hinged beams with either an axially restrained (hinged-hinged) or free (hinged-supported) end. Three geometrically exact equations of free motion in the axial and transverse displacement and in the shear angle are obtained. They are strongly

nonlinear and cannot be solved in closed form, so an asymptotic method is applied to obtain an analytical solution approximate to the third order, which is then investigated in detail. Longitudinal and transverse dynamics are decoupled at first order, which allows to assume vanishing (first order) axial displacement and obtain the equation of motion in the sole transverse displacement. It provides the first order normal mode and the linear natural (circular) frequencies of the system, both of which do not depend on the type of the boundary condition in the axial direction. The second order problem provides the axial displacement, which instead depends on the type of boundary conditions. The second order (nonlinear) frequency is provided by the solvability conditions of the third order problem, and depends on the square of the oscillation amplitude; it gives the bending of the so-called "backbone" curve. The main goal consists of studying the dependence of the second order frequency on the axial and rotational inertia, on the shear stiffness and, mainly, on the kind of axial (immovable or movable) boundary. The accomplished comprehensive treatment allows to resume and properly framework literature results, while also shedding new light on the comparative importance of the beam geometrical and mechanical properties.

205 - MULTI-MODE SOLUTIONS IN A PERIODIC ARRAY OF COUPLED NONLINEAR PENDULUMS UNDER PRIMARY RESONANCE

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Nonlinear periodic systems are frequently encountered in serval scientific domains such as biology, optics, acoustics and mechanics. The periodic array of coupled nonlinear pendulums represents a famous example which can be described by the sine-Gordon model. The latter is suitable for a large variety of physical systems, what explains the vast research area developed around this field. Although the dynamic behavior of coupled nonlinear pendulums were thoroughly investigated in the frequency and time-space domains in term of intrinsic localized modes, the collective dynamics has not been yet analyzed.
In this context, we investigate the nonlinear dynamics of a periodic lattice of coupled pendulums under primary resonance. The coupled equations governing the nonlinear vibrations of the considered system have been normalized and transformed into a set of coupled complex algebraic equations using the multiple scales method coupled with standing wave decomposition. The resulting nonlinear system has been numerically solved using the asymptotic numerical continuation technique. Several numerical simulations have been performed for different sets of design parameters in order to analyze the modal interactions resulting from the collective dynamics of pendulums. It is shown that the number of additional multi-mode solutions is large even for an array of few pendulums and the stability of the corresponding branches can be tuned with respect to the design parameters. In practice, the nonlinear stiffness can be functionalized in order to enhance the performances of the system in term of energy transfer.

225 - A PARAMETRIC STUDY OF THE NON-LINEAR RESPONSE OF PLANE FRAME STRUCTURES UNDER SEISMIC LOADS IN FREQUENCY DOMAIN

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The structural dynamic analysis in the frequency domain is a topic with great importance in the analysis of structures. In complex problems, the determination of the response in frequency domain, characterized by the resonance curves, is, in some cases, indirectly obtained through analysis in time domain, which leads to big computational efforts when analyzing structures with several number of degrees of freedom. In non-linear cases, the response in frequency domain becomes more complex than in linear cases because of the possibility of multiple solutions for certain frequencies. Those solutions can be stable, unstable or bifurcations, which create the conditions for the appearance of different limit points on resonance curves. In this work, an incremental technique for direct calculation of the non-linear dynamic response in frequency domain of plane frame systems subjected to seismic actions is presented. The transformation of discretized motion equations system, in the context of the Finite Element Method, to the frequency domain is made through the classical Harmonic Balance Method for the linear case. For non-linear analysis, a variant of the Harmonic Balance Method in conjunction

with the Galerkin Method to obtain the non-linear algebraic equations in the frequency domain is used. For the non-linear analysis, geometric non-linear formulation is considered. To obtain the resonance curves, the arc-lentgh control method is adopted for the solution of the algebraic non-linear system of equations. The influence of geometric parameters of the structure system over resonance curves is studied as well.

272 - NUMERICAL AND EXPERIMENTAL INVESTIGATION OF AN UNDER-PLATFORM DAMPER TEST RIG

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During operation mechanical structures can experience large vibration amplitudes. One of the challenges encountered in gas-turbine blade design is avoiding high-cycle fatigue failure usually caused by large resonance stresses driven by aeroelastic excitation. A common approach to control the amplitude levels relies on increasing friction damping by incorporating underplatform dampers (UPD). An accurate prediction of the dynamics of a blade-damper system is quite challenging, due to the highly nonlinear nature of the friction interfaces and detailed validation is required to ensure that a good modelling approach is selected. To support the validation process, a newly developed experimental damper rig will be presented, based on a set of newly introduced non-dimensional parameters that ensure a similar dynamic behaviour of the test rig to a real turbine blade-damper system. An initial experimental investigation highlighted the sensitivity of the measured response with regards to settling and running in of the damper, and further measurements identified a strong dependence of the nonlinear behaviour to localised damper motion. Numerical simulations of the damper rig with a simple macroslip damper model were performed during the preliminary design, and a comparison to the measured data highlighted the ability of the basic implicit model to capture the resonance frequencies of the system accurately.

293 - A ROTATING PENDULUM WITH IRRATIONAL NONLINEARITY

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In this paper, we consider a novel model which comprises a rotating pendulum linked by a pair of linear springs with fixed ends. This model provides a typically cylindrical dynamical system with irrational nonlinearity due to the geometry configuration. This system exhibits smooth or discontinuous characteristics depending on a mechanical parameter, which is similar to the conventional pendulum coupled with SD oscillator. We discuss the irrational restoring force, potential energy, equilibrium bifurcations and transitions of phase portraits for the unperturbed dynamics. The primary responses of the small angle oscillation can be studied by means of the averaging method under the perturbation of viscous damping and external harmonic forcing. Finally, numerical simulations is carried out to investigate the complicated dynamics behavior of periodic and chaotic motions in both smooth and discontinuous case.

308 - DISCONTINUITY INDUCED BIFURCATIONS IN HIGHER DIMENSION FILIPPOV SYSTEMS

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Discontinuity induced bifurcations in higher dimensional Filippov systems B Santhosh, C Padmanabhan, S Narayanan Department of Mechanical Engineering IIT Madras, Chennai, India 600036 Nonlinear systems with discontinuous nonlinearities involving impact, friction exhibit discontinuity induced bifurcation like sliding and grazing bifurcations. These bifurcations take place when periodic trajectories interact with a discontinuity surface. The sudden onset of chaos and stick-slip phenomena in dry friction systems can be explained in terms of these bifurcations. In this paper, numeric and numeric-analytic methods are used to study the dynamics of harmonically excited nonlinear systems with discontinuous nonlinearities by modeling them as Filippov systems. The switch model based numerical integration in combination with the shooting method is used to obtain the periodic solutions and the bifurcations. The smooth and discontinuous (SD) oscillator and systems with friction are considered as examples. The sudden transition of the periodic solution to chaotic solution in these systems are due to the grazing bifurcation. The Lyapunov exponents corresponding to the chaotic solution can be obtained by the chaos synchronization method. The system thus becomes a two dimensional Filippov system. A method to solve the higher dimensional Filippov system based on the switch model based numerical integration is also outlined.

Frequency-based spectral methods for vibration random fatigue (MS02)

10 - DERIVATION OF EQUIVALENT POWER SPECTRAL DENSITY SPECIFICATIONS FOR SWEPT SINE-ON-RANDOM ENVIRONMENTS VIA FATIGUE DAMAGE SPECTRA

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Launch vehicles may encounter a variety of mixed sine and random vibration environments during powered flight. The random vibration is typically driven by turbulent boundary layers, shock waves, and other aerodynamic flow effects. The sine vibration may be due to a thrust oscillation for the case of a solid motor. Furthermore, the thrust oscillation frequency and amplitude may each vary with time. Both the sine and random environments may thus be nonstationary. Avionics components must be designed and tested to withstand the composite vibration environment. A single power spectral density specification which envelops the complete environment is usually desired for simplicity. Furthermore, the power spectral density specification is assumed to have a corresponding time history which is both stationary and Gaussian. Traditional specification derivation methods involve assuming piecewise stationary flight data and making a maximum envelope from the piecewise segments. A more discerning method is to use the fatigue damage spectrum method to derive a stationary power spectral density which yields the equivalent fatigue damage of the composite nonstationary flight data. This paper demonstrates this fatigue damage enveloping method.

12 - FATIGUE ASSESSMENT OF NON GAUSSIAN RANDOM VIBRATIONS BY USING DECOMPOSITION IN GAUSSIAN PORTIONS

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For the analysis of random vibrations a well established set of tools is available based on the assumption of a Gaussian distribution of the analyzed signals. These tools may, for example, be applied very efficiently in the area of structural dynamics to perform a simulation based fatigue strength analysis. The procedure is based on the application of the power spectral density (PSD) of a given excitation signal, the frequency response functions of the analyzed structure, special methods (e.g. Dirlik's Method) for the estimation of load spectra directly from stress response PSDs and a method for the derivation of equivalent fatigue values from these stress load spectra (e.g. Miner's rule). These procedures are based on the assumption that the analyzed time signals have Gaussian distribution; any deviation from this theoretical distribution can cause conservative or non conservative deviations from the real fatigue damage value. Unfortunately lots of real excitation signals show such a deviation. Consequently, the above presented methods can not be used for reliable fatigue strength predictions. Therefore alternative methods are available, usually coming along with certain drawbacks. This paper introduces a new method for the substitution of a non Gaussian signal by a combination of several Gaussian signals (each having its own PSD) by preserving the spectral properties and the fatigue damage potential of the initial non Gaussian signal. By going back to these Gaussian distributions all the well established methods for Gaussian signals may still be applied without any extensions or modifications. The primary focus of this paper is the simulation based fatigue strength analysis; the results may also be applied to experimental procedures.

90 - AN ANALYTICAL APPROACH TO MEASURE THE ACCURACY OF VARIOUS DEFINITIONS OF THE "EQUIVALENT VON MISES STRESS" IN VIBRATION MULTIAXIAL FATIGUE

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The "equivalent von Mises stress" has been proposed by Preumont and co-workers as a criterion to approach multiaxial random fatigue in the frequency-domain. Since its first original formulation, the EVMS criterion has found wide use in academic and industrial research. Several studies have shown that the EVMS criterion is based on some inherent hypotheses: i) S-N fatigue lines for normal and shear stress must have equal slopes, ii) the fatigue strengths for normal and shear stress must be scaled by a factor $\sqrt{3}$=1.732. Such studies pointed out that The EVMS criterion may lead to inaccurate damage estimations for those materials, which do not comply with the above hypotheses. Some attempts have been proposed to correct these inaccurate estimations, by providing modified formulations of the original EVMS criterion. This study critically analyses and compares all available modified formulations of the EVMS criterion. Analytical expressions are derived to check the accuracy of such formulations for different random loading types (e.g. pure bending, pure torsion, combined bending plus torsion). The derived analytical expressions will also allow engineers to understand when the EMS criterion and its modifications can safely be applied in the fatigue design.

120 - SIMULATION OF THE WHOLE WIND-INDUCED FATIGUE LIFE OF A SLENDER STEEL STRUCTURE

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Wind-induced vibrations can lead to fatigue damage in many slender structures, such as wind turbines, cranes, poles and towers. Wind-induced load constitutes a non-stationary, non-Gaussian random process. The methods for fatigue analysis generally define a series of independent loading conditions, each corresponding to a fixed value of mean wind velocity and direction, whose long-term time variation is taken into account probabilistically. The wind effects associated to the loading conditions are usually evaluated adopting three different approaches. The time-domain procedure requires the acquisition of stress time series corresponding to all the considered loading conditions, then post-processed by the Rainflow counting method. Such method is numerically burdensome, however it is still largely adopted in many practical problems and standards codes. The frequency domain approach schematizes the wind effects associated to the loading conditions as stationary, Gaussian processes; the fatigue damage is obtained adopting analytic formulations based on the spectral properties of loads. Such methods can be adopted to derive engineering procedures for simple structures but are still unsuitable for extensive application in complex structures design. The third approach, referred to as statistical extrapolation method, is aimed at improving the efficiency of the time-domain approach starting from short-term simulated time series. The three approaches have mutual strengths and weaknesses and none of them meets with the general approvals of the technical community. The present paper contributes to the discussion, presenting the results of a long-term simulation of fatigue damage of a steel lighting pole, corresponding to 50 years of structural life, containing both macro- and micro-meteorological fluctuations of the same 'probable' wind. The simulated analysis is adopted to discuss the three traditional approaches above. In particular, the benchmark result is firstly used to discuss the reliability of time-domain methods, with reference to the uncertainties related to the transition cycles of fragmented time-histories and to the time length of independent loading conditions; then, it is compared with the most relevant frequency domain methods and with the statistical extrapolation method, to assess their suitability for modelling the wind-induced fatigue phenomenon in slender structures.

167 - SHAKER TESTING SIMULATION OF NON-GAUSSIAN RANDOM EXCITATIONS WITH THE FATIGUE DAMAGE SPECTRUM AS A CRITERION OF MISSION SIGNAL SYNTHESIS

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Experimental simulations of random excitations are nowadays performed digitally by applying the Inverse Fast Fourier Transform (IFFT) to the desired Power Spectral Density (PSD) profile, in combination with randomized IFFT phases. However, the excitations generated in this way will always have a Gaussian probability

distribution, whereas real-life random excitations are typically non-Gaussian. For example, in the case of land transportation some distinctive peaks will occur which exceed the average level of vehicle vibration. The statistical parameter known as kurtosis can characterize this feature and could be controlled in experimental simulations in addition to the PSD. The so-called "kurtosis control" can be achieved by special phase manipulation instead of selecting the phases randomly. By increasing the kurtosis, it is furthermore also possible to obtain an accelerated qualification test, whereby the time-to-failure (TTF) is decreased in a controlled manner. It is known that the response of a lightly-damped linear system is closer to Gaussian than the applied excitation. Therefore, in order to increase the response kurtosis in an accelerated test, the kurtosis control method must be able to effectively generate extra kurtosis. In this work a method was used which indeed achieves a high excitation kurtosis, which moreover passes into the response of the structure. According to the Fatigue Damage Spectrum (FDS) model, a singledegree-of-freedom system was hereby considered in order to calculate the structural response. Furthermore, the rainflow counting procedure and the Miner damage accumulation rule were employed to predict relative TTFs for operational excitation and accelerated test mission. Finally, the considered method of non-Gaussian shaker testing simulation was also advanced from kurtosis control to direct application of the FDS as a criterion for mission signal synthesis. An extensive experimental campaign was carried out, where an example of a real-life vibration excitation measured on the cabin floor of a car was considered. Shaker testing was performed for a cantilevered test specimen subjected to various simulated Gaussian, nonGaussian, accelerated non-Gaussian, and real road excitations

193 - FULL FIELD EXPERIMENTAL MODELLING IN SPECTRAL APPROACHES TO FATIGUE PREDICTIONS

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Experimental techniques based on optical dynamic measurements with high spatial definition proved to be able to model dynamic strain maps on the surface of components by means of corresponding strain frequency response functions. By means of a constitutive model, dynamic stress FRFs can be modelled directly from receptance estimations, avoiding the costly & time-consuming steps of building and tuning a numerical dynamic model of a flexible component or a structure in real life conditions. Once dynamic stress FRFs are obtained, spectral fatigue approaches can predict the life of a component in different excitation conditions. In this paper high quality receptance maps from three different full field technologies (SLDV, Hi-Speed DIC and dynamic ESPI), estimated on a thin plate as light-weight structure with broad band dynamics and high modal density in a unique comparative set-up, are used to obtain the dynamic stress FRFs. Different spectral shapings of the excitation can be used to enhance the comparison in the framework of the spectral approaches for fatigue life calculations. The fatigue life predictions from the three optical measuring techniques are compared and discussed in detail, highlighting benefits and drawbacks of a direct experimental approach to failure & risk assessment in structural dynamics.

282 - EXPERIMENTAL COMPARISON OF MULTI-AXIAL CRITERIA IN FREQUENCY-DOMAIN

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Vibration endurance must be ensured for structures that will be exposed to different vibratory loads, originating from environment and rotating and other machinery. Accelerated vibration tests until failure are usually done using shakers and other equipment. With the help of state-of-art vibration fatigue methods vibration endurance can be analyzed and estimated. The analysis procedure consists of structural dynamics analysis and is followed by fatigue analysis made on the resulting stress states. For broad-band excitation these are of random nature and very suitable for frequency-domain approach, e.g. fatigue cycle analysis of (equivalent) uni-axial stress which is well researched. This study researches the multi-axial criteria that are used to reduce the complex multi-axial stress state to an equivalent uni-axial stress. Several multi-axial criteria formulated for the frequency-domain can be found in literature. However, experimental studies exploiting natural response to induce multi-axial stress state are less frequent. This research first presents and then theoretically and experimentally compares selected multi-axial criteria for analysis in frequency-domain. The criteria of maximum normal stress, maximum shear stress and the C-S criterion are considered. Next, an experiment is performed to provide experimental data which serves as a basis for experimental comparison of selected multi-axial criteria. A special specimen is used with significant resonances present in the frequency range of applied vibration. Two broadband excitation sources are used to excite the specimen simultaneously. Time-to-failure results are compared across multi-axial criteria and with experimental data. Accuracy of multi-axial criteria is assessed with the aim of choosing the criterion that is most suitable for analysis of random stress response. Experimental data also show that selected methods give reliable time-to-failure estimates and can be used for fatigue analysis of mechanical structures exposed to broadband random vibration.

318 - A REVIEW AND COMPARISON OF CYCLE IDENTIFICATION METHODS FOR FATIGUE AND FRACTURE ANALYSIS

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A comprehensive review of fatigue cycle identification (counting) methods is presented for the purpose of encouraging a common standard of practice within the NASA and aerospace contractor community of practice. The primary source of commonly accepted standard cycle identification methods used in this review is ASTM E1049 - 85(2011)e1, "Standard Practices for Cycle Counting in Fatigue Analysis". An independent comparison of these methods, as well as other methods available in the literature, is presented by application of the methods to a number of time histories synthesized from numerous example power spectral densities (PSDs). The PSDs are selected to span a large range of bandwidth and spectral shapes to elicit cases for which particular counting methods may be best or poorly suited. Other factors influencing the selection of a cycle identification method, such as the specifics of the resulting fatigue spectrum's application in a fracture mechanics analysis (as by NASGRO for example), are discussed. Time domain cycle counting methods are also compared with some common spectral methods such as the Rayleigh, Wirsching-Light, Ortiz-Chen, Dirlik, Benasciutti-Tovo, Zhao-Baker, and Single-Moment.

Vibration Problems in the Solids Systems With Dry Friction (MS03)

271 - ON VIBRATIONAL SMOOTHING OF DRY FRICTION AND ITS APPLICATION TO REVOLUTE JOINTS

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The effect of vibrational smoothing of dry friction has been subject of many publications in the past. High-frequency vibrations have been shown to smooth the average characteristics of dry friction at low sliding velocities and, consequently, avoid undesired friction induced phenomena such as stick-slip motion. Intending an improvement in process quality, this effect is used in industrial manufacturing, especially in the field of metal forming. Concerning other manufacturing processes or in particular positioning applications, accuracy may be limited by joint friction. In order to overcome this problem, it is the objective to develop a revolute joint with little clearance but without undesired phenomena caused by dry friction. Avoiding lubrication, the effect of vibrational smoothing is to be used in order to ensure the intended properties of the joint. Yielding improved understanding of the underlying mechanisms, the effect of transverse high-frequency vibrations on a 1-DoF-friction oscillator is investigated here. Using a point contact model, the importance of contact compliance is carved out. Based on the friction model suggested by Dahl, a reduction of the smoothing effect is observed compared to classical Coulomb friction results. Finally, the application to revolute joints is discussed.

289 - IDENTIFICATION STRATEGIES FOR FRICTION LAWS: A NUMERICAL STUDY

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Many friction laws have been proposed but a law capable of accurately predicting all aspects of dynamic frictional behaviour from frictional damping to the thresholds and transients of stick-slip remains to be found. This paper describes an approach to identifying which features of a stick-slip waveform may be useful for experimental identification of a friction law; this will then aid the design of experimental procedures.
A numerical study of a single degree of freedom oscillator driven by the Spinodal rate and state friction law has been performed. A number of metrics that describe features of the waveforms have been extracted from the simulated data to produce surfaces across a parameter plane where experimental conditions are varied in one direction and a feature of the friction law is varied in the other. The surface then shows whether the metrics are sensitive to the friction law and/or to experimental conditions and so whether they are useful for experimentally discriminating between laws.
For rate and state laws the loop-area in the friction force - sliding velocity plane and the skew of the velocity waveform were seen to vary with both the normal load and with the timescale of the state evolution law which means these metrics may be useful experimentally. On the other hand, metrics such as the proportion of the period spent sticking only vary with the normal load, which makes them less useful experimentally.

298 - INFLUENCE OF CONTACT CHARACTERISTICS ON THE DYNAMIC BEHAVIOR OF RUBBING STRUCTURES

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The modelling of the vibratory response of jointed structures can become a very delicate task due to the nonlinear behavior induced by dry friction occurring at the interfaces. Sticking, macro or micro slipping between interfaces has non negligible effects on both the natural frequencies and damping properties. Dealing

with complex structures, reduced-order friction models are required. Thus the physics and modeling precision are often compromised for time calculation efficiency. Not to mention that due to the diversity of contact configurations, a large number of these models are non-generalizable. In most cases, experimental hysteresis curves are needed in order to identify which type of friction is occurring at the interfaces (macroslip or microslip), and curve-fitting is used to find the model parameters. These issues has motivated many researchers to develop physics based models only take into account the material and geometrical properties of the contacting surfaces, surfaces roughness data, and contact loading. Knowing the behavior of an individual asperity pressed against a flat surface, it is possible thanks to statistical summation to simulate the global behavior of two rough flat-on-flat surfaces rubbing against each other. These models are validated experimentally considering quasi-static case studies. In the current study, a simple, yet easily customizable test rig has been developed to measure the dynamic response of a steel beam associated with several friction devices. Along with the experimental work, numerical simulations taking into account the above mentioned physical parameters have also been investigated and comparisons between both spectrums are made.

335 - ON THE DYNAMICS OF THE SYMMETRICAL SOLIDS ON A VIBRATION RUBBED HORIZONTAL PLANE

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It is considered the influence of the combined dry friction on a free motion of the symmetrical solids on rubbed plane which is performing periodical oscillation in the vertical direction. Arising dry friction effects are described with aid of theory of multicomponent dry friction based on analytical approximants of the exact integral dry friction models. There are found solids trajectories with taking in account the dynamics coupling of the components defined the force state.

344 - FALLING MOTION OF A CIRCULAR CYLINDER INTERACTING DYNAMICALLY WITH A POINT VORTEX

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The problem of falling motion of a body in fluid has a long history and was considered in a series of the classical and modern papers. Some of the effects described in the papers, such as periodic rotation (tumbling), can be encountered only in viscous fluids and thus demand for their proper treatment the use of the Navier - Stokes equations with boundary conditions specified on the body's surface. As a rule, such problems can be addressed only numerically. The fluid's viscosity imposes resistive forces on the body. These forces manifest themselves not only through the skin friction but they also serve a source of vortex generation. To evaluate a model which is a more or less realistic and at the same time amenable to analytical treatment it is customary to assume the liquid to be ideal and add the vorticity ad hoc meaning that we postulate the existence of, say, circulation, point vortices or vortex sheets etc. In this paper we study the influence of the vorticity on the falling body in a trivial setting: a body (circular cylinder) subject to gravity is interacting dynamically with a point vortex. The dynamical behavior of a heavy circular cylinder and a point vortex in an unbounded volume of ideal liquid is considered. The liquid is assumed to be irrotational and at rest at infinity. The circulation about the cylinder equals to zero. The governing equations are presented in Hamiltonian form. Integrals of motion are found. Allowable types of trajectories are discussed in the case of single vortex. The stability of finding equilibrium solutions is investigated and some remarkable types of partial solutions of the system are presented. Poincare sections of the system demonstrate chaotic behavior of dynamics, which indicates a non-integrability of the system.

348 - EXPERIMENTAL INVESTIGATION ON SQUEAL-NOISE OF DISK-BRAKES FOR RAILWAY APPLICATIONS

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In this paper we propose a theoretical and experimental investigation on noise emitted by a disc brake for railway applications. Even though this analysis has been performed on one class of disc brake systems the results can be useful for better understanding the path which brings to the generation of the brake noise. The system analysed in composed by a steel disk assembly on which acts a pad made of an array of cylinders of friction materials. This pad system makes easy simulations because has not needs to be "discretised", indeed, we can assume that it acts on the disk surface just in some points. The experimental investigation were made on a test-rig in real scale on which we have measured, by means a sound intensity probe, the noise emitted by disc brake and performed on it the FFT for identifying the frequencies with more high amplitude. The numerical results agree with the experimental ones.

Optimization on Vibration Control of Seismic Structures (MS04)

22 - OPTIMIZATION OF TMDS FOR SEISMIC STRUCTURES CONSIDERING NEAR FIELD GROUND MOTION SETS

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Near field ground motions records may contain pulse-like motions. Forward directivity effect is the main cause of these velocity pulses. The main aim of the study is to find optimum tuned mass damper (TMD) parameters for seismic structures subjected to near-field ground motions. In order to find a global optimum solution, two sets of ground motions including 28 records from 14 stations were used. These sets are presented in FEMA-P695 report for quantification of building seismic performance factors. All records of these sets were taken from the stations which are located less than 10 km from fault rupture. One of the sets contain records strong pulses, while the other one has no records with strong pulses. In optimization of TMD, a metaheuristic algorithm called harmony search was used. In the methodology, the objective function of the optimization is to reduce the first story displacement of the structure for the most critical excitation. The design variables include mass, period and damping ratio of the TMD. During optimization time-domain analyses are done for all random design variables assigned by using algorithm rules. As a numerical example, a ten storey structure is investigated. Two different optimum TMD pa-rameters were searched by using set of records with and without pulses. Thus, the optimum pa-rameters for different types of excitations are compared. The proposed method is effective to find optimum TMD for the structure for both types of excitations. As conclusions, it is possible to reduce structural displacements more effectively for excitations without pulses, but the opti-mum damping is higher than the optimum results obtained for records with strong pulses.

23 - A ROBUST OPTIMUM DESIGN APPROACH OF TMDS CONSIDERING STRUCTURAL UNCERTANITY

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In the analyses of civil structures, several assumptions are done in determining of structural properties. These assumptions may be the results of unknown live loading conditions or non-linear behaviour of structures during random excitations like earthquakes. The tuned mass dampers (TMD) used for the reduction of structural responses are tuned according to the prop-erties of the structure. In this paper, a robust optimization procedure considering five different stiffness of the struc-ture is proposed. A metaheuristic algorithm called harmony search is used in the optimization methodology. All design variables such as mass, period and damping ratio of TMD are itera-tively searched according to the employed algorithm. The methodology was applied for ten-story structures. All story stiffness values were changed between $\pm$ 30 %. The methodology con-sidering five different properties of structures is effective to reduce first story displacement un-der six different excitations by 26% while the reduction is 23% for the optimum values obtained without considering stiffness change. Thus, the proposed methodology is feasible for the tuning problem.

118 - EFFECT OF ECCENTRICITY ON ACTIVE CONTROL OF SEISMIC STRUCTURES

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Generally, all structures are torsionally irregular because of several reasons like the irregularity of plan and accidental torsion. Although a symmetric structure has the same point for centres of mass and rigidity, an amount of torsional effects called as accidental torsion can occur because of different distribution of live loads, torsional effects of earthquake excitations or the difference between computed and actual structural properties. These torsional effects can be reduced by using active control for seismic structures. In this paper, the change of eccentricity is investigated for an active structural control system designed for torsionally irregular structures. A single story torsionally irregular structure using active tendons controlled by Proportional-Integral-Derivative (PID) type controllers was taken as a numerical example. A numerical algorithm which scans the combination of controller parameters such as proportional gain, integral time and derivation time was used in tuning of controller and time delay of the control signal was considered as 20 ms. Error signal is taken as the velocity at the critical direction and sides of the torsionally irregular shear building under bi-directional near-fault earthquake excitation. The system tuned for a constant eccentricity was investigated for different eccentricities. Three different orientations of active tendons were investigated. In the first orientation, the structure is controlled from a single side in critical direction. In the second orientation case, the structure is controlled from the both directions, but only from two sides where the displacements are mostly affected by the torsion. The third orientation is the symmetrically control of structure from all sides. As conclusions, the first two orientations are not physically applicable because the centre of mass or rigidity may change because of uncertainty. Thus, the critical sides or directions may change. The third orientation is robust for different eccentricities in mean of reduction of structural responses and obtaining a steady stead response.

169 - MULTI OBJCETIVE OPTIMIZATION OF DOUBLE TUNED MASS DAMPERS CONSIDERING MAXIMUM STROKE CAPACITY

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A multi objective optimization approach is presented for double tined mass dampers (DTMD) positioned on the top of the seismic structures. In the optimization methodology, set of grouped earthquakes is used in order to find a global optimum solution under two objectives such as minimization of maximum top story displacement and limitation of maximum relative displacement of masses of DTMD (stroke). The optimization problem of DTMD has six design variables such as masses, periods and damping ratios of two masses. Harmony search (HS) algorithm is employed in the optimization process. HS is a music inspired metaheuristic algorithm using iterative stages of local and global search. The optimum design variables were found for a structure with 10 stories and three different limits of the stroke are investigated. According to the results and comparison to single tuned mass dampers, DTMDs are more effective than TMDs in reduction of structural responses.

230 - CONTROLLING OF THE FULL VEHICLE MODEL USING SLIDING MODEL CONTROL OPTIMIZED BY GENETIC ALGORITHM

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In this study, the dynamic behaviour of a non-linear seven degrees of freedom full vehicle mod-el using linear motor controlled by Sliding Mode Controller optimized Genetic Algorithm con-troller is examined. Main feature of the study is to isolate car body motion from the road dis-turbance and improve the ride comfort. The aim of this study is to design Sliding Mode Control-ler tuned by Multi Objective Genetic Algorithm (MOGA)

for providing smooth pitch, yaw and roll motions of car body. Sliding mode control (SMC) has been preferred in many mechanical and structural systems due to its robust character and high control performance. Choosing tuning optimum controller parameters for the vehicle model is an important problem. Therefore, Genetic Algorithm with several fitness functions is used to tuning optimum SMC coefficients. The full vehicle model is excited by road disturbance. Then, simulation results of uncontrolled and MOGA integrated sliding mode controllers models are compared. The results show that the full vehicle model with SMC optimized by MOGA is effective to decrease the effects of road disturbance induced vibrations.

231 - SUPPRESSION OF STRUCTURAL VIBRATIONS USING DYNAMIC ABSORBER

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Analysis and design of a dynamic absorber for vibration reduction of buildings is studied in this paper. A small two-storey building model consisting of steel plates and columns has been constructed in laboratory. Free vibration tests have been performed on this model in order to obtain parameter values of the physical building model for simulations. Then a dynamic absorber has been designed to suppress the vibrations of the building. The simulation and experimental results have been presented for comparison. Furthermore an optimal mass value for the dynamic absorber has been investigated and obtained. Finally the experimental results for the building vibrations along with the dynamic absorber with optimal mass have been presented. The results have shown that designed dynamic absorber reduced building vibrations effectively.

351 - SEISIMC ANALYSIS ON MULTI-LEVEL SUPPORTED PRESSURE RETAINING COMPONENTS IN NPPS BY USING RESPONSE SPECTRUM METHOD

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As integrity and/or functionality of pressure retaining components in Nuclear Power Plants (NPPs) is highly important to guaranty more reliable use of nuclear energy and much more acceptance from public. To deal with the effect by seismic and vibration, two cases shall be considered. One is single supported case and the other is multi-level supported case. Multiply supported case, again can be categorized into two cases. The first one is flexible component such as pipe system, while the second one is (relatively) rigid component such as pressure retaining components. Multiply supported flexible cases have been studied quite a lot, however, multiply supported (relatively) rigid case have not been studied that much. So, in this paper, multiply supported NPP pressure retaining components case will be handled. Modal analysis will be performed followed by case by case study. The modal deformation in the frequency range of interest will be considered to study the relation with the deformation by relative movement of multi-level supports, or whole system will be considered as a single supported case.

361 - ADAPTIVE INERTIAL SHOCK-ABSORBER FOR VIBRATION DAMPING

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The goal of this paper is to briefly describe the concept of a new shock-absorber and to discuss its unique characteristics in reference to the problems of vibration damping. The specific construction of the so-called SPIN-MAN device is introduced and the semi-active control performed on this device is presented. In order to prove the potential of presented shock-absorber, one of possible control strategies is described and results of its numerical simulation are shown. A specific control technique is demonstrated as the main source of significant improvement of the overall impact damping process. Possibility of the shock-absorber application for mitigation of earthquakes effects is investigated and features of the system enabling adaptation to identified impact conditions are indicated. Various applications of the SPIN-MAN are considered and requirements resulting from them are specified. Challenges which have to be overcome are presented and some solutions are proposed.

Vibration Analysis of Steel and Steel-Concrete Composite Structures (MS05)

73 - VIBRATION ANALYSIS OF STEEL-CONCRETE COMPOSITE MULTI-STOREY BUILDINGS

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Based on a favourable economic scenario combined with technological advances of the material sciences and construction processes, in the last thirty years, the Brazilian cities have presented a substantial growth related to construction of residential and commercial multi-story steel and steel-concrete buildings. Nowadays, these buildings present greater slenderness and have been constructed with more challenging structures that encompass the experience and knowledge of structural designers by using newly developed materials and technologies boosted by the ever-growing investigations on this field. This way, this work aims to investigate the static and dynamic structural behaviour of a 20 story steel-concrete composite building, when submitted to nondeterministic wind dynamic actions. In the building's interior core three types of bracings are presented and analysed. The developed numerical model adopted the usual mesh refinement techniques present in finite element method simulations implemented in the ANSYS program. The computational model was developed using three-dimensional beam finite elements to simulate the steel beams and columns and the reinforced concrete slabs were represented by shell finite elements. The building bracing system was represented by spatial truss finite elements. The present investigation considered the results of a geometric nonlinear analysis for serviceability limit states. The investigated structural model nondeterministic dynamic response, in terms of displacements and peak accelerations, was obtained and compared to the limiting values proposed by several authors and design standards.

101 - HUMAN COMFORT ANALYSIS OF CONCRETE PEDESTRIAN FOOTBRIDGES USING BIODYNAMIC MODELS

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Recent publications related to the dynamic behaviour of pedestrian footbridges have been based on a modelling of the pedestrian-structure interaction using biodynamic models. Therefore, this investigation aims to contribute to this scenario by developing a more realistic modelling of the pedestrian-footbridge system taking into account the dynamic characteristics of the pedestrians (mass, stiffness and damping), when crossing the footbridge. This way, the investigated structural model is based on an existing internal concrete footbridge spanning 24.4 m, constituted by concrete beams and slabs, and being currently used for pedestrian crossing. Initially, experimental tests were carried out, in order to determine the dynamic properties of the structural system: natural frequencies, vibration modes and modal damping ratio. The computational model adopted the usual mesh refinement techniques present in finite element method simulations, based on the use of ANSYS program. The finite element model was developed and calibrated with the obtained experimental results. Finally, the pedestrian footbridge human comfort and its associated vibration serviceability limit states were investigated and the peak accelerations values were obtained, based on an extensive parametric study, with the use of biodynamic dynamic loading models.

112 - VIBRATION CONTROL AND HUMAN COMFORT EVALUATION OF STEEL-CONCRETE COMPOSITE FLOORS UNDER AEROBICS

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Vibration problems issues concerning the human comfort of individuals practising aerobic activities has been reported by several researches in the last years. Indeed, there are many causes in which the excessive vibration levels are associated. These causes can be attributed to the new trend concerning the structural design of composite floors as well as the way in which the human activity is carried out on the structural systems. On the other hand, it has been observed in design practice low floor structural damping ratios, which is related to the type of construction, materials, presence of non-structural elements, age and quality of construction. Besides, it is noticeable the design of slender low weight structural floors systems due to the technological advance in the materials field. Consequently, the floors natural frequencies tend to decrease. Therefore, such trend is completely unfavourable in relation to the vibration issues because the harmonics of the human rhythmic may cause resonance with composite floors and then leading the occupants to a very discomforting condition. Thus, considering these aspects, this work investigates a steel-concrete composite floor spanning 40m by 40m, with a total area of $1600m^2$. This system represents a typical interior floor bay of a commercial building used for gym. In this research, an extensive parametric study was developed aiming to obtain the peak accelerations, RMS and VDV values, based on five different mathematical formulations used for modelling human rhythmic actions (aerobics). The dynamic response of the investigated structural model have indicated that the steel-concrete composite floor presented high vibration levels that compromise the human comfort, according to the limiting values proposed by several authors and design standards. On the other hand, a vibration control system based on the use of TMDs (tuned mass dampers) was proposed and installed under the floor in order to mitigate excessive accelerations. It has been found that such vibration control system has reduced significantly the human discomfort.

Vibration of Solids and Structures Under Moving Loads: Modelling and Analysis (MS06)

72 - MULTIPOINT CONTACT MODEL FOR DYNAMIC INTERACTION ANALYSIS OF HIGH-SPEED TRAIN AND RAILWAY STRUCTURE AFTER DERAILMENT DURING AN EARTHQUAKE

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An efficent computational method to solve the dynamic interaction of a high-speed train and railway structure during and after derailment under an earthquake is given. The motion of the train with nonlinear springs and dampers used to connect the components is modeled in multibody dynamics (MBD). Mechanical models to express contact-impact behaviors between wheel and rail before derailment and between wheel and the track structure after derailment are given to solve the interaction during an earthquake. A simple and efficient contact model based on multipoint contact springs on the contact surface between wheel and the track structure with irregularities defined after derailment are presented. The contact area between wheel and track structure is divided as many sections as needed in the rail direction where a contact spring is given in each section to express the contact-impact behavior. A track element based on the multipoint contact model has been developed to express the contact-impact behavior between wheel and the long track structure after derailment combined with MBD and FEM, where the motion in plane of the cross-section of the track structure is expressed by MBD and the motion in out-of-plane of the cross-section is expressed by FEM.
For nonlinear equations of the combined motion of the train and railway structure, a modal reduction is applied to solve large-scale nonlinear equations effectively. Equations of motions of the train and the structure are solved in modal coordinates. However, since the equations are strongly nonlinear, iterative calculations are made during each time increment until the unbalanced force between the train and railway structure becomes small enough within a tolerance specified. Based on the present method a simulation program DIASTARS has been developed to solve the interaction after derailment during an earthquake.
Examples of the dynamic interaction analysis between a Shinkansen train (high-speed train in Japan) at a high speed and railway structure after derailment during an earthquake are demonstrated.

126 - AN ABAQUS NUMERICAL METHOD TO PREDICT GROUND VIBRATIONS INDUCED BY HIGH-SPEED RAILWAY LINES

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With the rapid development of high-speed railway and urban rail transit system, the environmental vibration induced by running trains has been given more attention. The vibration propagates from the track into the subsoil, causes the ground vibration and furthermore may arouse the secondary vibration and noise of nearby structures and buildings, which seriously influences the living and working environment of the people. Therefore, it is necessary to predict and evaluate the environmental vibration at the commencement of planning and design of a rail traffic system. In this paper, a numerical method is proposed to predict the ground vibrations induced by the high-speed surface lines, by means of the software ABAQUS, and the attenuation laws of wave propagating through the subsoil are studied. The train-track-subsoil finite element model is established, in which the dynamic interactions between adjacent parts are taken into account and the high-speed train is simulated by the rigid body and the moving axle load, respectively. In addition, a dynamic coupling model of finite elements and infinite elements for simulating infinite subsoil is put forward to prevent the reflection of vibration waves on the boundaries of a subsoil model. Moreover, the numerical modeling of track irregularity sample in time domain is generated by the MATLAB processing using the inverse Fourier transformation, on the basis of the Germany interference spectrum with low power. It is shown that the results from the proposed numerical model agree well with those from existing references with an acceptable accuracy. Some conclusions

can be drawn: (1) the numerical method can be used to make a preliminary prediction of ground vibrations induced by high speed railway lines; (2) when the train runs at low speed, the response of the foundation soil shows elastic displacement subjected to quasi-static axle loads; (3) however, when the train runs at high speed, the ground vibrates intensively under the inertia effect; (4) it is also shown that the ground vibration induced by moving trains is low-frequency vibration and there exist some attenuation functions to the high-frequency vibrations; (5) the damping factor has a direct impact on the accuracy of the results.

137 - ENERGY HARVESTING FROM MOVING LOADS ON A BEAM WITH ELASTIC FOUNDATION

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In this paper, the problem of energy harvesting from the vibrations of a moving load is present-ed. Potential application is in the rail industry, in which the passage of the train can induce vibration. The vibrational energy can be harvested to power up for example the sensors that are mounted on the rail track for structural health monitoring. An infinite beam on an elastic foundation under quasi-static moving load is considered. The response of the beam is obtained analytically. A single-degree-of-freedom energy harvester subject to beam vibration is designed to harvest energy from the motion of the moving load. The frequency of the harvester is tuned to match the excitation frequency in order to maximise the amount of the harvested energy. The maximum relative displacement between the harvester and the beam and the amount of the harvested energy at several excitation frequencies are obtained. The effect of the velocity of the moving load on the harvested energy is also discussed.

273 - ANALYTICAL MODELLING OF RAILWAY TRACK DYNAMICS

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Analytical procedures leading to effective parametrical analysis of structures subjected to dynamic excitations are of importance in recent railroads investigations. Improvements of existing structures and new techniques of modelling and design are sought by researchers and railways industry. Experimental measurements show that railway track imperfections can produce noticeably significant changes in the structure response associated with quasi-static force. The paper shows analytical solution representing railway track vibrations due to moving train. Two theoretical models are analysed. The first one is described by the dynamic equation of beam resting on viscoelastic foundation and the second one consists of two layers. The first layer is modelled by the Euler-Bernoulli beam on viscoelastic foundation (representing rail with fasteners) and the second one is the sleepers' layer (rigid bodies without bending) on viscoelastic foundation (ballast and subgrade). The rail modelled by in-finitely long beam is subjected to a set of moving forces related to a wheelset of single wagon. Each of wheels produces load harmonically varying in time with frequency calculated on the basis of distances between wheels and considered type of rail imperfections. The steady-state response of the beam is obtained by applying the moving coordinate system and coiflet based approximation of the Fourier transform, leading to analytical estimation of vertical vibrations amplitude. It is shown that the analysed models taking into account viscous damping of foun-dation can be considered as good enough representation of realistic railway track behaviour. Numerical examples using parameters taken from measurements carried out for Polish rail-way network during passage of fast train Pendolino EMU250 are presented. The obtained results are in accordance with measured data in wide range of physical parameters. A com-parative study of two considered models of railway track is carried out for different types of load distributions.

332 - UNIFORMLY MOVING LOAD ON A BEAM SUPPORTED BY A FOUNDATION WITH FINITE DEPTH

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The moving force and moving mass problems are still important subjects in investigations related to transport applications. For determination of critical velocity of the train a theoretical concept that is based on the assumption that the track structure acts as a continuously supported beam (the rail) resting on a uniform layer of springs, is traditionally used. Then the critical velocity of the moving force is given by the classical formula, where the inertia of the foundation is neglected. Practical experience, however, has shown that the realistic critical velocity is much lower. Other theoretical studies that consider a moving force on an elastic half-space relate the critical velocity to the velocity of propagation of Rayleigh waves.
A more realistic estimate of the critical velocity should be based on a model where an effective finite depth of the foundation that is dynamically activated is introduced. Thus the new contribution of this work lies in an introduction of a simplified model of a beam supported by a foundation with finite depth and subjected to a moving force. Analytical solution of such a problem is presented and the critical velocity is expressed as a function of the foundation mass over the beam mass ratio. The new formula approaches the classical formula for the low mass ratio and the velocity of propagation of shear waves for the high mass ratio. Preliminary results were presented in.
Another aspect to consider is the moving mass instead of the moving force. Moving mass problem does not have fully analytical solution, because, for instance in finite beams, the governing equations in modal space remain coupled. If a steady-state solution exists for an infinite beam, than the deflection shape is exactly the same as for the moving force, as already indicated in. If the solution is not steady, but stable, there is an oscillation around the steady-state value, and the amplitude and frequency of this oscillation can be solved by inverse Laplace transform and iterative procedure using the definition of the complex equivalent stiffness of the system. This work presents a method of their determination and the phenomenon of instability is connected to the mass ratio, defined in the previous paragraph.

Nonlinear Dynamic Interactions and Phenomena: Emergent Methods and their Applications in Engineering and Science (MS07)

11 - FORCED NONLINEAR VIBRATION ANALYSIS OF CYLINDRICAL PANELS

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This work analyzes the nonlinear forced vibrations of a cylindrical panel simply supported and excited by a transversely time dependent load. The cylindrical panel is modeled by the nonlinear Donnell shell theory. The lateral displacement field is determined by a perturbation procedure and the axial and circumferential displacement fields are described in terms of lateral displacement, thus generating a precise low-dimensional model. A general expression for the nonlinear vibration modes is provided in this paper, satisfying all boundary conditions. The discretized equations of motion are obtained by applying the Galerkin method. Various numerical techniques are employed to obtain the cylindrical panel resonance curves and bifurcation scenario. The results show the influence of geometry and nonlinear modal coupling on the nonlinear response of the cylindrical panel.

14 - INCREASING PRACTICAL SAFETY OF VON MISES TRUSS VIA CONTROL OF DYNAMIC ESCAPE

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In this paper a method for controlling the global nonlinear dynamics of mechanical systems is applied to the elastic von Mises truss model, which is a prototype for buckling analysis of several planar and spatial truss systems and shallow lattice shell structures, including the geodesic dome, and which has a theoretical and practical interest. The method consists of the (optimal) elimination of homoclinic intersection by properly adding superharmonic terms to a given harmonic excitation. By means of the solution of an appropriate optimization problem, it is possible to select the amplitudes and the phases of the added superharmonics in such a way that the manifolds distance is as large as possible. This methodology is here applied to increase the integrity of the basins of attraction of the system and its practical safety.

75 - CUBIC SOFTENING NONLINEAR ELASTICITY MEASUREMENT OF MAGNETIC ATTRACTION MODEL USING SELF-EXCITED OSCILLATION

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In this paper, a stiffness sensor for measuring cubic softening nonlinear elasticity is developed. The measurement system consists of an oscillator and a feedback circuit, and achieves the dynamics of van der Pol oscillator in the oscillator by the positive linear velocity feedback and the nonlinear feedback proportional to the squared position and the velocity. Then, the tuning of the nonlinear feedback gain can realize any setting of the magnitude of the response amplitude. It is well known that the natural frequency depends on the response amplitude in the case with nonlinearity in the system. Therefore, we can experimentally describe the backbone curve from the relationship between the response amplitudes, which are set by various nonlinear feedback gains, and the corresponding response frequencies and identify the nonlinear elasticity. In experiments, we employ a

magnetic attraction model as a measurement object with negative linear elasticity and cubic softening nonlinear elasticity. Similar to the measurement for the model with hardening nonlinear elasticity, softening nonlinear elasticity is also measured by setting a sign of the coefficient of the nonlinear feedback appropriately to produce the stable limit cycle.

83 - PARAMETRIC STUDY OF A MACRO-SCALE TUNING FORK GYROSCOPE

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In this paper, the dynamic behaviour of a macro-scale tuning gyroscope is presented. The gyroscope consists of two inverted pendulums on a suspension mass. The suspension mass is subjected to force excitation generated by an electromagnetic shaker. The dynamics of the shaker are included in the analysis. It is shown that the system is a parametrically excited system. Parametric excitation can lead to vibration in the horizontal motion of the suspension mass, when the two pendulums are in phase. The problem is particularly interesting for energy harvesting. Due to the interaction between the system's degrees-of-freedom, the energy is transferred from vertical (base excitation) to horizontal direction. Initial parametric studies are carried out to analyse the dynamic behaviour of the system by varying the initial conditions, base excitation frequency and amplitude. It is demonstrated that under certain parameters the system can exhibit complex dynamic behaviour such as chaotic motion.

98 - ON ENERGY TRANSFER BETWEEN VIBRATION MODES AND FREQUENCY-VARYING EXCITATIONS FOR ENERGY HARVESTING

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In summary, this paper presents an analytical and numerical analysis of vibration energy harvesting from the dynamic interaction and energy transfer between the two vibration modes of a 2-DOF model of a flexible portal frame. The frequencies of these modes are set in a two-to-one internal resonance condition. Excitation is provided by eccentric rotating mass-motor captured in external resonance. Next, we consider the same flexible portal frame excited from various directions with time-variable frequency. A piezoelectric device gives energy harvesting. Depending on how the piezoelectric energy harvester is installed (or coupled) different gains are obtained. Good performance of the harvester generator is detected. We also observed periodic, quasi-periodic or chaotic oscillations, depending on the saturation phenomenon

111 - DYNAMICAL VIBRATION ABSORBER BY USING SHAPE MEMORY MATERIALS

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The dynamic response of structures subjected to high-amplitude vibration is often dangerous and undesirable. Dynamic vibration absorbers have received special attention in recent years due to vibration attenuation offered by them. Thus, the present study analyzes the nonlinear dynamics of a system with a dynamic vibration absorber using a shape memory material (SMM) whose characteristics are highly dependent upon temperature. Numerical simulations show the effectiveness of using the SMM in reducing oscillations of a harmonic oscillator.

154 - NONLINEAR DISCONTINOUS PHENOMENA IN ATOMIC FORCE MICROSCOPY

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This study is motivated by the increasing attention toward nonlinear discontinous phenomena in atomic force microscopy. After introducing a reduced-order model which is able to take into account the most relevant aspects of the system dynamics, the overall scenario of the structure response is investigated. Extensive numerical simulations are performed. The AFM behavior is examined, with special attention devoted to the analysis of discontinuity-induced bifurcations. The nonlinear response is highlighted. Competing attractors with different characteristics are observed. Physical meaning and practical relevance of the nonlinear features are discussed. Multistability is examined in detail via the combined use of behavior charts and basin-of-attraction analysis.

180 - DYNAMICS OF BEAMS AND PLATES UNDER COUPLED THERMO-MECHANICAL LOADING

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An effect of thermal load on vibrations of beams and plates is investigated in the paper. Two types of elements are investigated: (a) a beam considered as an extended Timoshenko model with nonlinear terms resulted from large deflections and (b) a circular plate represented by the geometrically nonlinear Mindlin model. Dynamics of both structures is analysed under thermal and mechanical loadings. The importance of the elevated temperature around the selected resonance conditions are presented. The nonlinear characteristics with bifurcation points have been demonstrated.

Influencing Vibrations by Dissipative Effects (MS08)

77 - EXCITATION TECHNIQUES FOR THE SOUND ANALYSIS OF ELECTRIC GUITARS

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During the last centuries, the development of the quality as well as of the play of musical instruments was pushed empirically and experimentally by instrument makers and players. This development can hardly be surpassed. Therefore, at first sight, the scientific study of instruments does not seem to allow any further significant improvement. It is, however, very important to gain insight into these complex systems and to achieve an understanding of the generated sound and of what makes it agreeable for the listener.
A very popular instrument is the electric guitar, whose sound is commonly assumed to originate mainly from the plugged electronics. This assumption, however, is not compatible to the large variety of commercially available models of electric guitars, featuring a significant spread in material and construction, and also in quality and price. In fact, there is reason to believe that there is a not to be underestimated influence of the used materials, which is also motivated by investigations of acoustic guitars. However, the sound of acoustic guitars is mainly formed in there hollow body, strongly influenced by the structural behavior of the body and the neck. The body of an electrical guitar, instead, is made of solid wood, and a sound hole does not exist.
The goal of this investigation is to gain insight into the sound generation of electric guitars, the interaction between string excitation and structural response as well as the influence of material and geometry parameters. This contribution presents an experimental set-up for measuring the structural behavior of the guitar body using Laser-Doppler-Vibrometers, to be compared to the generated sound. To ensure a well-defined and reproducible excitation of the strings, a sophisticated mechanism is constructed, making use of the methods of multibody dynamics and optimization. With this mechanism, it is possible to determine the influence of different parameters on the induced vibrations and the generated sound, which can be assessed by specific criteria. Exemplarily, the influence of the adjustable settings of the electronics and the pickups are presented.

92 - PRELIMINARY STUDY INVESTIGATING THE CAPABILITY OF EULERIAN- AND LAGRANGIAN-ACOUSTIC ELEMENTS TO DESCRIBE THE COCHLEAR FLUID-STRUCTURE INTERACTIONS

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The inner ear or cochlea is a bone structure of spiral shape and is composed of conical chambers which are filled with fluid and separated by a soft membrane, the basilar membrane. The chambers are closed by the stapes footplate and the round window membrane. The cochlea can, therefore, be considered as a closed hydraulic system. In case of a normal ear, sound is received by the eardrum, transmitted through the middle ear ossicles and finally excites the inner ear fluid through the vibration of the stapes footplate. This leads to pressure changes in the cochlea fluid which in turn results in a characteristic vibration behavior of the basilar membrane. Related to the sound frequency, hair cells in a certain area of the basilar membrane are stimulated, causing hearing nerve stimulation. Furthermore, the round window membrane is displaced for pressure compensation. Since the motion of the basilar membrane is almost impossible to measure, the development of a simplified simulation model of the inner ear is proposed. In this Finite Element model, shell-elements and Lagrangian fluid elements are used to model the compliant membranes and slightly compressible fluid, respectively. With this model, the transient pressure distributions in the two chambers of the inner ear are investigated to understand the fundamental mechanism of the formation of the characteristic basilar membrane vibrations. For this purpose, simulations with varying excitation frequencies and different amplitudes at the oval window were conducted. These investigations show, that the position of the maximum amplitude of the basilar membrane depends on the excitation frequency at the oval window. It can be shown, that for low frequencies, the position of the maximum amplitude is located closer to the apex, while for high excitation frequencies the maximum is situated closer to the base of the cochlea. Thus, the model provides a deeper understanding of the correlation between the place of hair cell stimulation on the basilar membrane and the excitation frequency. Especially this so-called cochlear tonotopy plays a significant role in the development and design of new inner ear implants. Beside a deeper insight into the dynamic of the inner ear, this numerical model allows to predict the impact of pathological changes on the vibration of the basilar membrane and thus on hearing impression.

100 - NUMERICAL AND EXPERIMENTAL INVESTIGATION OF THE EFFECT OF A FLUID PIPE ON SYSTEMS SUBJECTED TO FORCED VIBRATIONS

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There are several reasons why unwanted vibrations can arise in a shift gearbox. For example, it can be caused by a friction-induced instability during shifting. In such a situation, some structural components can be seen as vibration inducer (clutch disc, shafts, gears), whereas other parts are forced to resonate (housing, control elements). Besides their actual purpose, hydraulic control elements such as fluid pipes of the actuation system can contribute to the passive amplification and/or suppression of vibrations. In order to get a first idea of the effect of a hydraulic aggregate on vibrations of a shift gearbox, two models of oscillating fluid pipes are analyzed. The first model is a rigid pipe with only one translational DoF in its own axial direction. It is hinged on a translational spring and force-excited. The two exits of the pipe are both closed; inside, hydraulic oil is situated, which can flow weakly because of its own compressibility and additional capacitances. The second model has the same structure as the previous one, but an additional mass is situated inside the fluid. The fluid pipe and the diving mass are connected to each other by a translational spring. The analysis consists of a numerical and an experimental part. For the numerical analysis, equations to describe the fluid dynamics are derived from the Navier-Stokes equations and the equation of continuity. Galerkin's method and a finite differences discretization are applied in order to obtain an ODE approach. The experimental setup consists of a closed pipe on a rail which is connected to a frame by a leaf spring and force-excited by a shaker. The hydraulic oil and the diving mass are optional components. When the pipe is forced to vibrate, it is observed that the stress acting between fluid and structure reduces the vibration amplitude. This effect works best when the first fluid eigenfrequency hits the eigenfrequency of the corresponding 1-DoF-oscillator (system without fluid). The diving mass increases the dissipative effect. A good correlation is found between the analytical results and the experiment.

107 - ON THE INFLUENCE OF DAMPING IN BRAKE VIBRATIONS

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Brake vibrations are prominent examples of NVH (Noise, Vibration, Harshness) problems in automotive engineering. Most brake vibrations are self-excited oscillations where energy is transferred from the rotation of the brake disk via the friction forces into a vibration of the brake system. If the self-excitation prevails the damping increasing vibrations occur finally in most cases ending in stable limit cycles. Therefore, beside the excitation effect by the friction forces, damping plays a decisive role, whether oscillations occur or not in brakes. The presentation shows some results of investigations on the influence of non-conservative forces in brakes. In linear models stability analysis can be performed by a calculation of the complex eigenvalues. The influence of nonlinearities is also discussed.

208 - ON THE EFFECT OF THE DISTRIBUTED FRICTION IN THE ARC SPRING ON THE DYNAMIC BEHAVIOR OF THE AUTOMOTIVE TRANSMISSION

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Torsional excitation of a combustion engine is usually very strong and requires special solutions for reducing the torsional vibrations in automotive transmissions. Dual mass flywheel (DMF) is one of the most effective devices for this purpose. The main element of the DMF is the "arc spring" which determines the dynamic behaviour of the whole system. A simplified model of the arc spring is developed. It takes into account both the large deformations of the spring and the distributed friction between the coils of the spring and the wall of the spring channel in the primary flywheel. It is demonstrated that the distributed friction causes extreme nonlinear behaviour of the DMF including the distinct memory effect which cannot be described by simplified models of dissipation. The main attention is directed to the modelling of the interaction between the outer and the inner springs which are the usual realization of the bilinear spring characteristic. It is shown that the friction interaction between the springs has to be taken into account in order to obtain realistic results in the overall model of the automotive drivetrain. Especially the "boom" noise of the differential and rattle noise in idle are sensitive for the accurate modelling of the springs.

279 - A MECHANICAL MODEL FOR THE DYNAMICAL CONTACT OF ELASTIC ROUGH BODIES WITH VISCOELASTIC PROPERTIES

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The contact between viscoelastic materials e.g. elastomers and a rough surface leads to a special friction characteristic, which differs greatly in its properties comparing to other materials like metals. In practice, this friction combination occurs for example in the tire-road contact, or in the use of rubber gaskets. Due to the frictional forces a system is significantly influenced in its vibrational properties. The friction force is composed of two main components adhesion and hysteresis. The adhesion results from molecular bounds between the contact partners, while the deformation of the viscoelastic material by the roughness of the counter body leads to power loss. This internal friction results in an additional frictional force, which is described by the hysteresis. To simulate the frictional behaviour of elastomers on rough surfaces and thus to determine the energy dissipation in contact, it is necessary to develop a mechanical model which considers the roughness of the contact partners, as well as dynamic effects and the dependence on normal pressure and sliding speed. The viscoelastic material behaviour must also be considered. The contact between two rough surfaces is modelled as a rough rigid layer contacting a rough elastic layer. The elastic layer is modelled by point masses connected by Maxwell-elements. This allows the viscoelastic properties of the elastomer to be considered. The behaviour of whole system can be described by equations of motion with integrated constraints. The degrees of freedom of the model depends on the varying contact conditions. A point mass not in contact has two degrees of freedom. A point mass in contact moving along the roughness path can be described by only one degree of freedom. For each Maxwell-Element also an inner coordinate and thus a further degree of freedom is needed. Because of varying contact conditions during the simulation, the simulation interrupts in case the contact conditions change. Then the equations of motions are adapted with respect to the contact constraints. As a result of the simulation one obtain the energy dissipation and thus the friction characteristic during the friction process. It is possible to use these results in three dimensional point-contact elements in order to model contact surfaces on lager length scales.

301 - SYNCHRONIZATION VIA DISCONTINUOUS COUPLING

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In this paper we present an influence of discontinuous coupling on the dynamics of multistable systems. Our model consists of two periodically forced oscillators that can interact via soft impacts. The controlling parameters are the distance between the oscillators and the difference in the phase of the harmonic excitation. When the distance is large two systems do not collide and a number of different possible solutions can be observed in both of them. With decreasing of the distance, one can observe some transient impacts and then the systems settle down on non-impacting attractor. The motion of oscillators on the non-impacting attractor is synchronized. As it is well known, the phenomena of synchronization is commonly encountered in non-linear systems. We can distinguish two main types of synchronization, i.e., a complete synchronization where all connected systems perform identical motion and the phase synchronization where the phases of interacting systems are locked while their amplitudes stay uncorrelated. As the coupling between mechanical oscillators is always bidirectional, when systems are completely synchronized, the value of coupling force is equal to zero, and only if common motion is perturb the systems once again start to interact. This is the straightforward analogy to the above mentioned discontinuous transient coupling via impacts, where the perturbation of stable non-impacting solution leads to appearance of transient impacting motion (coupling). We claim that with the properly chosen distance and difference in the phase of the harmonic excitation, we can reduce the number of possible solutions of the coupled systems. The proposed method is robust and applicable in many different systems.

Dynamics Drilling Deep Boreholes - Drillstring and Drillbit Vibrations (MS09)

5 - AXIAL EXCITATION TOOL STRING MODELLING

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Current types of axial excitation tool have been shown to produce beneficial results - in terms of load transfer to the bit, general reductions in string friction and reductions in drill dysfunctions - such as stick slip. The positioning of such tools to achieve optimum benefit is therefore extremely important - in order to maximize the axial excitation to the areas off the string that require a reduction in friction, and also to minimize the axial excitation to the surface - where damage may occur. This paper describes a string model that allows the position of axial excitation tools to be assessed - in terms of the string response - both locally and remotely from the tool. The model breaks the string down in to springs and masses- with 10 nodes in the upper string; and 5 nodes in the BHA. Additional components can also be added to the string - such as shock tools, jars and accelerators - in terms of mass and stiffness. The equations of motion are used to connect the nodes in terms of differential equations. The model is Mathcad based, and as a result, executes very quickly- so allowing comparative studies to be carried out with relative ease. Data input into the model is also achieved quickly. The model has been compared with and ANSYS spring mass model, and good agreement has been reached. Additionally, the model allows more than one axial excitation tool to be added to the string - in order to gauge the benefits of such a configuration. Damping can also be varied at different locations in the string model. The results from this model have been used to compare with field test data - derived from a string with instrumentation tool located at various points in the string. The results show that good agreement can be reached between the model and the field test results, however, careful consideration needs to taken of the damping assumed in the model. The model can, never the less, be used for comparative studies - i.e. tool location, number of tools and optimum frequencies. Further work is recommended in comparing model results with field test results - in order to get a better understanding of the effect of damping.

284 - LOCALIZING THE EXCITATION SOURCE OF HIGH FREQUENCY TORSIONAL OSCILLATIONS

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Increases in drilling performance and high-bandwidth MWD tools have recently led to the establishment of a new category of drillstring vibration, associated with high loads on the downhole tools, but poor mechanical indication thereof at the surface. High frequency torsional oscillations (HFTO) describe the BHA resonance at a high order natural frequency which corresponds to a mode shape with an anti-node close to the PDC bit. The latter of these points, along with the known weak dependency of HFTO on the WOB and RPM, has led to the hypothesis that the phenomenon is self-excited through bit-rock interaction. Many effects have been discussed in the literature, any of which could potentially be the root mechanism of this excitation. Reliable identification of the root is of high interest towards developing measures to counteract HFTO. The three classical categories of self-excitation defined in manufacturing engineering theory are revisited, with regard to their applicability towards drilling: Falling friction characteristics, regenerative chatter vibrations, and mode coupling. The excitation mechanisms that are considered most likely to be the root of HFTO are discussed. Excitation may be found in the cutting and chip extrusion processes themselves. Rock is commonly understood to experience internal friction, which explains its pressure dependent strength. Friction processes are known to cause self-excitement when large friction forces act on compliant structures, often manifesting itself as squealing. For further analysis, a discrete element method has been developed to model rock at high pressures and high strains. Here, applicability and a high-strain modification are discussed.

320 - PROPAGATION OF TORSIONAL VIBRATIONS IN DRILLSTRINGS: HOW BOREHOLE GEOMETRY AFFECTS TRANSMISSION AND IMPLICATIONS ON MITIGATION TECHNIQUES

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Single degree of freedom models have been used extensively to study stick-slip and other torsional vibrations in drill strings over the years and are used in currently deployed vibration mitigation systems. However, these systems cannot account for higher order dynamics, nor can they account for variations in borehole trajectories. This paper proposes a continuous beam model and compares it to an seven-degree of freedom laboratory model to study the effects of drillstring-borehole contact, modeled as distributed damping, on the propagation of torsional waves. By modeling the drillstring as a transmission line, the borehole environment, including borehole fluid, material hysteresis and friction, can be abstracted as distributed damping acting on each model element. The model is first applied to simplified test cases before being used to predict how borehole geometry may complicate the detection of stick-slip at the surface. A demonstration case of an S-shaped well is presented that illustrates how stick slip may be present at the bit without the typical torque and rpm fluctuation signature visible at the surface. An improved controller, based on frequency domain loop shaping techniques, shows that effective in drill-string vibration mitigation can be achieved.

Inverse Problems and Uncertainty Quantification (MS10)

74 - IDENTIFICATION OF UNCERTAIN BOUNDARY CONDITION OF A BEAM MODEL USING THE BAYESIAN APPROACH AND EXPERIMENTAL DATA

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In many mechanical applications (wind turbine tower, substructures joints, etc.), the stiffness of the boundary conditions is uncertain and might decrease with time, due to wear and/or looseness. In this paper, a torsional stiffness parameter is used to model the clamped side of a Timoshenko beam. The goal is to perform the identification with experimental data. To represent the decreasing stiffness of the clamped side, an experimental test rig is constructed, where several rubber layers are added to the clamped side, making it softer. The Bayesian approach is applied to update the probabilistic model related to the boundary condition (torsional stiffness parameter).

125 - ROBUST OPTIMIZATION OF HORIZONTAL DRILLSTRING RATE OF PENETRATION THROUGH A NONLINEAR STOCHASTIC DYNAMIC MODEL

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A drillstring is a long column under rotation, composed by a sequence of connected drill-pipes and auxiliary equipment, which is used to drill the soil in oil prospecting. During its operation, this column presents a three-dimensional dynamics, subjected to longitudinal, lateral, and torsional vibrations, besides the effects of friction, shock, and bit-rock interaction. The study of the dynamics of this equipment is very important in many engineering applications, especially to reduce costs in the oil exploration process. In this sense, this work aims to formulate and solve a robust optimization problem that seeks to maximize horizontal drillstrings rate of penetration into of the soil, subjected to the restriction imposed by the structural limits of the column. To analyze the nonlinear dynamics of drillstrings in horizontal configuration, a computational model, which uses a nonlinear beam theory of Timoshenko type is considered. This model also takes into account the effects of friction and shock, induced by the lateral impacts between the drillstring and borehole wall, as well as bit-rock interaction effects. The uncertainties of the bit-rock interaction model are taken into account using a parametric probabilistic approach. Two optimizations problems (one deterministic and one robust), where the objective is to maximize the drillstring rate of penetration (ROP) into the soil, respecting its structural limits, are formulated and solved. In order to optimize the ROP, it is possible to vary the drillstring velocities of translation and rotation. The solutions of these optimization problems provided two different strategies to maximize the ROP.

146 - STABILITY OF TRANSVERSE VIBRATIONS OF A ROTATING UNIFORM WIND TURBINE BLADE USING THE FLOQUET THEORY

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In many engineering applications, such as wind turbines and helicopter rotor dynamics, the resulting system of differential equations is periodic. In such cases, it is possible to assess the stability of the system applying the Floquet theory. In this work, the stochastic stability of a wind turbine blade is assessed by means of the the Floquet exponents. The uncertain parameter is the wind speed, which is modeled as a random variable. The propagation of the uncertainty is obtained using the Monte Carlo method.

194 - PARTIAL EIGENSTRUCTURE ASSIGNMENT IN VIBRATING SYSTEMS THROUGH HOMOTOPY OPTIMIZATION

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Passive eigenstructure assignment on vibrating systems is aimed at computing the modifications of the inertial and elastic parameters ensuring the desired dynamical behaviour, in terms of natural frequency and mode shape. In many cases, it is desirable assigning only the response of some critical parts rather than the response of the whole system. However, the currently available methods do not provide a way to distinguish the degrees of freedom with different levels of interest. To solve this relevant open issue, this paper proposes a method intended for the assignment of partial parts of an arbitrary number of eigenvectors. In order to determine the optimal struc-tural modifications satisfying constraints on the feasible values, the assignment problem is cast as an optimization problem solved numerically. The presence of some not-imposed eigenvector entries leads to a non-convex optimization problem. Therefore, to boost the convergence to a global minimum, homotopy optimization is implemented by morphing from a convex relaxation of the problem to the original non-convex one. The convex approximation is performed through some auxiliary variables and the McCormick's relaxation of the bilinear terms. The proposed approach can handle general assignment tasks, with an arbitrary number of modification parameters and prescribed eigenpairs. Interrelated modifications can be also accounted for. The method is numerically validated in the dynamic optimization of a vibratory linear feeder. The aim of the system modification is to specify the shape of the displacement of the upper tray where the conveyed parts flow, through the assignment of the eigenvector with the highest participation factor in the forced dynamics. At the same time, the assignment of the related eigenvalue in a neighbourhood of the excitation frequency allows obtaining large amplitude displacements with small driving force. The numerical results show that partial assignment significantly improves the fulfilment of the specifications on the eigenvector entries representing the tray translation, which are those of greater concern.

214 - COMPARISON BETWEEN MULTI-OBJECTIVE GENETIC ALGORITHM AND BAYESIAN INFERENCE ON IDENTIFICATION OF ROTATING MACHINERY PARAMETERS.

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Rotating systems are critical components of power generation plants, as they are critical to its operation. Therefore, the study and modeling of Rotating machinery have been developed, where the rotor is modeled by finite element method and the bearings by numerical or analytical approach. These rotating systems have stochastic characteristic, which makes the identification of parameters by model updating (solution of inverse problems) a very complicate procedure, when considered deterministic model responses. This work proposes the use of model updating techniques that take into account the stochastic characteristic of the system. The first method is the application of multi-objective optimization, in order to obtain a feasible region of possible responses (Pareto set). Thus, it is possible to evaluate the effect of model uncertainties on the variability of the Pareto optimal set. The optimization methodology proposed is based on multi-objective genetic algorithms. Another proposed approach is application of Bayesian inference. In this case, it is taken into account a priori distribution, which represents the previous knowledge about the parameters (before the observations) for different degrees of uncertainty. It also takes into account the likelihood distribution, represented by a distribution of the difference (or residual) between the experimental results and the response of the dynamic model. In other words, the likelihood distributions typifies the observations. The parameters to be determined correspond to the posterior distribution, which takes into account the prior knowledge and the observations. The solution to this method can be obtained through a numerical search method Monte Carlo Markov Chain (MCMC). For the application of model updating, experimental data from a test-rig will be obtained.

216 - DAMAGE IDENTIFICATION UNDER MODELLING UNCERTAINTIES

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This work presents a damage identification strategy using reduced computational models. Modelling errors are taken into account as random variables. Model uncertainties are taken into account with the Approximation Error Theory. Uncertainties about the applied load is taken into account. The effectiveness of this approach is assessed using several numerical examples.

221 - DETERIORATION OF TENSILE STRENGTH AND STIFFNESS OF ELASTIC STRUCTURAL ADHESIVE JOINTS DUE TO ENVIRONMENTAL FACTORS

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Adhesive bonding is becoming increasingly popular as an alternative to traditional joining techniques in various industrial applications. However, often its use is limited to statically loaded structures. In case of dynamic loads the structural elasticity and vibration damping properties mostly result from the characteristics of the substrates used, not from the adhesive joint. Many research activities have been conducted on the widely used and more brittle adhesive types like epoxies. Tougher and less brittle adhesives are characterised by a lower tensile strength and modulus but they have very distinct advantages regarding sound and vibration damping. In the context of numerical modelling of adhesive joints, there are a number of rheological models that describe the viscoelastic behaviour of these adhesive material types and which have been subjected to experimental validation. So far, not much research is performed on the estimation of the durability of bonded joints that use more elastic structural adhesives. This paper presents a variability study as part of an extensive research project concerning the durability estimation of structural elastic adhesively bonded joints in dynamically loaded structures. The first part of this paper discusses the bonding mechanics of the adhesive to the substrate and analyses the main factors that influence the elastic properties and the mechanical durability of the bonded joint. Therefore the state of the art in literature is summarised. Also, some environmental ageing factors are discussed. A second section focusses on the characterisation of the effect of the factors described in the first part on the mechanical behaviour of the joint. This is done by performing uniaxial and dynamic mechanical tests on bonded samples. These results are then compared to simple but adequate finite element models. These models are used to relate the mechanical properties of the joint with the observed variability in the various experiments. The final part summarizes and makes important conclusions on the obtained experimental and numerical results. This part also outlines the research prospects concerning durability uncertainty quantification when adhesive ageing is taken into account.

Substructuring Techniques in Structural Dynamics (MS11)

150 - SELECTION OF INTERNAL DOFS TO REPLACE HARD-TO-MEASURE COUPLING DOFS IN SUBSTRUCTURE DECOUPLING

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Substructure decoupling consists in the identification of a dynamic model of a structural subsystem, starting from a dynamic model (e.g. FRFs) of both the assembled system and a known portion of it (the so-called residual subsystem). The degrees of freedom (DoFs) of the assembled system can be subdivided into internal DoFs (not belonging to the couplings) and coupling DoFs. To achieve decoupling, a fictitious subsystem that is the negative of the residual subsystem is added to the assembled system, and appropriate compatibility and equilibrium conditions are enforced at interface DoFs. Interface DoFs can include coupling DoFs only (standard interface), additional internal DoFs of the residual subsystem (extended interface), subsets of coupling DoFs and internal DoFs of the residual subsystem (mixed interface), or a subset of internal DoFs of the residual subsystem only (pseudo interface). In previous papers, the use of a mixed interface is applied in order to get rid of hard-to-measure coupling DoFs, such as for instance rotational DoFs at junctions involving bending and/or torsion. In this paper, criteria are sought for an appropriate selection of internal DoFs used to replace coupling DoFs at which it is hard to obtain experimental FRFs.

218 - ADAPTIVE FEEDFORWARD CANCELLATION FOR REALTIME HYBRID TESTING WITH HARMONIC EXCITATION.

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Cyber Physical Testing or Realtime Hybrid Testing is an experimental technique making it possible to test components of structural systems with realistic boundary conditions. The basic idea is to split a given mechanical system into a virtual and an experimental sub- system. Both subsystems are coupled in a real time test. This type of testing can be valuable where neither an experimental test of the overall system nor a full simulation are reasonable or applicable. This study concentrates on the implementation of an adaptive feedforward cancellation algorithm for interface synchronization of the hybrid test. It is applicable in cases with known harmonic excitation. In contrast to existing Realtime Hybrid Testing control schemes we developed an adaptive harmonic excitation generator, which produces harmonic interface forces and the associated interface forces are simultaneously applied on both substructure in- terfaces. The interface force frequencies are chosen in accordance with the excitation on the numerical substructure. Amplitudes and phases of the harmonic components of the interface force, however, are retrieved from an adaption law which successively minimizes the interface gap.This type of testing can be valuable where neither an experimental test of the overall system nor a full simulation are reasonable or applicable. The experimental substructure is subject to a durability test, a certification test or an investigation regarding its dynamical properties. This study concentrates on the implementation of an adaptive feedforward cancellation algorithm. It is applicable in cases with known harmonic excitation frequencies assuming that interface forces are only higher harmonics of these excitation frequencies. In contrast to existing control schemes we developed an adaptive harmonic excitation generator, which produces harmonic interface forces. The interface forces are simultaneously applied on both substructure interfaces. The interface force frequencies are chosen accordingly to the excitation on the numerical substructure but the amplitudes and phase shift of the interface force are retrieved from an adaption law which successively minimzes the interface gap. In this contribution the developed method is verified in experiments on a simple test rig with an one-DoF substructure interface.

270 - COMPARISON BETWEEN PRIMAL AND DUAL CRAIG-BAMPTON SUBSTRUCTURE REDUCTION TECHNIQUES

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Dynamic substructuring is an efficient way to reduce the size and to analyse the dynamical behaviour of large models. The most popular approach is a fixed-interface method, the Craig-Bampton method (1968), which is based on fixed-interface vibration modes and interface constraint modes. On the other hand, free-interface methods employing free-interface vibration modes together with attachment modes are also used, e.g. MacNeal's method (1971) and Rubin's method (1975). The methods mentioned so far assemble the substructures using interface displacements (primal assembly). The dual Craig-Bampton method (2004) uses the same ingredients as the methods of MacNeal and Rubin, but assembles the substructures using interface forces (dual assembly). This method enforces only weak interface compatibility between the substructures, thereby avoiding interface locking problems as sometimes experienced in the primal assembly approaches using free-interface modes. Moreover, the dual Craig-Bampton method leads to simpler reduced matrices compared to other free-interface methods and these reduced matrices are similar to the classical Craig-Bampton matrices. In this contribution we want to refine the first formulation of the dual Craig-Bampton method from 2004 and present the derivation in a comprehensible consistent manner. Special attention is directed to the influence of the applied eigensolver for computing the required free-interface vibration modes. Moreover, a detailed comparison between the primal (classical) formulation of the Craig-Bampton method and the dual formulation of the Craig-Bampton method will be given. The presented theory and the comparison between the two substructuring methods will be illustrated on a three-dimensional beam frame and on a two-dimensional solid plane stress problem.

286 - A COMPARISON ON MODEL ORDER REDUCTION TECHNIQUES FOR GEOMETRICALLY NONLINEAR SYSTEMS BASED ON A MODAL DERIVATIVE APPROACH USING SUBSPACE ANGLES

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As model order reduction is a significant step in the construction of efficient models describing nonlinear structural dynamics, the demand for reduction methods not building on training data sets is very high. While sharp and meaningful error estimates exist for linear systems based on invariants like frequency response functions or the concept of observability and controlability, there is a lack of quantification methods for nonlinear systems. In this paper an error quantification method is proposed. This method is built on subspace angles, which are able to describe the differences between subspaces in a mathematical rigorous way. The approach is exemplarily applied to a geometrically nonlinear finite element model, extending reduction techniques based on the linearized system to nonlinearity with modal derivatives. As representative linear methods a modal truncation method, a modal truncation method with augmented static modes and a Krylov subspace method is chosen. The results are compared to perfectly trained POD sets for the given excitations with the proposed method. As the method will show, the extension methods capture essential behaviors of the nonlinear system.

302 - AN INTERFACE FORCE MEASUREMENTS-BASED SUBSTRUCTURE IDENTIFICATION

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Substructure-decoupling techniques are used to identify a substructure as a stand-alone system while it is coupled to a complex structure (an assembly of substructures). These recently introduced techniques can be used for various applications, e.g., when the substructure cannot be measured separately from the complex structure, when modal testing methods are not appropriate due to the limits of the measurement equipment and for vibration-control techniques. The complex structure consists of the unknown substructure and the remaining structure. A drawback of the available substructure-decoupling techniques is that they require a model of the remaining substructure. However, when the model cannot be calculated or (experimentally) identified, the substructure-decoupling techniques cannot be used. In this article a new approach is presented that does not require a model of the remaining substructure, but is based on an experimental identification of the interface forces. As an illustration, the subsystem identification is introduced on a generalized mass-spring-damper system. To research the application possibilities for real situations, complex structures with beam-like coupling elements are investigated. The sensitivity of the approach to experimental errors was researched using an uncertainty propagation analysis. The article includes numerical and experimental test cases.

325 - EFFECTS OF INTERFACE LOADING IN DYNAMIC SUBSTRUCTURING

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Over the last few IMAC conferences, the SEM substructuring focus group's benchmark; the Ampair A600 wind turbine, has been thoroughly studied, at substructure as well as system levels but also by implementation of different substructuring techniques for assembling experimental and/or analytical component models. Within the focus group, work dedicated to appropriate interfacing between substructures has furthermore been an area of increased interest. This is notable through the use of the transmission simulator method. This paper draws on that paradigm in studying the end effects on assembled structures of using nominally identical substructure models derived from experimental setups with different levels of mass loading at the interface. Specifically, experimental models for an A600 blade and bracket system attached to dummy masses of different sizes are coupled to an analytical model of the hub. The results are compared to analytical results of the full system.

Gresimo (MS12)

79 - DYNAMIC RESPONSE OF LAMINATED STRUCTURES USING A REFINED ZIGZAG THEORY (RZT) SHELL ELEMENT

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Shell-like structures are common in many engineering applications such as aerospace structures, civil constructions and automotive components. In all these fields, composite materials and laminated sandwich are used as a viable lightweight alternative to standard engineering materials. Simulations of multilayer structures often require explicit modelling in the through-the-thickness direction to account for properties discontinuities. This is especially true in sandwich structures, where stiff layers are interleaved with soft viscoelastic layers for vibration attenuation. However, the use of solid elements significantly increases the time necessary to build and analyse the models. Reduction of both modelling and computational costs can be achieved by the use of equivalents single layer models. However, equivalent single layer theories fail to represent the piecewise distribution of displacements in the through-the-thickness direction. This is where Zigzag Theories find application. Zigzag theories, which were first proposed by Di Sciuva and Averill, combine an equivalent single layer approach with a linear piecewise function of the thickness coordinate. Di Sciuva and Averill zigzag functions presented few shortcomings, such as the vanishing of reaction forces at clamps and the layer-dependent function definition. These drawbacks are overcome by the Refined Zigzag Theory proposed by Tessler. Tessler zigzag formulation is hereby used in the framework of a shell element for vibration analysis of standard laminates and laminated sandwich structures. The main objective of the paper is to show that zigzag refined elements can be effectively used to reduce the computational cost of simulations within a reasonable level of accuracy.

197 - SURFACE IMPEDANCE PREDICTION USING PHASED GEOMETRICAL ACOUSTICS, A SMALL REVERBERANT CHAMBER AND OPTIMIZATION

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An inverse method is proposed to determine the normal surface impedance of acoustic materials using phased geometrical acoustics and a least-squares optimization algorithm inside a small reverberant chamber. A material with unknown impedance is placed on the floor of the reverberant chamber, and the steady-state acoustic pressure is measured. Then the surface impedance of the material is predicted using an optimization algorithm and phased beam tracing as the forward model. In phased beam tracing, the center ray of a triangular beam is traced specularly throughout the acoustic cavity. During this analysis, incident angles, indices of reflection and total distance traveled are saved for each image source detected. The strength of each image source is then the product of all successive plane wave reflection coefficients, which are dependent upon the surface impedance of each reflecting surface encountered. The calculation time of the cost function is greatly reduced, because beams do not need to be re-cast in order to calculate the simulated pressure for different impedance values and because the image sources are separated based on whether or not they depend on the floor. The reverberant chamber used is a multifunctional vibro-acoustic test rig common in the automotive industry. Beam tracing results with added noise are used as the known values. The optimization is more robust and accurate if more than 40 frequencies and if more than two receivers are used. The outputs of this prediction technique are the real and imaginary parts of the normal surface impedance for different 3rd-octave bands of a material placed on the floor of a small reverberant chamber.

204 - ON THE EFFECTS OF DAMPING ON WAVE PROPAGATION IN PERIODIC VIBRO-ACOUSTIC META-MATERIALS

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In search for novel materials which combine lightweight characteristics with good acoustical behavior, triggered by ecological and economic reasons, resonant meta-materials come to attention, be it at least in some targeted and tunable frequency ranges, referred to as stop bands. Meta-materials are defined as the general family of materials engineered to have specific properties, uncommon in nature, for dedicated applications. In this paper, an infinite periodic meta-material panel composed of unit cells with local resonators is discussed. The panel is designed to obtain stop band behavior for bending waves in vibro-acoustic applications. As the panel is periodic, a single unit cell contains all essential information and the Bloch-Floquet theorem can be applied to reduce the computational effort required to analyze its dispersion behavior. More specifically, the effects of damping are investigated, since this can have an important influence on wave propagation. In order to capture both propagating and attenuated parts of waves, an alternative formulation of the Bloch-Floquet theorem is employed to scan the k-space (wavenumber) for a given frequency and evaluate the dispersion behavior. Unlike the classic Bloch-Floquet approach, this approach captures complex wavenumbers as the governing equations are reformulated to form a quadratic eigenvalue problem with respect to wavenumber. This allows the investigation of the dispersion behavior in the complex k-space providing more information on attenuating waves. The alternative formulation can also facilitate the analysis of structures with complex damping configurations allowing direct inclusion of damping in the constitutive law with a more detailed description. In addition, it reduces the computational effort required to analyze structures with frequency-dependent properties as the eigenvalue problem is solved for eigen-wavenumbers at discrete frequency steps. Finally, the dispersion behaviors of structures with various levels of viscous damping are compared to capture the effects of damping on wave propagation of such periodic meta-materials.

269 - NVH PERFORMANCES OF AUTOMOTIVE CAR BODIES WITH DIFFERENT STRUCTURAL CONTRASTS

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To reduce the greenhouse gas emissions produced by cars, one solution considered is to reduce their masses by using composite materials. However, the introduction of such orthotropic materials can significantly modify the automotive design due to the new distribution of local stiffness. These modifications may result in very different vibro-acoustic behaviours and therefore different NVH performances. Indeed, the panels can participate more greatly to the overall stiffness of the car, reducing the ratio of frame in the architecture and therefore changing the structural contrast between frame and panels. The objective of this work is to investigate the NVH performance of several models of car bodies built with different structural contrasts. Several strategies can be used to highlight the structural contrast of a mechanical system made of frame and panels. In this work, this concept is developed by using input point mobilities. This approach allows building maps which are representative of the vibrational behaviour of the car body. On such a map, the areas corresponding to the presence of stiffeners (frame) can be identified, and a histogram containing the input point mobility values allows the definition of a structural contrast indicator. This indicator is used to evaluate the level of contrast of several models of car bodies. On another hand, the NVH performance of a car body can be defined in the "low frequency" range as the mean pressure level at the passenger's ears. This performance indicator is calculated for each studied model, so that the relation between the structural contrast and the NVH performance can be done and analysed. The results show how the NVH performance changes when the structural contrast is modified.

321 - ON VARIABLE SCREENING AND OPTIMIZATION OF CAR BODY STRUCTURES SUBJECT TO MULTIDISCIPLINARY CONSTRAINTS

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Besides eigenfrequency and other NVH related targets vehicle structures are required to satisfy multidisciplinary design criteria. Efficient multidisciplinary design while taking in to account conflicting structural requirements for car body structures comes with many chal-lenges: the large number of parameters or design variables spans a vast high dimensional search space; the high computation cost for crashworthiness simulations strongly limits the number of available design evaluations; and the highly non-linear and non-convex simula-tion model responses complicate the search procedure for global optimization algorithms. There are various state of the art techniques that could be used to deal with these challenges separately, there are however only few significant guidelines available in the literature that help to select effective methods for the application to vehicle design problems which involve NVH, crashworthiness and light weight criteria, and the resulting previously mentioned challenges. Variable screening and sensitivity analysis methods can be applied in order to reduce the dimensionality of the search space by selecting the most relevant design variables, this comes however at additional function evaluation and computation cost. For the optimization of highly nonlinear and non-convex multidisciplinary structural problems many nature in-spired optimization algorithms have been proposed, the selection of efficient optimization algorithms remains however difficult.
This communication presents an interdisciplinary review of state of the art on variable screening, sensitivity analysis, and optimization methods and comparisons on their perfor-mance to deal with some typical challenges that occur in the design of automotive structures. Since the design of car body structures deals with expensive simulations the performance of the methods are compared in terms of the computational effort and efficiency. Also the com-bined effects of variable screening based dimension reductions on the optimization efficien-cy will be assessed, to identify effective design strategies

322 - THE IMPACT OF THE STRUCTURAL NON-LINEARITY ON THE VIBRATION FATIGUE DAMAGE ACCUMULATION

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High cycle vibration fatigue is the main cause for the damage in structural components which accumulates while structure is excited by random dynamic loads. Significant influence of the structural non-linearity on the damage accumulation is supposed. A validated numeric investigation of a linear dynamic structure is used for vibration fatigue damage accumulation estimation. The accelerated vibration tests are performed for vibration fatigue lifetime determination and non-linearity quantification. The structure is excited at increasing excitation levels where an increasing level of non-linearity is observed by a FRF based approach. The FRF based structural non-linearity rate is used for the linear damage accumulation correction. The research is expected to give results with applicability to similar cases and opens up new potential in the field of structural - vibration fatigue optimization.

324 - EQUIVALENT MATERIAL MODELLING OF SANDWICH BEAM ASSEMBLIES: PROPAGATING AND EVANESCENT WAVE CONSIDERATIONS

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An approach to modelling sandwich structures in bending with a homogenised equivalent material is presented. The dispersion of the layered system is brought to a Timoshenko behaviour, and an equivalent damping coefficient is derived. The equivalent model can then be implemented in finite element (FE) models by means of commonly used shell elements with transverse shear stiffness. A critical review of the limitations of such an equivalent material is made, specifically in relation to the evanescent parts of the dispersion, which are of importance in assembled structures. A benchmark case with specific boundary conditions is presented to demonstrate the strengths and weaknesses of the approach.

326 - AN INVERSE METHODOLOGY FOR LOW-FREQUENCY TRANSMISSION LOSS CHARACTERIZATION OF A LIGHTWEIGHT PANEL IN A SMALL REVERBERANT TRANSMISSION SUITE

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A new procedure for the low frequency Transmission Loss (TL) characterization of panels, by means of a small reverberant transmission suite is discussed. Moreover, in the case of lightweight panels the measurements are affected by a strong vibro-acoustic coupling between the sample tested and the fluid in the cabin, resulting in an unreliable TL prediction below the Schroeder's frequency. This paper proposes a novel methodology to retrieve the structural interface mobility matrix of lightweight panels, unaffected by the fluid coupling, using the Patch transfer Function (PTF) sub-structuring method. The retrieved mobility matrix allows then for reliable and standard-like TL predictions in different environments. This new approach has been numerically validated by a simple reference case of a homogeneous Aluminium plate coupled to a small cabin with simply supported boundary condition. The results show a very good matching between the known reference mobility and the estimated one. The limitations of this new procedure, possible applications and further studies are also discussed.

336 - THE FINITE ELEMENT ANALYSIS ASSESSMENT OF STRUCTURE PROPERTIES FOR A L7E CLASS VEHICLE UNDER THE BENDING, TORSION STATIC AND CRASH LOADS

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To resolve the burning question of the future mobility at medium and big urban areas some ideas of small lightweight vehicles were proposed. Currently dominating trend represents the L7e vehicle class with the electric driven powertrain. Up to now there are not defined any legislative requirements of crash safety for the L7e vehicle class. This fact together with the inflammable risk during the crash situations is one of motivations for the recently appearing attempts for the crash tests standards proposed by the European New Car Assessment Programme. In the frame of this lecture the mechanical properties of vehicle body and the vehicle behavior during the crash as the influence factors on the safety of the lithium ion battery packs will be considered. The base for this consideration is by Virtual Vehicle adapted electric driven quadricycle, called eQuad. As the effect of conversion design the original triangulated tube structure of eQuad was modified for the packaging purpose of electric powertrain components. By the application of FEA and using the automotive evaluation tests the results of the bending and torsion static strength of vehicle structure will be presented. For this calculation, as well as, for the crash test scenarios, like front, rear and side with both, rigid wall and rigid pole obstacle, the nonlinear material models were applied. The special care was done for the Finite Element model preparation of battery pack in order to capture the critical deformations. The model preparation phase together with the modeling technique will be demonstrated. The results of various relevant crash scenarios will be discussed and the battery inflammable risk during the crash phenomena will be regarded.

337 - A SAMPLING CRITERION FOR ACOUSTIC RADIATION PROBLEMS: PRACTICAL APPLICATIONS

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When dealing with sound radiation problems, the radiating surface is discretised into elemental areas also referred to as patches. It can be shown that the discretisation of the structure according to the acoustical Nyquist criterion rather than the structural one will still result in a accurate estimate of the radiated power provided the complex valued vibration field is averaged over each patch. This is due to the fact that the averaging process, on one hand, reduces the structural velocity and simultaneously, determines an increased radiation effi-ciency. In this paper the theoretical background is briefly reviewed and experimental and numerical examples are given.

338 - DETERMINING VIBRATION SOURCES IN SOLID MEDIA USING TIME REVERSAL TECHNIQUE

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The identification of the noise source and its transfer path becomes more demanding in several fields of industry; that calls for a robust technique, which can guide to identify the noise source. The propagation of elastic waves is time reversible in a linear non-attenuative medium. This property can be used to rebuild the original response signal on the excitation point by means of recorded response signals at receiving points. This technique is called the time reversal mirror, which is based upon the feature of symmetry of the acoustic wave equation in some media, where the standard wave equation only contains even order derivatives. In this paper, the problem of determining the different source locations and their mutual importance using the time reversal technique is considered for some simple engineering structures. The responses of the structures to two forces of unknown magnitude and location are recorded in several receiver positions, reversed in time and sent back through the system. The resulting waves converge back at the points where they were originally emitted, a process referred to as 'focalisation'. Analytical models are built to support this theory, followed by experimental validation. The influence of parameters such as the number of transceivers, the structural complexity and the type of input signals were investigated. Particular interest was given to the effect of multiple inputs and the relation between the focalisation response and the original input power.

400 - SIMULTANEOUS OPTIMIZATION OF COMPOSITE STRUCTURES WITH SHUNTED PIEZOCERAMICS

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Vibrations in modern machines such as cars, airplanes and bridges constitute a real issue that can cause undesirable noise, damages and even catastrophic failures. In order to reduce this harmful effect, passive vibration attenuation measures have been extensively used, but can no longer cope with the increasing complexity of engineering systems. In this sense, novel smart structures have been created to efficiently suppress vibration without notable adverse effects. In this work, a novel approach to deal with the application of shunted piezoceramics in lightweight composite structures for vibration attenuation is proposed. It is based on the simultaneous optimization of different sub-systems of the smart structure, i.e. host structure, transducers and electronics, so that a set of technical requirements can be met. Instead of being considered as an add-on solution, the shunted piezoceramics are regarded as additional design variables. In this sense, passive structural mass is substituted by active material in an intelligent way, which can potentially reduce overall weight and at the same time improve the dynamic response of the smart structure. Initially, numerical and experimental analyses are carried out using a scale model of a control arm. It consists of a cantilever carbon fiber beam with "I"-shaped cross-section, controlled by the use of piezoceramics. Vibration attenuation is achieved through an RL-shunt

circuit connected in series with a negative capacitance, which is built through a synthetic circuit based on an operational amplifier. The classical sequential approach is first introduced, in which the piezoceramics are applied onto the surface of the beam. Then, it is compared to the novel approach, in which the beam, now with integrated piezoceramics, is fully optimized taking into account its geometry, the stacking sequence, the transducer dimensions and the shunt circuit components. Thanks to the simultaneous approach, not only the mechanical requirements of the structure, such as mass, global stiffness and dynamic behavior can be respected, but also the electrical characteristics of the shunt circuit.

Power-transformer noise (MS13)

243 - THE INFLUENCE OF MAGNETIC ANISOTROPY ON MAGNETOSTRICTION FORCES AND VIBRATION IN POWER TRANSFORMERS

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The paper presents results of finite elements modelling of steady state magnetostriction forces in power transformer core together with resulting vibration. The phenomena included in analysis are: magnetically nonlinear material orthotropy of core sheets, artificial magnetization curves of overlaping areas, tensor model of magnetostriction deformation (without volumetric changes). The 2D model of magnetic field takes into account coupled circuit-field solutions with sinusoidal, three-phase voltage as the external constraint for delta connected windings. The time-stepping approach applied to 2D model of transformer was used. The flux density vector field was extracted at the each time step from areas of interest and converted by specialized post-processing into volume force and volume moment of forces. Results are given after DFT transform of forces and moments of forces acting in transformer joints, limbs and yokes. Initial steady state deformations of transformer core are also presented obtained after solution of mechanical 3D model of transformer assembled core. This model consists of artificial materials approximating real, composite structure of transformer core and windings.

278 - A COMPARISON BETWEEN NUMERICAL AND EXPERIMENTAL MODAL PARAMETERS OF TRANSFORMER CORE

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A comparison between numerical and experimental modal parameters is shown for three different full-size transformer cores from a regular production process. Furthermore, the measurement setup for experimental modal analysis of the cores is presented and the numerical model used is outlined. On average the results show a discrepancy of approximately 17% between numerical and measured natural frequencies. This is considered to be a good result given the size and complexity of transformer cores.

329 - MEASUREMENT AND ANALYSIS OF NOISE AND VIBRATION OF 800KV CONVERTER TRANSFORMERS

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While ultrahigh voltage (UHV) converter transformers provide economic advantages for long distance power transmission, they also pose serious environmental noise issues. This paper summarizes the outcomes from a systematic field test of the vibration and noise of a large number of converter transformer units at Jing Hua UHV converter station in China. This experimental study not only offers the an assessment of the emitted noise from the transformers with the same rating and loading but by different manufactures against the existing standard for transformer noise, but also allows an analysis of the characteristics of the noise and vibration, structural and loading relevance that are specific for converter transformers.

340 - SPATIAL DISTRIBUTION OF MAGNETOSTRICTION, STRAIN, DISPLACEMENTS AND NOISE GENERATION OF MODEL TRANSFORMER CORES

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Recently, the relevance of audible noise of power transformers increases due to the growing environmental awareness. For sound assessment, two standardised methods reveal the global noise of the whole system as resulting from the interaction of core, windings, oil and tank. But a deeper understanding of noise generation needs to investigate the role of the single above components in closer way. This paper summarizes studies on the first component, i.e. the core. Apart from the windings, the core can be assumed as a primary source of noise. The cores noise generation is a complex process depending on many parameters like material, stacking, clamping, induction, rotational magnetization, additional DC-bias, etc. From previous work [1], the individual core regions (limbs, yokes, corners and T-joints) show strong variations of local magnetostriction. Here we present correlations between local distributions of magnetostriction and the corresponding strain, displacement and noise generation. For the study, two 3-phase model cores (of g.o. and h.g.o. material) were stacked with three packages of different width, respectively. The cores were magnetized with BNOM = 1.3 T up to 1.8 T. In-plane strain was measured with strain-gauges, displacements with acceleration sensors. Sound pressure measurements were performed in the near-field mode by means of automatic scanning by microphone in 20 mm distance from free core regions within a noise-isolating scanning chamber. As to be expected, the results show strongly inhomogeneous distributions. Displacements in the area of laminations revealed very small intensities ($< 1\ \mu$m) in chaotic ways. On the other hand, the other parameters showed considerably high correlations. In particular, all three the in-plane strain, the off-plane displacements and the power of noise showed distinct maxima at T-joints (due to rotational magnetization) and at corners. As an interpretation, two basic sources of strain are involved, i.e. magnetostriction and magneto-static forces, both acting in complex interaction.

341 - NUMERICAL MACC-MODELLING OF LOCAL PEAK-TO-PEAK MAGNETOSTRICTION DISTRIBUTIONS IN A 3-PHASE TRANSFORMER CORE PACKAGE

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For the estimation of regional distributions of magnetostriction (MS) in transformer cores, the current paper proposes a novel methodology. It is based on a four-step procedure that is sum-marized in the following: (i) Local induction values of the transformer core are calculated by a novel Multidirectional Nonlinear Equivalence Circuit Calculation (MACC) method. The meth-od considers the multi-directional non-linearity and anisotropy of the material. Local induction values in a large number of flux paths can be determined not only in rolling direction (RD), but also in transvers direction (TD) in order to simulate rotational magnetization and also in diag-onal direction (DD) in order to consider the effects of the overlaps. (ii) A look-up table is estab-lished for MS-values for the given type of material for different magnetization conditions. The values are obtained from catalogue data or measured e.g. by means of Single Sheet Tester or Rotational Single Sheet Tester. (iii) The corresponding MS-values are assigned to each investi-gated flux path, taking into account the peak induction in RD and TD. This yields a 2D map of magnetostriction (3D maps being possible as well). (iv) Numerical integration is performed for individual directions, e.g. for the axis of the yoke, in order to estimate the global displacements of the core. The method was tested for a 3-phase transformer core package stacked from GO material C130-30 with outer dimensions of 1200 mm. Minimum values below 1 ppm resulted for the limbs. As to be expected, maximal values up to the order of 10 ppm resulted in the T-joint due to rotational magnetization. The results are in rough agreement with experimental data of model cores.

342 - DEVELOPMENT OF NUMERICAL MODEL FOR COMPUTATION OF POWER TRANSFORMER NOISE

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The prediction and the reduction of power-transformer noise are of increasing interest for the electrical power industry. In this paper the recently developed calculation scheme for numerical prediction of vibroacoustic properties of an oil-insulated power transformer is presented. Finite-element and boundary-element methods have been effectively applied to predict multi-physical nature of the power-transformer noise. The numerical model is capable of predicting the load and no-load noise, the electromagnetic field, the mechanical displacement field, as well as the acoustic pressure field. It is based on newly developed experiments, made in connection with original methods for modeling the magnetostriction and the dynamics of laminated structures. Finally the numerical model is implemented in the form of engineering software that enables geometrical, functional and technological optimization analyses.

346 - ACOUSTIC FIELD INSIDE THE OIL-FILLED TRANSFORMER TANK MODEL AND ITS CONSEQUENCE IN THE OVERALL NOISE RADIATION

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Vibration energy created in the active part of the oil-filled transformers is transferred to the tank walls, mainly through the fluid-structure interactions between insulating oil and structural parts as well as through mechanical couplings themselves. The question of how much vibration energy is transferred through oil and how much through mechanical connection remains unanswered. The paper describes the results of research on the propagation of acoustic waves inside the tank filled with transformer oil, in which a model transformer core was used as the source. Acoustic pressure inside the oil cavity was measured using a hydrophone, and the sound pressure level was then compared to the results of numerical prediction. The obtained good correlation allowed to describe the vibration pattern of the tank wall and to evaluate the propagation paths in the model.

347 - VIBROACOUSTIC BEHAVIOR OF 120 MVA POWER TRANSFORMER

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The origin of the power transformer noise takes place in the active part itself, where electro-magnetic phenomena are responsible for conversion of energy into mechanical vibration. The mechanical vibrations are then transferred to the surroundings which are, in the case of power transformers, oil cavity and tank. Eventually, the noise is radiated from the tank walls and also from the auxiliary equipment such as radiators, connection boxes etc. These elements, especial-ly radiators, can have a significant influence on the noise radiation and in consequence sound power that is then calculated. This paper presents the results of detailed study on noise and vi-bration behaviour of a 120 MVA power transformer, which was investigated using sound inten-sity probe(s) and a laser vibrometer. The results of this study bring general conclusions, which can be transferred to a wider range of transformers and provide insight to the transformer noise from the perspective of vibration.

363 - THE BEHAVIOUR OF VIBRATION, NEAR- AND FAR-FIELD NOISE OF ULTRAHIGH VOLTAGE (1000KV) POWER TRANSFORMERS - A FIELD TEST INVESTIGATION

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An extensive field test was undertaken to measure the vibration, near and far-field noise of two ultrahigh voltage (UHV) power transformer units at Ji An UHV power station in China. Different from the conventional power transformers, the UHV power transformer unit consists of three closely located transformer tanks. Each tank encloses one of the three phase windings of the unit. As a result, the near and far-field low frequency noise radiated from those tanks are affected by the interference of the radiated sound fields from individual vibrating tanks. This paper reports some observed properties of the measured vibration and noise of the transformer units and discuss the possible relationship between the locations of the transformer tanks and spatial distribution of the radiated transformer noise.

The dynamics of an axially moving continuum (MS14)

20 - MODELLING THE BELTS - ENVELOPE INTERACTIONS DURING THE POSTAL MAIL CONVEYING BY A SORTING MACHINE

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The purpose of this study is to predict the trajectory of an envelope when conveyed between two flat belts in a mail sorting machine, as it is often the case in postal centers. Each of the envelope side is in contact with one belt. The friction coefficient can differs between the two sides in the cases of postcard or plastic windowed envelope. The two belts are supposed to travel horizontally with the same velocities, but it is not always true and some very little velocity differences can occur. Also, some deviation from the horizontality of the belts can be observed. These phenomena can lead to unexpected situations where the envelope relative position to the belt changes while being conveyed. The work focuses on the belts-envelope mechanical interactions in order to predict the envelope position during its conveying. A 2D model is developed, it considers the dynamic equilibrium of the envelope. The key point is, at each time step, the determination of the contact surfaces between the envelope sides and the belts, they are represented by polygonal areas. One side of the envelope is considered stuck to the belt while the other is slipping. The position of the envelope center of gravity and the angle with the horizontal axis are calculated. The belt/envelope friction forces are applied at the centers of the contact surfaces. Finally, some cases of operation are simulated. The results obtained show consistency with the observations done on the machine. The influence of some driving parameter are highlighted: the belt misalignment, the plastic window location on the envelope, the friction coefficient, the speed difference between belts.

76 - EXPERIMENTAL ANALYSIS OF NONLINEAR RESPONSE IN SIMPLY SUPPORTED BEAM SUBJECTED TO PARAMETRIC EXCITATION

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Recently, parametric resonances become positively utilized in MEMS devices such as mechanical filters, energy harvesters, and so on, due to the characteristic resonance mechanism and the large response amplitude. The presentation is to show the basic nonlinear investigations for the parametric resonance using a macro simply supported beam. The nonlinear characteristics of the frequency response curve are theoretically and experimentally investigated under the parametric resonance produced in the axial harmonic excitation. First, according to the conventional way, taking into account the nonlinearity of curvature of beams and using Hamilton's principle, the equation of motion of the beam in the lateral direction is derived. Employing the method of multiple scales, the equations which show the modulation of the amplitude and phase of the parametric resonance are obtained. The stability and bifurcations of the response amplitude are investigated considering the nonlinearities of the systems. The theoretically obtained frequency response was partially agreement with the experimental one in the third order analysis, but they have a big difference in the global point of view. Hence, there is a saddle-node bifurcation in the experimental frequency response curve. It is clarified that the fifth-order analysis is needed to theoretical analysis. Accordingly, we perform the nonlinear analysis in the accuracy of fifth order and compare the theoretical frequency response curve with experimental one.

168 - THE NATURAL FREQUENCIES OF AN AXIALLY MOVING BEAM SUPPORTED BY AN INTERMEDIATE SPRING

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This paper evaluates the natural frequencies of an axially moving beam having an intermediate simple support resting on a spring for pinned and clamped ends. The intermediate support of the Euler-Bernoulli beam means that there is one simple support on spring-foundation in-span. The beam travels under an applied tensional force. The differential equations of motion and boundary conditions are obtained using Hamilton's Principle and solved using a perturbation technique namely the Multiple Scales Method. The natural frequencies are obtained numerically for various combinations of flexural rigidities, intermediate support locations and spring constants under various end conditions. Natural frequency-mean axial speed curves showing the effects of variations of mean axial speed and location constant of the intermediate support on the natural frequencies of the beam are depicted. The first three transverse mode shapes of the axially moving beam were given. The variation of the natural frequencies with the increase in the mean moving velocity occurs as follows: While the mean translating velocity increases, the natural frequencies decrease.

343 - ROTATIONAL RESPONSE AND SLIP PREDICTION OF SERPENTINE BELT DRIVES USING ABSOLUTE NODAL COORDINATE FORMULATION

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In the past decade the applicability of belt-drives has been extended significantly due to their increased reliability. A serpentine belt drives are widely used to power all front accessories of the engine in modern vehicles. Although belt drives are much quieter compared to gear drives they can exhibit complex dynamics behavior; therefore it is very important to predict the dynamic response of such systems using validated numerical models. In this study the dynamic response and slip behavior of V-ribbed belt drive is investigated. The relation between belt-drive parameters and the speed loss is predicted using numerical model based on absolute nodal coordinate formulation. Moreover, the belt pulley contact forces were formulated as a linear complementarity problem, which enabled the incorporation of the discontinuous Coulomb friction law.

Engineering solutions for damping vibrations (MS15)

9 - TUNED MASS DAMPER USE FOR STRUCTURAL IMPROVEMENT BEHAVIOUR IN SOME REPRESENTATIVE ITALIAN CONSTRUCTIONS

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The paper discusses the Tuned Mass Dumper (TMD) use in some representative Italian constructions having a symbolic architectural value. In particular, the paper presents the TMD use for a new tall building in Milan, two footbridges (having each other different structures) and an historical chimney (hit by a strong earthquake in 2012) located in Lombardia region. By the TMDs, these constructions improve their structural behaviors, either in the Ultimate Limit State (ULS), either in the Serviceability Limit State (SLS). Therefore, by the TMDs, the structural performances improve under the seismic and wind actions with a greater comfort, in daily use, for the occupants. For each cases the structural analysis (by finite elements model, FEM) without TMD, the related TMD's parameters optimization and a subsequent structural analysis with TMD (emphasizing the improvements) are illustrated. Finally, for each TMDs, a design hypothesis are showed pointing out the installation procedures and the related costs.

87 - STIFFNESS AND LOSS FACTOR OF UNBONDED, MULTI-STRAND BEAMS UNDER FLEXURAL DEFORMATION

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Beam-like structures constructed from many long strands that are constrained rather than bonded together can provide high levels of structural damping through friction between individual strands. This paper describes experimental and numerical studies carried out on square-section metal beams that are aimed at improving understanding of the relationship between construction and performance. The beams used in this study are constructed from lengths of square-section, key steel. The bundle of strands is held together at various compression loads with pre-calibrated clamps. Flexural behaviour of an assembled beam is simulated using standard finite element analysis and simple Coulomb friction at the interfaces. The validity of the assumptions used in the models is confirmed by comparison with three point bend tests on a regular nine strand construction at several different clamp loads. Subsequent numerical studies are used to investigate the effects of increasing the number of strands whilst the overall cross-section of the bundle remains unchanged. It is found that overall stiffness drops and loss factor increases when more strands are used. Interestingly, the energy dissipated by each beam construction is almost the same.

121 - NONLINEAR DYNAMIC ABSORBER TO REDUCE VIBRATION IN HAND HELD IMPACT MACHINES

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Pneumatic impact machines have been used since the early 20th century. Up to day still a little has been changed in their fundamental design. Despite their being robust and efficient, vibration, noise, dust and poor ergonomics cause a large number of injuries to the operators, especially in the stone industry. In the proposed paper vibration dynamics of the hand held impact machine (HHIM) equipped with nonlinear dynamic absorber

is in focus. The considered HHIM has the same parameters as the existing conventional one with respect to total weight, piston weight, impact energy and operating frequency. The paper presents the mathematical and computational models of vibration dynamics of the HHIM with nonlinear dynamic absorber as well as the experimental set-up developed for model validation. Using the validated computational model the sensitivity analysis of vibration dynamics has performed on a broad set of feasible operational scenarios with respect to structural parameters of the HHIM equipped with nonlinear dynamic absorber. It was shown by simulations as well as it was proved by experiment that the vibration of the HHIM equipped with nonlinear dynamic absorber can be reduced significantly and in a broader operating frequency compared to the vibration of the same machine equipped with linear tuned vibration absorber. The results obtained confirm the possibility to design a user friendly low vibration impact machines efficiently operating in a broad frequency range. A nonlinear dynamic absorber combined with vibration isolation has shown to significantly reduce the vibration on the operator.

143 - EHRLICH-ABERTH ITERATION FOR VIBRATIONAL SYSTEMS

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We consider the computation of the eigenvalues of the quadratic eigenproblem $Q(\lambda)x = (M\lambda^2 + C\lambda + K)x = 0$, where the coefficient matrices M,C,K are known as mass, damping and stiffness matrix. They are positive definite and (M, K) is regular. The damping matrix is the sum of internal and external damping of rank r, hence $C=C_{int}+C_{ext}$. Internal damping is an essential property and it can guarantee characteristics such as passivity and stability of the problem. The most popular models are Rayleigh or proportional critical damping. Computing the eigenvalues of is viewed as a root-finding problem on det Q(λ) by an Ehrlich-Aberth iteration (EAI) which is a Newton-like method to find all eigenvalues simultaneously. By including internal damping of the aforementioned form, we extend an idea of Taslaman that is designed to work with low rank matrices. The flop count of the Newton-like update in the EAI is then of order $O(r^2n+r^3)$. Starting points are crucial to the performance of EAI and can be given by the eigenvalues of the quadratic eigenproblem neglecting external damping or by further insight into the problem.
Matrix polynomials of the form appear in the analysis of vibrating structures with discrete viscous dampers. For example, a special structure arises when optimizing the positions i_j of the discrete dampers. The external damping C_{ext} is varied due to the discrete positioning and viscosities, but the internal damping C_{int} remains constant. Numerical experiments illustrate that similar external damper configurations yield similar eigenvalues, and hence good starting points for EAI.

330 - STRUCTURAL OPTIMIZATION OF A MATERIAL EXHIBITING NEGATIVE STIFFNESS

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A typical representation of negative stiffness mechanism is formed by two inclined springs/bars allowing for snap-though. Material realization to this effect, using a continuous material, is still a challenging task. This contribution is a continuation of the authors' previous research where such a realization was done by polyethylene sheets with additional cuts, i.e. from a material that is easily accessible. In preliminary testing it was shown that such a material gives the expected results under displacement control tests. Results presented showed that the attained loss modulus is much higher than the one of the base material. The objective of this contribution is to apply techniques of structural optimization to maximize the global loss factor.
An adequate material model is used accounting for orthotropy due to the polyethylene bubbles direction, high compressibility and stretching occurring in cuts and material viscoelasticity. Several appropriate material models have been presented in previous works. Here specimens of base material with different sizes and densities were tested experimentally under unilateral tension, compression, cyclic and relaxation tests using a universal testing machine. Distribution of the Lagrangian strain tensor is extracted with the help of digital image correlation and

tracking and transformed to the left or right Cauchy-Green strain tensors. Then available hyperelastic model was analytically studied and adjusted by fitting Matlab modules.
Using such material model, optimization is performed numerically based on a finite element analysis model. First of all design of experiments indicate significant factors and interactions. As key factors we identified size, shape and arrangement of the additional cuts, as well as the density of the base material. Allowable ranges of these factors define the design space and the global loss factor is maximized by metaheuristic algorithm, the simulated annealing.

Full Field Measurements for Advanced Structural Dynamics (MS18)

191 - COMPARATIVE STUDIES ON FULL FIELD FRFs ESTIMATION FROM COMPETING OPTICAL INSTRUMENTS

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Advanced optical measurement systems are nowadays at disposal for complex dynamic and modal tests on lightweight structures, each with its own advantages, drawbacks and preferred usage domains, in order to obtain highly spatially defined vibration patterns for many applications in vibration engineering and product development. This work aims at comparing the potential of three completely different technologies on a common target and test rig. SLDV, dynamic ESPI and hi-speed DIC are here deployed in a unique test on the estimation of FRFs with high spatial accuracy from a thin plate, which exhibits a broad band dynamics and high modal density in the common frequency domain where the techniques can find an operative intersection. The comparison of estimated FRFs and related quality features is detailed with notes on acquisition and processing techniques, in order to draw conclusions on the full field measurement approach and the specific gear. Assessing the successful Full Field FRF estimation stage turns to be the basic step in developing further analyses, like experimental full field modal analysis for enhanced reliability in modeshapes estimation, numerical model tuning and risk assessment in complex structures.

192 - ACCURATE FRF ESTIMATION OF DERIVATIVE QUANTITIES FROM DIFFERENT FULL FIELD MEASURING TECHNOLOGIES

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Full field measurement technologies can not estimate only spatially detailed displacement fields, but can exploit the consistency of the results by means of differentiation operators to obtain rotational degrees of freedom and superficial strain distributions. Both extracted results can be used as advanced benchmarks for numerical models, advanced finite element formulation and fatigue analysis, as well as experimental and hybrid models in sub-structuring frameworks. Approaching the task with the aid of superior quality receptance maps, this work implements proper differentiation operators and signal processing techniques to calculate and to compare rotational dofs and dynamic strains from three different full field technologies: SLDV, Hi-Speed DIC and dynamic ESPI. A thin plate dynamics is benchmarked as light-weight structure with broad band dynamics and high modal density in a unique comparative set-up. The extraction of dynamic rotational dof & strain distribution features is discussed, benchmarked and compared in detail.

196 - MODEL UPDATING FROM FULL FIELD OPTICAL EXPERIMENTAL DATASETS

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Are optical measurements and high spatial dense datasets effective in advanced model updating of lightweight structures with complex structural dynamics? The generally accepted reference in measuring vibration patterns with high spatial definition might be the Laser Doppler Velocimetry, with it's scanning variances, but also with the noise shown in the raw signal of some experiments, which poses issues in proficiently exploiting the added data in a fruitful model updating procedure. Instead, native full field measuring technologies like Hi-Speed DIC and dynamic ESPI have shown recently intrinsic smoother data fields due to their image-based nature and evaluation algorithms, promising benefits on model optimisations. In this paper, in the framework of established

procedures for model updating of dynamically excited structures, a comparison is made by means of all the cited challenging technologies on the same broad band vibration measurement problem, with different spatial resolution and quality of the measured patterns. Model updating results are compared between scanning and native full field technologies, with comments and details on the test rig, on the advantages and drawbacks of the approaches.

251 - DETERMINING SUBPIXEL FULL-FIELD DISPLACEMENTS FROM VIDEOS BY USING OPTICAL FLOW

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Visual information captured with a high speed camera offers full-field displacement measurements using different computer vision methods, e.g. Digital Image Correlation. This study proposes the use of Optical flow on colour images to measure full-field displacements in the time frequency space. Displacement amplitudes are determined from a linear relation between the colour intensity and the dispacement in every pixel. The resolution potential and the noise sensitivity of the proposed method are explored in a synthetic experiment. Sub-pixel resolution of around 0.001 pixel is achievable and a reconstruction is still possible at a high noise of 0 dB if the colour pattern provides appropriate conditions. The proposed method involves much less computation than Digital Image Correlation, making it suitable for long image sequence analysis expected in structural vibration measurements.

Non-smooth Dynamical Systems (MS19)

248 - HIDDEN DYNAMICS OF DRY-FRICTION OSCILLATORS

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The theory of nonsmooth dynamics describes how discontinuities in dynamical laws, such as those caused by friction, impacts, shape buckling, or mechanical relays, affect the deterministic and otherwise smooth behaviour of a mechanical system. In the geometric theory of dynamics, a system "flows" through a phase space, sometimes encountering limit sets, bifurcations, or chaos. The phase space of a nonsmooth flow is also permeated by switching thresholds. The flow can kink as it crosses the threshold, but it can also stick to the threshold, corresponding to frictional sticking, and resulting phenomena like stick-slip oscillations have been a fruitful area of study for mechanical modeling. The interaction of multiple objects undergoing coupled stickslip oscillations have not been studied from the same point of view, however, because, perhaps surprisingly, the continuous time dynamical methods for multiple sticking events were derived only recently. We summarize those methods here, including the extension of Filippov's methods to multiple switches, and the introduction of hidden dynamics inside a discontinuity. We show the implications these have for a series of coupled dry friction oscillators, giving insight into complex self-sustained oscillations. We derive the basic mechanisms of entry and exit from single or multiple sticking modes (i.e. sticking of multiple oscillators), which include both deterministic and determinacy-breaking exit points. Both of these kinds of exit point can cluster in higher dimensional systems, and both lead to complexity of behaviour in the form of robust, repeatable, but unpredictable behaviour. The study of exit points reveals how large scale unpredictability, with no obvious global structure, nevertheless has local origins in the form of local sensitivity to initial conditions at exit point singularities.

259 - MODELLING THE NON-SMOOTH DYNAMICS OF WINDSCREEN WIPERS

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This paper anticipates some results of the previous work, addressed to explore the dynamics of a mass-spring-damper system on a moving frictional surface, reproducing the motion of a windshield wiper blade. Since the contact between the system and the surface is governed by Stribeck's friction law, and impacts of the system on the surface are modelled by Poisson's impact law, the resulting dynamics is non-smooth. The model is numerically implemented in an event-driven code, and simulations are performed with the aim of reproducing and investigating the undesired squeal and chattering vibrations typically observed in the wiping motion of windscreen wipers.

292 - THE STICK-SLIP CHAOTIC MOTIONS OF AN ARCHETYPE SELF-EXCITED SD OSCILLATOR WITH DRY FRICTION

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In this paper, we propose an archetypal self-excited smooth and discontinuous (SD) oscillator driven by moving belt friction, which is constructed with the SD oscillator and the classical moving belt. The moving belt friction is modeled as the Coulomb type for the proposed self-exited SD oscillator. The analytical expressions of homoclinic orbits of the unperturbed SD oscillator are derived by using a special coordinate transformation without any pronominal truncation to retain the natural characteristics, which allows us to utilize the Melnikov

method to get the chaotic thresholds of the self-excited SD oscillator in the presence of the damping and external excitation. Numerical simulations are carried out to demonstrate the multiple stickslip dynamics of the proposed system, which show the efficiency of the prediction for stick-slip chaos of the perturbed self-excited system. The results presented here in this paper show the complicated dynamics of the multiple stick-slip motions, coexistence of asymmetric stick-slip solutions for the self-excited oscillator.

300 - MULTIPLE BUCKLING AND HIGH CO-DIMENSION ANALYSIS OF A NOVEL SMOOTH AND DISCONTINUOUS OSCILLATOR

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In this paper, we propose a nonlinear smooth and discontinuous (SD) oscillator which is composed of a lumped mass and three titled springs. Even the springs are linear, the oscillator behaves strongly nonlinear due to the geometrical configuration admitting multiple well dynamics leading to multiple bucklings and high codimension with multiple parameters. we will formulate the dimensionless mathematical model using Langrange method to derive the complex multiple bucklings and multiple well dynamics with transition as the parameters changing over the parameter space. The codimension four bifurcation phenomena with three parameters are presented by employing the unfolding theory. Meanwhile, we will propose the engineering applications in vibration isolation by providing an opportunity to construct a series of high order quasi-zero stiffness system.

Posters

99 - THERMAL BUCKLING OF FUNCTIONALLY GRADED PANELS BASED ON PHYSICAL NEUTRAL SURFACE

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Present study deals with the thermal buckling behavior of Functionally Graded (FG) plates with the gradually changed material properties from one surface to the other. General-ly, the model is developed as microscopically inhomogeneous composites using a mixture of two different materials such as a metal and a ceramic. Due to the asymmetry of material properties in the thickness direction, neutral surface concept is used as a reference plane. In this regards, various research works already have been performed using the neutral surface concept. In this work, thermal buckling of FG plate model with temperature dependent ma-terial properties is analyzed using finite element method. In the numerical analysis, the buck-ling behaviors under temperature rises in the thickness direction are investigated. The results reveal that the neutral surface position of the model is a very important factor for the beha-vior of Functionally Graded Materials.

142 - MODAL PROPERTIES AND SIMULATION OF SELF-SUPPORTING SANDWICH FACADE PANELS

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Exterior design of buildings is important part of civil engineering. There many requirements and restrictions to facades, which must be satisfied. It was demonstrated, that it is very important to use sandwich panels as noise barriers, heat insulation and because of its other makings such as low weight and quite high stiffness. Especially low weight directly influences good manipulation, transport and installation process. This article is aimed to modal properties and simulation of self-supporting sandwich exterior panels, which are manufactured and certified in accordance with EN standards. Facade consist of alumi-num facing reinforced by low density honeycomb core which is bond by polyurethane (PU) based adhesive. It is necessary to investigate mechanical properties like natural frequencies of structures and its relationship to the temperature. There are many possibilities how to pre-dict elastic features in the main directions of anisotropy. However studying of mechanical properties for steady modulus of elasticity is well known, to describe the influence of vibra-tions is more complicated. It is known that properties investigated at equilibrium state of strain may give different values of natural frequencies. If the adhesive is near to its glass transition temperature or its melting point, natural frequencies depend more on dynamic strain values. As first we bring mechanical properties and mechanical model of composite panels at different temperatures and directions of anisotropy, then we carry a natural fre-quencies which we obtained by the experimental. We were also interested to the properties of connecting joints and its influence to the modal properties of facade. Finally there is compar-ison of results which we obtained from FE analysis, analytical solution and experiments.

161 - INTERACTING ACOUSTIC WAVES WITH STATIONARY STRATIFIED MEDIUM COMPRISING A LAYER OF BUBBLY LIQUID

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The dynamics of acoustic waves in stationary stratified medium comprising a layer of liquid with polydisperse gas bubbles is theoretically studied. The proposed method to calculate pressure pulse propagation in a multilayer medium uses a fast Fourier transform algorithm. An illustration of the method is given for an acoustic waves propagation problem: a piezoelectric transducer generated a pulse of pressure that propagated through water, transmitted through three-layer medium (plastic, bubbly liquid, plastic), and reached the hydrophone in water. Thus the acoustic signal did not propagate only through the bubbly liquid but through five media: water, plastic, bubbly liquid, plastic, and water again. Each layer of the stratified medium has a finite thickness; the amplitude of the acoustic signal is small. For calculations of the interaction acoustic waves with a layer of polydisperse bubbly liquid the dispersion relation (i.e. the function of the complex wave number on the frequency) is presented. The results show that the special dispersive and dissipative properties of the layer with bubble liquid can significantly affect the dynamics of the acoustic signal in a multilayer medium, depending on the central frequency of the signal. Dispersion behavior is distinctly observed when the center frequency of the acoustic signal is in the same frequency range as the peak of the attenuation coefficient of the bubbly liquid, this leads to a strong signal attenuation and distortion. The present calculations show good agreement with the available experiments.

176 - DMA ANALYSIS AND VISCOELASTIC MODEL OF POLYURETHANE BASED ADHESIVE UNDER VARIOUS CONDITIONS

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Exterior design of buildings is important part of civil engineering. There many requirements and restrictions to facades, which must be satisfied. It was demonstrated, that it is very important to use sandwich panels as noise barriers, heat insulation and because of its other makings such as low weight and quite high stiffness. Especially low weight directly influences good manipulation, transport and installation process. This article is aimed to modal properties and simulation of self-supporting sandwich exterior panels, which are manufactured and certified in accordance with EN standards. Facade consist of alumi-num facing reinforced by low density honeycomb core which is bond by polyurethane (PU) based adhesive. It is necessary to investigate mechanical properties like natural frequencies of structures and its relationship to the temperature. There are many possibilities how to pre-dict elastic features in the main directions of anisotropy. However studying of mechanical properties for steady modulus of elasticity is well known, to describe the influence of vibra-tions is more complicated. It is known that properties investigated at equilibrium state of strain may give different values of natural frequencies. If the adhesive is near to its glass transition temperature or its melting point, natural frequencies depend more on dynamic strain values. As first we bring mechanical properties and mechanical model of composite panels at different temperatures and directions of anisotropy, then we carry a natural fre-quencies which we obtained by the experimental. We were also interested to the properties of connecting joints and its influence to the modal properties of facade. Finally there is compar-ison of results which we obtained from FE analysis, analytical solution and experiments.

299 - LAMB WAVE GENERATION USING LASER ABLATION

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This paper proposes a method of Lamb wave generation using laser ablation for a non-contact damage detection. Conventional inspections of aircraft structures integrity with wide area, such as hammering tests and visual checks, are difficult to detect the damages of the aircraft structures precisely and quickly, because these inspections are based on empiri-cal and subjective approaches. In past years, Lamb waves that were generated by contact-type sensors such as piezoelectric zirconate titanate devices were studied for detecting the damages. Since the contact-type sensors have to be attached to the aircraft structures at site, they cannot be used for conducting cost-effective and time-efficient damage detection. In this paper, Lamb waves that contain a broadband frequency element more than several hundred kHz are generated by non-contact impulse excitation using laser ablation. Laser ablation is widely used for vibration test in high frequency range, laser peening, propulsion of micro-aircraft, bolt loosening diagnosis, etc. In addition, scanning laser Doppler vibrometer is used to measure Lamb waves. Therefore, we establish a non-contact damage detection based on Lamb waves using laser ablation for acting the input, and laser Doppler vibrometer for measuring the output.

315 - ELASTIC WAVE PROPAGATION IN PLANE ROD SYSTEM

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Problem of stresses and strains waves propagation in the rod system is solved using the Laplace transform by time. Longitudinal movements are described by the classical wave equation, transverse movements - by Timoshenko equation. It is demonstrated that Timoshenko equations can be equivalently represented relatively to the cross sections rotation and shear angles. In this case the deflection function is obtained by coordinate integration of the angles sum. Thus the dynamical model of the beam can be considered as a combination of two waveguides with relative load, reflecting their interactions. The structure of forces and movements representation is found out. It allows to determine the values of the reflection and refraction coefficients at passing through the rod system node quickly. There was performed the calculation of wave passing through the sample plane node. This node is the connection of four rods of different cross-sections with perpendicular axes. It is shown that the consistent application to several nodes of the derived formulas for refraction and reflection coefficients allows to execute full rod system calculation. In this case, the equations for the kinematic characteristics and internal force factors representations do not depend on the parameters of the system as a whole. They are the multiplication of the corresponding to the traversed nodes coefficients. Thus the calculation can be performed locally, without taking into account all structure characteristics. The suggested method allows to reduce the computation time significantly in comparison with existing numerical methods.

317 - SIMULATION OF LIQUID OSCILLATIONS IN ROAD TANK AT ITS BRAKING

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The results of computer simulation of liquid cargo oscillations in the road tank are presented. The models created in the ANSYS-CFX software considered liquid-structure interaction. It was performed the comparison of maximal hydrodynamic pressures in the reservoir and liquid cargo energy dissipation per one oscillation cycle for Newtonian and non- Newtonian liquids. The obtained results demonstrated that the maximal values of hydrodynamic pressures take place at first 0.2-0.3 seconds after braking starting. These values are directly proportional to liquid densities both for Newtonian and non-Newtonian liquids. The analysis results for 50-70 %

filling levels of the reservoir have shown that the values of liquid energy dissipation for liquids with the identical density are 2-2.9 times more for the Bingham- Shwedov model and 30 % less for the model of Ostwald de Waele in comparison with the Newtonian model. Thus, the fulfilled analysis demonstrated that liquid energy dissipation values for Newtonian liquids can be applied to the non-Newtonian liquids movements with constant correction coefficients.

349 - OVERVIEW OF THE SOURCE AND ADDITIONAL FACTORS WHICH INFLUENCE THE POWER TRANSFORMER NOISE

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Core and winding vibrations are the main noise sources of power transformers. The basic physical effects of magnetostriction in core sheets and Lorentz forces on the conductors are well known, but for the noise emission the total coupled system is relevant. It starts with the non-linear and anisotropic sheet material, where thousands of them are stacked to a core and ends at the texture of the tank surface which radiates the noise. In this paper we give an overview of the relevant effects starting from the noise sources to the emitting surface, based on measurements and simulations. As a result, the laminated core structure has a wide resonance width, the different phase angles of the excitation in the limbs caused a directed radiation, the oil connects all mechanical vibrations of the active part directly to the tank and the tank structure distributes the vibration energy over the surface.

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