4^{th} International Conference on Structural Nonlinear Dynamics and Diagnosis

M. Belhaq, M. Houssni & I. Kirrou

Group of Nonlinear Dynamics
Department of Physics
Faculty of Sciences Aïn chock

University Hassan II – Casablanca

CSNDD 2018

Conference on Structural Nonlinear Dynamics and Diagnosis

June 25–27, 2018, Tangier

Booklet of Abstracts

Eds.: M. Belhaq, M. Houssni & I. Kirrou

In memoriam:

Ali H. Nayfeh, University Distinguished Professor Emeritus of nonlinear dynamics (1933-2017)

Imprimé au Maroc.

The abstracts of the paper in this Booklet were set individually by the authors. Only minor typographical changes have been made by the local organizing committee.

Booklet of Abstracts

Preface

The last three versions of the International Conference on Structural Nonlinear Dynamics and Diagnosis (CSNDD 2012, CSNDD 2014 and CSNDD 2016) organized by the nonlinear dynamic group of the University Hassan II in Casablanca were held in Marrakech (2012, 2016) and Agadir (2014). The three meetings have attracted a representative international scientific community in nonlinear dynamics and control. More than 450 scientists from 30 countries attended the meetings. About twenty mini-symposia were organized in each conference by leading experts in nonlinear dynamics.

Following the success of the last versions of the conference, the nonlinear dynamic group of the University Hassan II in Casablanca is pleased to organize the 4^{th} version of the conference in Tangier during the period of June 25-27, 2018.

The 4^{th} CSNDD 2018 is organized in memoriam of Ali H. Nayfeh, University Distinguished Professor Emeritus of nonlinear dynamics (1933-2017). Professor Nayfeh has been the honorary chairman of the CSNDD series and he greatly contributed to its success. He helped launch the first conference and he gave the first opening keynote. The meeting aims to provide a forum for scientists in different branches of applied mathematics, physics and mechanics to present and discuss recent advances in theoretical, numerical and experimental techniques in nonlinear dynamics. Focuses are directed toward diverse topics, ranging from dynamical systems theory to different physical and engineering applications. The CSNDD 2018 covers a large field of nonlinear dynamics, including:

Applications of the method of multiple scales in engineering
Dynamics and multiphysics problems of micro- and nano-electro-mechanical systems
Analytical and semi-analytical methods in nonlinear dynamics
Deterministic, stochastic dynamics, control of vibrating systems
Vibration energy harvesters
Nonlinear dampers and vibration absorbers
Time series analysis methods for fault diagnosis and prognosis
Time delay in nonlinear systems
Linear and nonlinear vibrations of periodic and near-periodic lattices
Nonlinear phenomena of electrical power and energy circuits and systems
Nonlinear dynamics in rotating machinery
Structural health monitoring
Nonlinear vibrations of cables, beams, plates, shells, and innovative structures
Nonlinear dynamics of aeroelastic and hydroelastic systems
Nonlinear PDEs and their dynamics

It is a great privilege for the nonlinear dynamic group in Casablanca to host this 4^{th} version of the conference and to sustain such a high-level meeting in Morocco.

I am happy to report that the 4^{th} CSNDD 2018 has attracted more than 150 participants from more than 25 countries. Thirteen keynote lectures are invited.

On the behalf of the organizing committee, I would like to thank the Keynote lecturers, the mini-symposia organizers as well as reviewers for their precious help in maintaining a high-quality scientific program of the conference.

At the same time, I would like to thank all participants, PhD students, colleagues and friends who meaningfully helped with the organization.

On behalf of the CSNDD 2018 committees, welcome to Tangier.

Enjoy a scientific stimulating and socially nice conference!

Mohamed Belhaq
CSNDD 2018 Chair

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Scientific Program

The scientific program includes:

- Plenary Lectures
- Minisymposia Sessions and Poster Sessions on pre-defined topics

The minisymposia are organized through parallel lecture sessions. As a rule, the available time slot per lecture presentation is 20 min, including discussion.

Plenary Lectures

- M. Hajj, Virginia Tech, USA
  Highlights of Professor Nayfeh's achievements that influenced the development of nonlinear dynamics and its applications
- H. Hetzler, University of Kassel, Institute for Mechanics, Kassel, Germany
  Quasiperiodic motion and synchronization classical phenomena, modern approaches, recent advances
- A. Chaterjee, Indian Institute of Technology, Kanpur, India
  Net-impulse based restitution models for simultaneous multiple impacts of two types
- W. Zhu, Department of Mechanical Engineering, University of Maryland, USA
  Dynamics of continuous systems: from time-varying, nonlinear, and flexible multibody systems to phononic structures
- B. Fiedler, Institute of Mathematics Free University of Berlin
  Good to be late, precisely
- D. Quinn, Department of Mechanical Engineering The University of Akron, USA
  Reduced-order models of structural damping arising from mechanical joints and interfaces
- M. Younis, King Abdullah University of Science and Technology, Saudi Arabia
  Exploiting dynamical phenomena of micro and nano systems for superior devices
- S. Lenci, Polytechnic University of Marche, Ancona, Italy
  On the strange effects of boundary conditions in the nonlinear vibrations of beams
- H. Nijmeijer, Technical university Eidhoven, Netherlands
  Emergent behavior, synchronization and control
- A. Pirrotta, University of Palermo, Italy and Department of Mathematical Sciences, University of Liverpool, UK
  The use of complex fractional moments for nonlinear systems
- C. Nataraj, Villanova University, Villanova, PA, USA
  Integration of nonlinear dynamics in the problem of rotating machinery diagnostics
- M. Tlidi, Université Libre de Bruxelles, Belgium
  Vegetation patterns: A self-organized response to resource scarcity
- M.G. Velarde, Instituto Pluridiciplinar-UCM Madrid, Spain
  Drops and their selfpropulsion: microfluidics (drops as microreactors or as carriers)

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Minisymposia and chairs

- **MS1. Symposium in Memoriam of Prof. Ali H. Nayfeh: Applications of the method of multiple scales in engineering**
  E.M. Abdel-Rahman (USA), A. Abdelkefi (USA), N. Kacem (France), F. Najar (Tunisia), W. Lacarbonara (Italy)
- **MS2. Analytical and semi-analytical methods in nonlinear dynamics/time delay in nonlinear systems**
  R.H. Rand (USA) K.W. Chung (Hong Kong), M. Belhaq (Morocco)
- **MS3. Nonlinear phenomena of electrical power and energy circuits and systems**
  A. El Aroudi (Spain), E. Ponce (Spain), L. Benadero (Spain)
- **MS4. Linear and nonlinear vibrations of periodic and near-periodic lattices/Structural health monitoring**
  N. Kacem (France), M. Ichchou (France), N. Bouhaddi (France), O. Bareille (France)
- **MS5. Nonliear dynamics in rotating machinery**
  J. Mahfoud (France), P. Keogh (UK)
- **MS6. Deterministic and stochastic dynamics and control of vibrating systems and their applications to engineering and science**
  J.M. Balthazar (Brazil) A. Cunha Jr (Brazil), P.B. Gonçalves (Brazil), E.M. Jarzebowska (Poland)
- **MS7. Time series analysis methods for fault diagnosis and prognosis**
  G. Litak (Poland), P.S. Heyns (South Africa), C. Nataraj (USA), C.K. Kwuimy (USA)
- **MS8. Nonlinear dynamics in spatially extended systems/Dissipative solitons**
  M. Tlidi (Belgium)
- **MS9: Nonlinear PDEs and their dynamics**
  A. Azouani (Morocco), B. Fiedler (Germany)

Conference Synthetic Timetable

Registration (Royal Tulip Hotel, Tangier)

– Sunday, June 24, 16:00–20:00

Monday, June 25, 2018

08:00–09:00	***Registration***
09:00–09:50	Opening Ceremony
09:50–10:15	Opening Plenary Lecture 1: Muhammad Hajj
10:15–11:00	***Conference Photo and Coffe Break***
11:00–11:30	Plenary Lecture 2: Hartmut Hetzler
11:30–12:00	Plenary Lecture 3: Anindya Chaterjee
12:00–12:30	Plenary Lecture 4: Weidong Zhu
12:30–14:00	***Lunch***
14:00–15:40	Minisymposia (Parallel Sessions: S1, S2, S3, S4)
15:40–16:20	***Coffee Break***
16:20–18:00	Minisymposia (Parallel Sessions: S1, S2, S5, S4)

Tuesday, June 26, 2018

08:30–09:00	Plenary Lecture 5: Bernold Fiedler
09:00–09:30	Plenary Lecture 6: Dan Quinn
09:30–10:00	Plenary Lecture 7: Mohammad Younis
10:00–10:30	***Coffee Break***
10:30–12:30	Minisymposia (Parallel Sessions: S1, S6, S7)
12:30–14:00	***Lunch***
14:00–15:40	Minisymposia (Parallel Sessions: S1, S6, S7, S8)
15:40–16:20	***Coffee Break and Poster Session***
16:20–18:00	Minisymposia (Parallel Sessions: S1, S6, S9)
20:00	***Conference Dinner***

Wednesday, June 27, 2018

08:30–09:00	Plenary Lecture 8: Stefano Lenci
09:00–09:30	Plenary Lecture 9: Henk Nijmeijer
09:30–10:00	Plenary Lecture 10: Antonia Pirrotta
10:00–10:30	***Coffee Break***
10:30–11:00	Plenary Lecture 11: Chandrasekhar Nataraj
11:00–11:30	Plenary Lecture 12: Mustapha Tlidi
11:30–12:00	Plenary Lecture 13: Manuel G. Velarde
12:15–12:30	***Closing***
12:30–14:30	***Lunch***
15:00	**City Tour**

Technical Program

Sunday, June 24, 2018		Monday, June 25, 2018		Tuesday, June 26, 2018		Wednesday, June27, 2018	
16:00	Registration and welcome mint tea Royal Tulip Hotel	08:00	Registration Royal Tulip Hotel	08:30	Plenary Lecture 5 **Bernold Fiedler**	08:30	Plenary Lecture 8 **Stefano Lenci**
		09:00	Opening Ceremony	09:00	Plenary Lecture 6 **Dann Quinn**	09:00	Plenary Lecture 9 **Henk Nijmeijer**
		09:50	Opening Plenary Lecture 1 **Muhammad Hajj**	09:30	Plenary Lecture 7 **Mohammad Younis**	09:30	Closing Plenary Lecture 10 **Antonina Pirrotta**
		10:15	**Conference Photo and Welcome Reception**	10:00	**Coffee Break**	10:00	**Coffee Break & Poster Session**
		11:00	Plenary Lecture 2 **Hartmut Hetzler**	10:30	S1 / S6 / S7	10:30	Plenary Lecture 11 **Chandrasekhar Nataraj**
		11:30	Plenary Lecture 3 **Anindya Chaterjee**			11:00	Plenary Lecture 12 **Mustapha Tlidi**
		12:00	Plenary Lecture 4 **Weidong Zhu**			11:30	Closing Plenary Lecture 13 **Manuel G. Velarde**
						12:15	**Closing**
		12:30	**Lunch**	12:30	**Lunch**	12:30	**Lunch**
		14:00	S1 / S2 / S3 / S4	14:00	S1 / S6 / S7 / S3	15:00	**City Tour**
		15:40	**Coffee Break**	15:40	**Coffee Break & Poster Session**		
		16:20	S1 / S2 / S5 / S4	16:20	S1 / S6 / S9		
				20:00	**Conference Dinner**		

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Abstracts

Plenary Lectures Abstracts

Scheduled:

Monday *9:50–12:30* Royal Tulip Hotel **Room Henri Matisse**

Highlights of Professor Nayfeh's achievements that influenced the development of nonlinear dynamics and its applications

Mon.
09:50–10:15
R H. Matisse

M. Hajj
Virginia Tech, USA

Professor Nayfeh pioneered the implementation of perturbation techniques to advance the state of our knowledge of important nonlinear phenomena and their occurrence in many applications. We highlight some examples from the fields of fluid mechanics, structural dynamics, fluid structure interactions, power systems, and microelectromechanical systems to show the breadth of his knowledge and contributions. The examples include: (1) identification of the saturation phenomenon in ship motions and its exploitation in other applications to control structural vibrations, suppress flutter and design a single actuation mechanism that can change from pure horizontal flapping to pure vertical flapping, (2) demonstration of different approaches for laminar flow control to delay the transition to turbulence of boundary layers, (3) identification of slow and fast scale instabilities of different electrical devices, (4) identification of the dynamic pull-in instability, use of bifurcation-based sensing mechanisms, and development of methods to determine higher order estimates of the split in initially identical neutral frequencies of micro-gyroscopes and frequency shifts in mass sensors due to minute mass, and (5) identification of the shortcomings of direct averaging when assessing the stability of hovering insects among other phenomena and applications.

Quasiperiodic motion and synchronization classical phenomena, modern approaches, recent advances

Mon.
10:00–11:30
R H. Matisse

H. Hetzler
University of Kassel, Institute for Mechanics, Kassel, Germany

Analyzing stability and bifurcation of static or periodic motions has become a standard analysis in science and engineering application. Thus, a broad variety of methods and numerical tools has been developed and numerous textbooks are available on this topic. Compared to this, quasi-periodic motions are often regarded as a kind of scientific oddity or "gimmick", which is usually discussed only very briefly in textbooks. Hence, one may raise the question, whether it is really relevant to think about such things. We believe: yes, it is!
Within this contribution we would like to present some practical examples from engineering which may give a convincing motivation to analyze quasiperiodicity and thus advance

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existing numerical approaches from mathematics towards application to "real world" problems.
Starting from some classical examples and phenomena, the typical bifurcation scenario of Neimark-Sacker is introduced and some notions on torus functions are given. Classical Fourier-Galerkin methods as well as PDE-based approaches to approximate invariant manifolds are described and discussed with regards to applicability to practical problems. Based on this we devise some recent modifications and extensions of existing methods. Finally, we will give some new approaches to investigate stability and bifurcations of flows on these manifolds.
The contribution is based on work of Robert Fiedler, Simon Bäuerle and myself.

Net-impulse based restitution models for simultaneous multiple impacts of two types

Mon.
11:30–12:00
R H. Matisse

A. Chaterjee

Indian Institute of Technology, Kanpur, India

For multibody dynamics simulations in games, robotics, granular flows and other areas, we often study brief impacts between solid bodies where motions during impact are small, and motions and times between impacts are large. If large overall motions between impacts are well described using rigid body dynamics, then net-impulse based impact models are useful, though always approximate. Such net-impulse formulas are usually called rigid body impact models, although in fact deformations determine impact outcomes. I will discuss net-impulse modeling for two different problems: (1) impacts between several stiff bodies touching simultaneously at many points, and (2) vibration dominated impacts of single bodies with flexible barriers. For both problems I will describe new, and philosophically similar, restitution models in terms of velocity inequalities, Newtonian or kinematic restitution, impulse restrictions, contact-wise local inertias, and energy minimization, formulated overall as a quadratic program. Our models are conceptually simple and broadly applicable, and easily implementable in, e.g., Matlab. They have very few fitted parameters, never predict impossible behaviors like interpenetration or energy increases, and match physical reality somewhat better than comparable models. For the first problem, our restitution model is superior to the popular complementarity based approaches for many cases. For the second problem, we consider multiple sub-impacts wherein the solid body interacts with several collocated oscillators, and our restitution formula accounts approximately for vibrations, mode shapes, and relative inertias. Our approach to the first problem generalizes, for the first time, Newtonian or kinematic restitution to simultaneous multiple impacts. Our approach to the second problem has no parallel in the impact literature, as far as I know.

Mon.
12:00–12:30
R H. Matisse

Dynamics of continuous systems: from time-varying, nonlinear and flexible multibody systems to phononic structures

W. Zhu

Department of Mechanical Engineering University of Maryland, Baltimore, USA

Some interesting results on the dynamics of continuous systems that are obtained by the author and his co-workers are reviewed. They involve: 1) vibration and stability of translating media with timevarying lengths and/or velocities; 2) nonlinear vibrations of systems with large degrees of freedom and general nonlinearities; 3) new spatial discretization and substructure methods for one- and twodimensional continuous systems; 4) new formulations of flexible multibody dynamics with application to elevator traveling cables; and 5) guiding and tuning of elastic wave propagation in nonlinear phononic structures and cloaks. Two types of dynamic stability problems are addressed from the energy viewpoint in the first area: dynamic stability of translating media during extension and retraction, and parametric instabilities in continuous systems with periodically varying lengths and/or velocities. The incremental harmonic balance method is used and modified in the second area to handle periodic responses of high-dimensional models of nonlinear continuous systems and their stability and bifurcations, as well as quasi-periodic responses. The new spatial discretization and substructure methods in the third area ensure that all matching conditions of continuous systems are satisfied, and hence uniform convergence of solutions. The methods overcome drawbacks of classical assumed modes and component mode synthesis methods. New nonlinear models of slack cables with bending stiffness and arbitrarily moving ends are developed for moving elevator traveling cables in the fourth area. A minimal number of degrees of freedom are needed to achieve the same accuracy as those of finite element and absolute nodal coordinate formulation methods. Wave propagation analyses of phononic structures with finite deformations are developed in the fifth area to study influences of nonlinearities on wave propagation characteristics. An excellent broadband cloak is presented to control wave propagation in an elastic solid based on nonlinear transformation in combination with a ray trajectory equation. Some experimental results are presented to validate theoretical predictions.

Scheduled:

Tuesday *8:30–09:50* Royal Tulip Hotel **Room Henri Matisse**

Good to be late, precisely

Tue.
08:30–09:00
R H. Matisse

B. Fiedler

Institute of Mathematics Free University of Berlin, Germany

Delays are a nuisance in control. But, are delays all that bad? Following an idea of Pyragas, we attempt noninvasive and model -independent stabilization of unstable periodic phenomena $u(t)$ by a friendly delay τ. Our feedbacks are based on delayed differences like $u(t...\tau)u(t..\vartheta)$ When the time delay τ is chosen to be an integer multiple np of the minimal period p, the difference and the feedback vanish: the control strategy becomes noninvasive on the target periodic orbit. We pursue this idea for an example: control of a delay equation by additional delays. Results include joint work with Alejandro Lopez, Sergio Oliva, Isabelle Schneider, and others. See also
http://dynamics.mi.fu-berlin.de/

Reduced-order models of structural damping arising from mechanical joints and interfaces

Tue.
09:00–09:30
R H. Matisse

D. Quinn

Department of Mechanical Engineering The University of Akron, Akron, OH, USA

Structural systems are typically designed with multiple components, connected together with mechanical joints and interfaces. When properly designed, these interfaces have little effect on the overall load carrying capability of the system as compared to a corresponding monolithic design. However, the mechanical interfaces often provide a significant component of the overall damping observed in structural systems. Unfortunately, due to the localized nature of the joints, incorporating microslip, the primary source of dissipation, into larger structural models is difficult at best and often leads to computationally intractable models. Moreover, microslip is a highly nonlinear phenomena so that common linear approaches to include dissipation such as modal damping fail to describe the phenomena over a wide range of loading conditions. This lecture surveys ongoing efforts to develop computationally efficient reduced-order models of joint dynamics. Such models can ultimately be incorporated into larger structural dynamics simulations, providing a predictive model of structural systems with mechanical joints and interfaces.

Exploiting dynamical phenomena of micro and nano systems for superior devices

Tue.
09:30–10:00
R H. Matisse

M. Younis

King Abdullah University of Science and Technology, Saudi Arabia

Miniature structures and devices have captured the attention of the scientific community for several decades for their unprecedented attractive features. Today, several micro-electro-mechanical systems MEMS devices are being used in our everyday life, ranging from accelerometers and pressure sensors in automobiles, radio-frequency (RF) switches and microphones in cell phones, and inertia sensors in video games. With the quest to boost sensitivity, reduce power consumption, and increase integration density, the past decade has witnessed the emergence of Nano-electro-mechanical systems NEMS.

Along with their great promise, micro and nano devices have brought new challenges and a wide spectrum of unexplained and less-understandable behaviors and phenomena. Because these devices employ moveable compliant structures, many of these challenges are related to their dynamical behavior, which is mostly nonlinear.

In this talk, we demonstrate that by developing a proper understanding and deep insight of the dynamics and nonlinear mechanics phenomena at the micro and nano sale, new technological solutions and innovative ideas can be realized leading to new generations of superior devices. The talk will first discuss the realization of smart switches triggered by the detection of a physical quantity (combining sensing and actuation into a single device). In one application, switches triggered by the detection of gas will be discussed. Toward this, electrostatically microbeams resonators are fabricated, then coated with highly absorbent polymers (MOFs), and afterward are exposed to gases. Such devices can be useful for instant alarming of toxic gases. The second part of the talk will discuss the intriguing static and dynamic behavior of actively tunable structures; which dynamics features can be altered using electrostatic and or/electrothermal actuation. We will discuss several interesting nonlinear phenomena and their exploitation for logic, memory, filtering, and sensing applications

Scheduled:

Wednesday *8:30–12:00* Royal Tulip Hotel **Room H. Matisse**

On the strange effects of boundary conditions in the nonlinear vibrations of beams

Wed.
08:30–09:00
R H. Matisse

S. Lenci

Polytechnic University of Marche, Ancona, Italy

It is well known that the boundary conditions affect significantly the nonlinear vibrations of beam. For example, a simply supported beam (free axial displacement) shows a softening behavior while a hinged beam (fixed axial displacement) shows an hardening characteristic. In this talk a survey of the recent authors' work on the subject will be illustrated. A spring is added in the axial direction at one end of a Timoshenko beam, permitting to consider different axial boundary conditions. The effect of spring stiffness and of various mechanical parameters (axial and shear stiffness, axial and rotatory inertia) on the nonlinear correction coefficient are investigated in depth. The most relevant results is that while in the linear regime the axial and transversal behavior are decoupled, in the nonlinear regime they are coupled providing interesting dynamical behavior. To further investigate this axial transversal coupling, and inclined roller is subsequently considered. In this case the coupling exists also in the linear regime, but it is strongly modified in the nonlinear range.

Emergent behavior, synchronization and control

Wed.
09:00–09:30
R H. Matisse

H. Nijmeijer

Technical University Eindhoven, Netherlands

Synchronization is a subject apparently first discussed by the Dutch scientist Christiaan Huygens around 1650. Today the subject is seen in a large number of biological and engineering applications. In some cases this is well understood, but in many cases, particularly in case a large network of systems is involved, this is much less the case. The purpose of this talk is to review the basics of network synchronization and to develop an understanding how cooperative behavior can develop in networks. Examples from biology and engineering (including Huygens's pendulum clocks and vehicle platoons) will enlighten the presentation.

The use of complex fractional moments for nonlinear systems

Wed.
09:30–10:00
R H. Matisse

A. Pirrotta

University of Palermo, Italy and Department of Mathematical Sciences, University of Liverpool, UK

Excitations such as ground motion, wind turbulence, sea waves, surface roughness, blasts and impacts loads being stochastic processes induce that structural responses are stochastic processes too. Thus, the analyst is concerned with the problem of the response statistical characterization. However, to consider a model closer to reality a

nonlinear system has to be considered, and then a complete statistical characterization of the response may be performed by solving the Fokker Planck Kolmogorov (FPK) equation, a partial differential equation whose solution is the joint probability density function (PDF) of the response variables. Unfortunately, the FPK equation admits analytical solution in very few cases, for this reason we resort to numerical methods. Among the numerical approaches, more attractive, from a computational point of view, is the moment equation (ME) approach, in which the response statistical characterization is given b y the response moments or by other quantities related to the former such as cumulants or quasi-moments. This method consists in writing differential equations for the response statistical moments of any order. However, when dealing with nonlinear systems, a serious problem arises in the ME approach, the entire system is hierarchic in the sense that the equations for the moments of a fixed order, say K, contain moments of order higher than K. In this way, the ME forms an infinite hierarchy. In order to overcome this difficulty, the so called closure methods were born. The key idea is to express the response PDF as a Edge worth or Gram-Charlier series, truncating it at a certain term. The coefficients of the above mentioned series can be written as functions of the response central moments or of the response cumulants or of the response quasi-moments. Thus, neglecting the terms beyond a given order is equivalent to make central moments or cumulants or quasi -moments zero, which makes the ME solvable. The moments of order larger than K are expressed in terms of moments of order equal or lower to K by means of the relationships that are obtained by putting the above cited quantities equal to zero.
In this talk a survey of the recent author's findings on the subject will be introduced. In particular it will be explored the useful tool of the complex fractional moments to overcome this moment closure procedure.

Integration of nonlinear dynamics in the problem of rotating machinery diagnostics

Wed.
10:30–11:00
R H. Matisse

C. Nataraj

Villanova Center for Analytics of Dynamic Systems Villanova University, Villanova, PA, USA

Fault diagnostics in complex machinery is an important problem that attracts high interest in the industry as it helps to ensure safey and reliability. Traditionally, this problem has been attacked by signal processing and pattern matching, a procedure that relies heavily on heuristics and past experience. This ad-hoc approach however does not give consistent results and ignores the potentially valuable contribution from physics. Physics-based approaches on the other hand have been used mostly by academic researchers to explore the effect of faults on dynamical behavior. This approach has some drawbacks as well. The author's research has targeted the reconciliation of these two approaches, in particular, focusing on the valuable insights provided by nonlinear dynamics in order to uncover hidden faults. We have also explored some novel ways of characterizing nonlinear response in real systems. This talk will discuss these methods with a focus on application to rotating machinery problems such as bearings and gears.

Vegetation patterns: A self-organized response to resource scarcity

Tue.
11:00–11:30
R H. Matisse

M. Tlidi

Université Libre de Bruxelles Bruxelles, Belgium

Desertification due to climate change and increasing drought periods is a worldwide problem for both ecology and economy. Our ability to understand how vegetation manages to survive and propagate through arid and semiarid ecosystems may be useful in the development of future strategies to prevent desertification.
In this talk, a review on recent studies of dissipative structures observed in semi-arid ecosystems will be presented. These non-uniform vegetation covers exhibiting large spatial structures, generically called vegetation patterns. The arid landscapes are characterized by either water limited resources and/or nutrient-poor territories. In the former case, the potential evapo-transpiration of the plants exceeds the water supply provided by rainfalls. At the level of individual plant, the water scarcity provokes an hydric stress that affects both the plant s survivability and growth rate. At the community level, this hydric stress promotes clustering behavior which induces spatial landscapes fragmentation. It is now generally admitted that this adaptation to hydric stress involves a symmetry -breaking modulational instability leading to the establishment of a stable periodic spatial patterns. Vegetation patterns are not always periodic. The spatial distribution of vegetation may consist of isolated or randomly distributed patches or gaps. Such irregular patterns can involve groves within grasslands or spots of bare soil within a grass matrix. They consist of patches which are either isolated or forming clusters. In both cases, such patterns have been interpreted as localized structures. We have investigated these aspects by characterizing quantitatively, with a simple mathematical model, a new class of instabilities that lead to the self-replication phenomenon observed.
Finally as an application, we will consider the halfa Stipa Tenacissima L vegetation in the steppe plateau of eastern Morocco. We will focus in particular on local interactions and the ways in which they influence global emerging properties of the vegetation (spatial variations of biomass, species, etc.). Large-scale validation of the theoretical results will be done by analyzing remote sensing methods (Fourier, wavelets) and analyzing the individual structure of the halfa.

Drops and their selfpropulsion:
microfluidics (drops as microreactors or as carriers)

Wed.
11:30–12:00
R H. Matisse

M.G. Velarde

Instituto Pluridiciplinar-UCM Madrid, Spain

A survey would provide of a variety of problems where a passive or an active drop experiences directed motion consequence of the action of an external or internal agent or a combination of both, like external temperature and/or solute gradients, illumination, internal heat generation or surface chemical reaction or phase transformation. An active drop is capable of reacting by engendering autonomous, self-propelled motion in favor or against the agent. The phenomena involved offer diverse complexity but one way or another the drop motion finally rests on thermo-or soluto-capillarity hence on interfacial tension gradients causing the directed flow.

Orale presentations

MS 1

Symposium in Memoriam of Prof. Ali H. Nayfeh: Applications of the method of multiple Scales in engineering

Organizers: *M.I. Younis* USA, *E.M. Abdel-Rahman* USA, *N. Kacem* France, *F. Najar* Tunisia, *A. Abdelkefi* USA, *W. Lacarbonara* Italy

Scheduled:

Monday	*14:00–15:40*	Royal Tulip Hotel	**Room Henri Matisse**
Monday	*16:20–18:00*	Royal Tulip Hotel	**Room Henri Matisse**
Tuesday	*10:30–12:10*	Royal Tulip Hotel	**Room Henri Matisse**
Tuesday	*14:00–15:40*	Royal Tulip Hotel	**Room Henri Matisse**
Tuesday	*16:20–17:40*	Royal Tulip Hotel	**Room Henri Matisse**

Application of multiple scales method to problems with impact interaction

Mon.
14:00–14:20
R H. Matisse

R.A. Ibrahim

Wayne State University, Department of Mechanical Engineering, Detroit, USA

“Can the engineer afford to ignore nonlinear vibration in the design of mechanical systems?” This question was the main key issue of the legacy of Professor Ali Nayfeh. This presentation will focus on this question together with the main theme of the multiple scales method and other techniques (such as averaging method, harmonic balance and Struble method) employed in the area of nonlinear oscillations. The application of method of multiple scales is considered to determine the response of mechanical systems involving impact interaction. The analysis involves the simultaneous occurrence of parametric resonance and internal resonance conditions in a mechanical system simulating elastic structure carrying a liquid container allowing high power impact forces. An overview of impact problems of coupling effects of ship motion and sloshing will be presented. Limitations of the multiple scales method to systems involving extreme loading will be discussed.

A novel self-priming dielectric elastomer generator for vibro-impact energy harvesting

Mon.
14:20–14:40
R H. Matisse

Z.H. Lai[1], G. Thomson[2], E.M. Abdel-Rahman[3], D. Yurchenko[2], D.V. Val[4]

[1] *School of Mechatronics Engineering, Nanchang University, People’s Republic of China*
[2] *IMPEE, Heriot-Watt University, Edinburgh, UK*
[3] *Department of Systems Design Engineering, University of Waterloo, Canada*
[4] *Institute for Infrastructure and Environment, Heriot-Watt University, Edinburgh, UK*

The dielectric elastomer generator (DEG) has shown great potential in energy harvesting from ambient vibrations due to the variable capacitance of dielectric elastomers (DEs).

Most DEGs can generate high voltage output with the capacitance variations of DE membranes under vibration input. However, the requirement of input high-voltage power supply has restricted the potential applications of most DEGs in wireless sensors and wearable devices. In this paper, a novel self-priming DEG is proposed to discard the input power supply. The proposed DEG is a dynamic vibro-impact system with a cylinder and a metal inner ball moving freely inside. Both sides of a cylinder, along which an electromagnetic transducer is installed, are fitted with two DE membranes sandwiched with compliant electrodes under a self-priming circuit. The electromagnetic transducer converts the kinetic energy captured by the inner ball into low voltage output, which is harvested and accumulated through the self-priming circuit. Once the accumulated voltage is large enough for the DE membranes to produce higher voltage output, the DEG starts to convert vibrations into electric energy. The structure and operating mechanism of the self-priming DEG are introduced in detail based on the previous research results on electromagnetic transducer and DEG. A numerical model is developed to predict the energy harvester performance under deterministic and stochastic loading.

Nonlinear analysis and energy harvesting optimization for fish-like robots

Mon.
14:40–15:00
R H. Matisse

R. Salazar[1], G. Taylor[1], M. Khalid[2,3], A. Abdelkefi[1]

[1] *College of Engineering, New Mexico State University, USA*
[2] *College of Electrical and Mechanical Engineering, Univ of Sciences and Technology, Pakistan*
[3] *Research Center for Fluid Machinery Engineering and Technology, Jiangsu University, China*

Aquatic unmanned vehicles (AUVs) are making a shift to more capable swimming designs inspired from nature that utilize more flexible materials to make the system more mimetic. Creating more mimetic body caudal fin swimming AUV designs means that aquatic locomotion is achieved through an oscillatory body undulation. Depending on the species, caudal fin animals have differing oscillatory spinal motion to produces a propulsive force from the tail fin. This oscillatory motion can be modeled as a spatio-temporal function by replicating the behavior of spinal flexion. The spatio-temporal function is defined for an Anguilliform, Subcarangiform, Carangiform, and Thunniform motion. These motions are capable of a frequency range (2.5-5 Hz), and are defined for a cantilever beam under actuation from this spatio-temporal function. Because these systems express an oscillatory body undulation, they have energy harvesting potential where piezoelectric patches can be attached along the fish length. Since these motions are undulatory the inclusion of geometric nonlinearities for the beam must be considered. Investigations into impacts of piezoelectric material length, placement, and frequency of oscillation for these fish motions are carried out to determine the best system arrangement that generates maximum power.

Charge doubler electrostatic vibrational energy harvester

Mon.
15:00–15:20
R H. Matisse

M.A. Ben Ouanes[1,2], F. Najar[1], H. Samaali[1,2], P. Basset[2]

[1] *LASMAP, Tunisia Polytechnic School, Univ. of Carthage, Tunisia*
[2] *ESYCOM, ESIEE Paris, Univ. of Paris-Est, France*

In this work, we analyze the mechanical response of an electrostatic vibrational energy harvester e-VEH based on a springless system and using the Bennet's machine as a charge doubler. A guided central mass is free to oscillate between the border switches. The central mass forms two anti-symmetric variables capacitors with the fixed electrodes. The capacitance variations and the self actuation of switches, occurring during contacts between the fixed and mobile parts, lead to (ideally) double the charge at the electrodes at each cycle of vibration. As a result, the voltages across the two variable capacitances increase, as for the energy conversion per mechanical cycle. However, the increasing electrostatic forces applied at each side of the central mass lead to a voltage saturation. The dynamic analysis of the system is intended to understand how to correctly tune the system's parameters in order to maximize the harvested electrical energy at a wide range of vibration frequencies. The presence of the border switches is mechanically regarded as stoppers, they generate a non-smooth applied force on the central mass. The system's response is analyzed in the time domain for various applied accelerations and frequencies. The proposed model is also compared with experimental results of the fabricated kinetic energy harvester.

Hyperelastic modeling of a dielectric elastomer membrane for energy harvesting applications

Mon.
15:20–15:40
R H. Matisse

K. Mrabet , F. Najar

Applied Mechanics and Systems Research Laboratory, Tunisia Polytechnic School, Tunisia

Dielectric Elastomer (DE) have been recently used for energy harvesting application were thickness variation, due to large deformations and incompressibility, is exploited to transduce mechanical energy into electricity using a pump charge circuit. In fact, the electrostatic DE energy harvester transduces vibrations through the electric field fluctuation between its compliant electrodes forming a variable capacitor. This latter, is forced to vary its capacitance when the thickness is varied. A conditioning circuit based on diodes and electronic switches is used for the management of the charging-discharging cycles. simulate its behavior. In addition, in order to increase the harvested energy, large deformation will be considered. The proposed system is composed of a circular membrane made of a commercially available elastomer (2M VHB2510) covered by a conducting grease that plays the role of a compliant electrodes. The equations of motion are derived using the Hamilton's principle and considering that the internal energy of the system is following the Neo-Hookean model. The principal stretches of the membrane are first described as a function of the displacements assuming axisymmetric behavior. The transverse and the radial displacements will be considered in this analysis. The eigenvalue problem of the unforced system is solved first to extract natural frequencies and mode shapes. It is shown that the linear part of the equations of motion are uncoupled which generates two independent eigenvalue problem. However, considering the non-

linear equations, truncated to the third order after a Taylor series expansion, we deduce that a nonlinear coupling exist between the two displacements. The Galerkin method is used to solve the nonlinear equations that are also coupled to the electrical equations that model the conditioning circuit. We demonstrate that nonlinear coupling can be used to significantly increase the harvested energy.

Nonlinear response of a Rott's pendulum for rotating energy harvesting systems

Mon.
16:20–16:40
R H. Matisse

E. Zaouali[1], F. Najar[2], N. Kacem[1], E. Foltete[1]

[1] *FEMTO-ST Institute, Univ. Bourgogne Franche-Comté, France*
[2] *Applied Mechanics and Systems Research Laboratory, Tunisia Polytechnic School, Tunisia*

Rott's pendulum is a two degrees of freedom system having two-to-one internal resonance. The objective of this work is to demonstrate that the Rott's pendulum can be used as a kinematic transformation design that can be used for rotating systems in order to transfer kinetic energy between the rotation of the pendulum itself and an electromagnetic generator linked to its main rotation axis. In fact, the periodically applied gravity onto the Rott's pendulum, whose base is rotating at constant speed, can be used to generate large displacement responses that maximizes the harvested energy at the electromagnetic generator. We derive the nonlinearly coupled equation of motion of the system and solve the obtained equations using the method of multiple scales. The principal parametric resonance of the second mode is considered with the inclusion of the two-to-one internal resonance.

2D electrostatic energy harvesting device using a single shallow arched microbeam

Mon.
16:40–17:00
R H. Matisse

H. Samaali[1], F. Najar[1], H. Ouakad[2]

[1] *Applied Mechanics and Systems Research Lab., Tunisia Polytechnic School, Tunisia*
[2] *Mechanical Eng. Dep., King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia*

We use a MEMS based shallow arched microbeam to design a 2D energy harvesting device with a single transducer electrostatic transducer. The proposed design can transform any inplane applied acceleration into motion of a variable capacitor whose displaceable electrode is linked to the shallow arched microbeam. In addition, a secondary electrode is placed to directly apply a force on the microbeam in order to tune its natural frequency to better match externally applied acceleration frequency and increase the amount of harvested energy.

We derive the equation of motion and associated boundary conditions governing the motion of the initially curved beam (shallow arched beam) using the Hamilton's principle. The associated nonlinear integro-partial-differential equations are reduced to a nonlinear ordinary differential system using the Differential Quadrature Method (DQM) that discretizes the space derivatives. The limit-cycle solutions, for a given applied acceleration in different directions, are obtained by using a Finite Difference Method (FDM) to estimate displacements and generated voltage. The equations of motions are also coupled to a conditioning circuit using diodes to store the harvested energy into an external capacitance.

Modeling of the nonlinear dynamic behavior of circular capacitive microplate in interaction with squeeze air film

Mon.
17:00–17:20
R H. Matisse

A. Jallouli[1], N. Kacem[1], F. Najar[2], G. Bourbon[1] J. Lardies[1]

[1] *University of Bourgogne Franche-Comté, FEMTO-ST Institute, France*
[2] *Applied Mechanics and Systems Research Laboratory, Tunisia Polytechnic School, Tunisia*

For resonant MEMS devices, the surrounding fluid has an important impact on the dynamic behavior of microsystems. For capacitive microdevices, the distance between the two electrodes is relatively small compared to the lateral dimension. The vibration of one of these electrodes can lead to a massive movement of the fluid underneath it. For macrodevices, the effect of surrounding fluid can be negligible compared to other forces, such as inertia and gravity forces. However, for microdevices, the fluid film effects increase as we decrease the system size. For most MEMS devices, squeeze film effect is the most important effect on its dynamic behavior because it can cause a shift in the resonance frequencies and it adds damping to the system. In this work, a new approach is used to investigate the effect of squeeze film damping on a capacitive micromachined ultrasonic transducer (CMUT). The microsystem is a capacitive resonator with clamped circular plate. The behavior of a CMUT is modeled with mechanical equations that takes into consideration the effect of residual stress, electrostatic nonlinearities and geometric nonlinearities. The trapped air between the two electrodes is modeled using the Reynolds equation with an effective viscosity using the Veijola model. The discretization of the coupled partial differential equations is implemented using the Differential Quadrature Method (DQM) for the structural and fluid domains. The advantage of this method is that it takes only few grid points for the solution to converge. A first validation is conducted on our model using ANSYS software. For low squeeze number the two numerical results, obtained with DQM and ANSYS, are in a good agreement. However, when the squeeze number is important, the error between the two models increases. Another validation is performed between the experimental and numerical results by taking into account the thickness of the electrode. The nonlinear dynamic behavior of the CMUT is studied by solving the nonlinear differential equations using FDM in order to determine the steady state solution of the microplate. For the nonlinear frequency response of the CMUT, we modeled the microsystem with a clamped boundary condition for the microplate and with an open boundary condition for the fluid. The decrease in the static pressure in the gap leads to a decrease in the resonance frequency and an increase in the vibration amplitude. At atmospheric conditions, the nonlinear frequency response of the CMUT is obtained by applying high DC and AC voltages. The increase in the static pressure leads to an increase in the bistability domain of the force response curves.

On an analytical investigation of saturation phenomenon and energy harvesting of a two-degrees-of-freedom portal frame excited by an emergent non-ideal excitation

Mon.
17:20–17:40
R H. Matisse

R.T. Rocha[1], A.M. Tusset[1], F.C. Janzen[1], R.M.L.R. Brasil[2], J. Balthazar[1]

[1] *Dept. of Electronics, Federal University of Technology -Parana, Brazil*
[2] *CESC, Federal University of ABC, Brazil*

In nonlinear dynamics theme, there are many unsolved analytical problems due to their complexity. Nowadays, as the classical problems have been deeply investigated and

many different influences and phenomenon appeared, then such theme has been increased their interest in many different sub-areas. Systems of two or more coupled degrees-of-freedom, depending on their coupling, may present Sommerfeld effect, saturation phenomenon or others. Saturation phenomenon of dynamical system is an old and new problem faced by two-degrees-of-freedom with quadratic coupling. Therefore, the dynamics and energy harvesting of a model of portal frame of two-degrees-of-freedom, which has its columns clamped in their bases and the beam is clamped in the columns is analytically investigated in this work. The structure possesses two-to-one internal resonance between its coordinates, which is one of the conditions to saturation phenomenon occurs. A nonlinear piezoelectric material is coupled to a column, which is considered as a circuit that converts a proportional mechanical energy into electricity, to harvest energy from the sway mode of the structure. However, it is considered with an approximated relation as an adjustment between the strain constant and electric field. The analytical procedure of this study is the method of multiple scales to analyze modal interactions of the coordinate. The excitation device is an electro-dynamical shaker, which is a newest kind of non-ideal source, considering its mechanical and electrical part. The results showed the occurrence of saturation phenomenon between the modes of vibration making possible the energy harvesting from the sway of the portal frame.

Usefulness of nonlinear vibrations for the detection of nanoparticles using carbon nanotube-based sensors

Mon.
17:40–18:00
R H. Matisse

H.R. Ali-Akbari[1], S. Ceballes[2], A. Abdelkefi[2]

[1] *Sharif Technology Services Complex, Sharif University of Technology, Tehran, Iran*
[2] *Department of Mechanical and Aerospace Engineering, New Mexico State University, USA*

In recent years, many researchers have focused on the utilization of nanomaterials in devices, such as microelectromechanical systems (MEMS) and nanoelectromechanical systems (NEMS), and have surveyed their potential application as physical, chemical, or biological sensors. Carbon nanotubes (CNTs), for example, have been found to possess unique structural properties, leading to their use in devices requiring low mass, high mechanical resonance frequency, and a high surface-to-volume ratio, which can be useful for surface-based sensing mechanisms. These nano-scale mechanical resonators and sensors have proven to be successful components in a wide range of micro-/nano-scale devices.

In this work, an accurate nonlinear reduced-order model is proposed for a CNT based mass detector accounting for not only the mass and the location of a deposited nanoparticle, but also the effect of the particle's shape and/or orientation with respect to the central axis of the CNT. Furthermore, this nonlinear reduced-order model accounts for the nonlocal residuals inside the structure of the CNT and the geometric nonlinearity. After deriving the full nonlinear equations of motion by virtue of the extended Hamilton's principle, linear and nonlinear analyses are performed, with emphasis on the effects of the excitation force, mass of the nanoparticle, CNT dimensions, and size dependent phenomena. The nonlinear frequency response curves are presented using the relation derived by the method of multiple scales and the results are compared to those obtained by the numerical (Runge-Kutta) solution. Next, frequency-based mass sensing solutions are presented, considering the effects of the excitation force and Q-factor and the influences of the nonlocal parameter on the nonlinear sensitivity of the CNT based resonator. Following the frequency-based mass sensing, a similar analysis is performed for amplitude-based mass sensing. The results show that the frequency and amplitude based response are highly dependent on the excitation force, Q-factor, CNT dimensions, and deposited mass.

Resonant vibrations of the micromechanical gyroscope

Tue.
10:30–10:50
R H. Matisse

R. Starosta[1], G. Sypniewska-Kaminska[2], J. Awrejcewicz[2]

[1] *Institute of Applied Mechanics, Poznan University of Technology, POLAND*
[2] *Department of Automatics and Biomechanics, Technical University of Lodz, POLAND*

Dynamic analysis of the torsional micromechanical gyroscope designed to measure one component of the angular velocity is the subject of the paper. This type of gyroscopes belongs to broad class of microelectromechanical systems (MEMS). The crucial part of the appliance under research consists of the sensing plate and the intermediate frame (gimbal). The Cardan suspension is applied to connect these elements via anchors with the substrate which angular velocity is measured. The mathematical model includes non-linear characteristics of the torsional links. The dynamical problem has been solved using the method of multiple time scales that belongs to the broad class of asymptotic methods. The approximate solution of analytical form has been obtained for non-resonant vibration as well as for the case of the main and internal resonances that occur simultaneously. That gives the opportunity to qualitative analysis of the behavior of the system for wide range of parameters. Resonance oscillations are the desired state of work of the investigated system, therefore investigation is focused on analysis of that kind of vibration.

Experimental and theoretical study of two-to-one internal resonance of MEMS resonators

Tue.
10:50–11:10
R H. Matisse

F.K. Alfosail, A.Z. Hajjaj, M.I. Younis

King Abdullah University of Science and Technology, Saudi Arabia

In this work, we investigate theoretically and experimentally the two-to-one internal resonance of an arch microbeam tuned using electrothermal voltage and driven using electrostatic actuation. The electrothermal voltage is tuned such that the frequency ratio between the first and third natural frequencies is two. The multiple time scales (MTS) method is used to analyze the response and stability of the nonlinear system accounting for the simultaneous excitations under the competing effects of the V_{AC} and V_{DC} voltages due to the direct excitation of Ω and 2Ω periodic terms when the excitation is around the first primary resonance. The results of the multiple scales method are compared with the results obtained from experiments and Galerkin solution and a good agreement is found in all voltage cases. The multiple scales solution shows that the solution undergoes multiple saddle node and Hopf bifurcations. The dynamical solution of the system demonstrates that the response experiences quasi-periodicity and period doubling which might lead to have chaotic solution.

Nonlinear dynamics and chaos suppression in a nonlinear MEMS oscillator

Tue.
11:10–11:30
R H. Matisse

A.M. Tusset[1], R.T. Rocha[1], F.C. Janzen[1], T.C.L. Marsola[2], J. Balthazar[1]

[1] *Dept. of Electronics, Federal University of Technology - Parana, Brazil*
[2] *Aeronautics Technological Institute (ITA), Brazil*

In this paper, the dynamical analysis and control of a nonlinear Microelectromechanical systems (MEMS) resonator system is considered. Phase diagram, Power spectral density (FFT), bifurcation diagram and the 0-1 test were applied to analyze the influence of the nonlinear stiffness term related to the dynamics of the system. The aim is to control the system forcing it to an orbit of the analytical solution obtained by the multiple scales method. The considered controls are the Chebyshev polynomial expansion of the Picard interaction and Lyapunov-Floquet transformation and State Dependent Riccati Equation (SDRE) for controlling the trajectory of the system. The controls techniques proved to be effective in controlling the trajectory of the system. Additionally, the robustness of the control strategies are tested considering parametric errors and measurement noise in the control loop.

Sensitivity analysis of cantilever-based bifurcation MEMS sensors

Tue.
11:30–11:50
R H. Matisse

M.S. Al-Ghamdi[1,2], M.E. Khater[3], A. Alneamy[4,5], E.M. Abdel-Rahman[1]

[1] *Department of Systems Design Engineering, University of Waterloo, Waterloo, Canada*
[2] *King Abdulaziz City for Science and Technology (KACST), Riyadh, Saudi Arabia*
[3] *Department of Mechanical Engineering, Dhahran, Saudi Arabia*
[4] *Department of Mechanical Engineering Department, Jazan University, Jazan, Saudi Arabia*

A numerical model for an electrostatic MEMS bifurcation-based sensor was introduced. As a first time, a sensitivity closed-form function for dynamically actuated cantilever-beam was derived. Multiple scale method was utilized throughout this work to study the relationship of the effective mass on the sensitivity at the bifurcation point. One-mode approximation was utilized to derive the sensitivity function. We found the sensitivity has inversely proportional to the effective beam mass and linear beam stiffness; however, it has directly proportional to the quality factor and actuation voltage.

Nonlinear reduced-order modeling and characteristics of gannet-inspired diving systems

Tue.
11:50–12:10
R H. Matisse

S. Zimmerman[1], S. Ceballes[1], G. Taylor[1], B. Chang [2], S. Jung[2], A. Abdelkefi[1]

[1] *Department of Mechanical Aerospace Engineering, New Mexico State University, USA*
[2] *Virginia Polytechnic Institute and State University, Blacksburg, USA*

In this effort, a nonlinear reduced-order model is proposed, aimed at answering the question of why the gannet bird does not injure itself during diving. In doing so, the critical velocities at which buckling will occur for various boundary conditions in vertical dives are obtained and the resulting forces at the point of impact are investigated. The gannet-inspired system is modeled as an Euler-Bernoulli beam to represent the body of the

gannet, while the head of the gannet is modeled as a cone with varying half-angles. The initial experimental investigations of gannet-like diving systems are first presented to demonstrate how varying parameters will affect the overall behavior of the system. Next, the resulting forces during impact are investigated and a study is conducted to compare various approximations of the coefficient of drag for the cone-shaped head. The boundary conditions and nonlinear equations of motion for the structural system are derived using the Hamilton's principle. The characteristic equation, buckled configurations, critical velocities are determined for each set of boundary conditions. The results show that the system with the smallest half-beak angle and beam length will delay the critical velocity and is most representative of a gannet during diving. The obtained results demonstrate a qualitative agreement with the conducted experiments. For clamped-clamped boundary conditions, the critical velocity was found to be the greatest because of the increased stability at both ends of the beam. It is also noted that a nonlinear approximation for the coefficient of drag offers the best fit with the provided experimental values when compared to a hyperbolic tangent approximation, which predicts the coefficient of drag to be less than that obtained in experiments, and thus predicts that the systems will buckle at higher velocities.

Identification of nonlinear piezoelectric coefficients

Tue.
14:00–14:20
R H. Matisse

V. Meesala M. Hajj

Virginia Tech, USA

Attention to piezoelectric materials has increased dramatically in recent years. This interest rises from the potential for their use in many applications for various objectives. They have been suggested for developing self-powered micro systems and sensors, active-passive vibration control and damping systems, energy harvesters, and impedance based structural health monitoring devices. In more recent studies, piezoelectric/ceramic materials have been proposed in biomedical applications as load and wearable sensors for knee joints and as receivers to oxygenate tumors and charge pacemakers. Extending the realm of applications of piezoelectric materials comes with a price, as large strains can cause the material to behave in a nonlinear manner and exhibit amplitude-dependent resonant frequencies, sub- and super-harmonics in the response, saturation phenomena, and hysteresis behaviors. As such, identification of the nonlinear electromechanical constitutive relation must be performed to design, analyze, optimize and/or exploit such behaviors.

We discuss a parameter identification scheme that exploits the vibration response of an energy harvester to estimate parameters representing nonlinear piezoelectric coefficients. We develop the governing equations of a beam with tip mass and piezoelectric layer using generalized Hamilton's principle and by accounting for mechanical energy, virtual work and electric enthalpy. We then use the method of multiple scales to determine the approximate solution of the response to a direct resonant excitation. We show that the nonlinear behavior captured by the method of multiple scales in the form of an approximate solution and amplitude and phase modulation equations can be used to identify parameters of the nonlinear piezoelectric constitutive relations.

Nonlinear dynamics of a planar hinged-supported beam with one end lumped mass and longitudinal elastic support

Tue.
14:20–14:40
R H. Matisse

L. Kloda[1,2], S. Lenci[1], J. Warminski[2]

[1] *Polytechnic University of Marche, Ancona, Italy*
[2] *Dept. of Applied Mechanics, Lublin University of Technology, Poland*

Moderate and large vibrations of an initially straight, homogenous, planar hinged-simply supported beam with lumped mass and axial spring at one end are studied. Coupled axial-transversal displacements are investigated, and shear deformation and rotational inertia are taken into account. The structure is excited by a concentered periodic force, applied in the mid point of the beam, and has a linear viscous damping in longitudinal, transversal and rotational directions [1,2].

The exact partial differential equations of motion, and the associated boundary conditions, are expanded in Taylor series up to the third order, and then the multiple time scales method [3] is applied to get approximate solutions up to third order as well. The frequency response curves and backbone curves for various spring stiffnesses k_s and one end additional mass M are thoroughly analyzed. There are three particular cases for the spring stiffness $k_s = 0$ representing the simply supported beam, $k_s = \infty$ which results in the hinged-hinged beam and the most general case $0 < k_s < \infty$ corresponding to the hinged-simply supported-spring beam. Additionally, varying the lumped mass affects the frequency response curves, and the backbone curve changes from hardening to softening.

Selected examples have been validated by numerical simulations performed by the commercial Abaqus CAE software. A special technique of explicit computation, similar to continuation method, is applied to get resonance curves, where the frequency of excitation is varied along steady state motions. The simulation runs gradually by sweeping frequency of excitation forward and backward in order to draw the frequency response curves. This approach allows us to reduce time of very demanding computations, and reduces the occurrence of unwanted jumps between paths in bifurcation areas [4].

Bibliography

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Analytical approach to a two-module vibro-impact system

Tue.
14:40–15:00
R H. Matisse

P. Fritzkowski[1], R. Starosta[1], J. Awrejcewicz[2]

[1] *Institute of Applied Mechanics, Poznan University of Technology, Poland*
[2] *Department of Automatics and Biomechanics, Technical University of Lodz, Poland*

Among strongly nonlinear problems, the vibro-impact systems are of considerable practical importance. Unfortunately, applicability of most approximate analytical methods for nonlinear systems is usually limited to weak nonlinearities. However, over recent years, some techniques for the vibro-impact systems have been developed by imposing certain conditions on their motion [1-3]. In what follows, the approach based on the multiple time scales method combined with a saw-tooth function is used [2,3]. A two-module vibro-impact system is considered. The primary coupled oscillators are linear, while the impacting particles that can move freely in the straight cavities are the sources of nonlinearity. It is assumed that mass of the particles is relatively small; the impacts are characterized by the restitution coefficient. The system is subjected to an external harmonic excitation.
Equations of motion for the system are derived and presented in a non-dimensional form. The relation describing the slow invariant manifold is found. The final approximate solutions in the resonant case have a semi-analytical character. The interplay between the model parameters is analyzed.

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Point of contact analysis and characterization of constrained pipelines conveying fluid: the grazing phenomenon

Tue.
15:00–15:20
R H. Matisse

G. Taylor, S. Ceballes, A. Abdelkefi

Department of Mechanical and Aerospace Engineering, New Mexico State University, USA

In general, because of their interesting linear and nonlinear dynamic behaviors, cantilevered pipes conveying fluid have become a great topic of research. Since the early 1950s, many researchers have studied variations of the seemingly straightforward application through modifying and introducing several new parameters to the system, such as motion limiting constraints. As such, this topic has remained of interest in an extensive list of applications in which proper characterization of the stability of the system holds great importance.
Modern methods of nonlinear dynamics including time histories, phase portraits, power spectra, and Poincaré sections are used to characterize the stability and bifurcation regions of a cantilevered pipe conveying fluid with symmetric constraints at the point of

contact. In this study, efforts are made to demonstrate the importance of characterizing the system at the arbitrarily positioned symmetric constraints rather than at the tip of the cantilevered pipe. Using the full nonlinear equations of motion and the Galerkin discretization, a nonlinear analysis is performed. After validating the model with previous results using the bifurcation diagrams and achieving full agreement, the bifurcation diagram at the point of contact is further investigated to select key flow velocities of interest. In addition to demonstrating the progression of the selected regions using primarily phase portraits, a detailed comparison is made between the tip and the point of contact at the key flow velocities. In doing so, period doubling, pitchfork bifurcations, grazing bifurcations, sticking, and chaos that occur at the point of contact are found to not always occur at the tip for the same flow speed. Thus, it is shown that in the case of cantilevered pipes with constraints, more accurate characterization of the system is obtained in a specified range of flow velocities by characterizing the system at the point of contact rather than at the tip.

Nonlinear response of a piezoelectric-flexoelectric clamped-clamped nanobeam actuator

Tue.
15:20–15:40
R H. Matisse

S. Baroudi , F. Najar

Tunisia Polytechnic School, University of Carthage, Tunisia.

Flexoelectricity, defined as the electromechanical coupling between polarization and the strain gradient, becomes interesting at the nanoscale where it largely overcomes piezoelectric coupling. However, nanoscale deformations easily get over the linear regime when relatively large displacement are observed. To correctly model such nanoactuators, geometric nonlinearity should be taking into account. In this work, we propose to model the nonlinear behavior of piezoelectric-flexoelectric nanobeams where the nonlinear von Kaman strain is considered. The model is derived using a general form of the enthalpy density that provides electromechanical couplings to the third order. Using Euler-Bernoulli beam's model and employing the inextensibility conditions, applying the Euler-Lagrange principle and implementing a Galerkin discretization, the corresponding reduced-order model is derived. Clamped-clamped boundary conditions are used where the midplane stretching effect is dominant. The effects of the nonlinearities on the nanoactuator response is investigated using the method of multiple scales.

Analysis of frequencies synchronization and nonlinear phenomena in rotary cantilever oscillation in vertical position between movement limiters

Tue.
16:20–16:40
R H. Matisse

P. Wolszczak[1], G. Litak[1,2], K. Lygas[1]

[1] *Faculty of Mechanical Engineering, Lublin University of Technology,*
[2] *Department of Process Control, AGH University of Science and Technology, Poland*

The efficiency of the mechanical energy harvesting with the use of vibrating elements can be improved by synchronizing stimulation vibrations and own frequencies of systems as well as non-linear phenomena. The article presents numerical cross-sectional study of the mechanical system. The system consists of an elastic beam set vertically, which

the lower end is fixed in the rotary support, and is stimulated to move in the horizontal axis. The upper end of the beam is free but below its level there are bumpers limiting the free rotation of the beam. Numerical studies took into account the variability of the frequency and amplitude of the excitation beam movement, and horizontal distance between bumpers. Beam deflection was observed, on the basis of which the amount of energy generated by the piesoelement was estimated. Nonlinear phenomena and analysis of frequency synchronization of vibrations improving the energy effect of an energy generator are presented.

Quasiperiodic energy harvesting in a delayed piezoelectric oscillator

Tue.
16:40–17:00
R H. Matisse

I. Kirrou[1], A. Bichri[2], M. Belhaq[3]

[1] *2MGC Group, ENSA Agadir, Ibn Zohr University, Morocco*
[2] *FST Errachidia, University Moulay Ismaïl, Morocco*
[3] *Faculty of Sciences Aïn Chock, University Hassan II-Casablanca, Morocco*

In the present work, we report on the quasiperiodic (QP) vibration based energy harvesting. The device under consideration consists in a delayed nonlinear damper oscillator coupled to piezoelectric energy harvesting system. Analytical investigation using the multiple scales method is performed to obtain approximation of the periodic and QP amplitude response. The influence of different parameters of the harvesting system on the periodic and QP responses is examined. Results show that for appropriate values of the delay parameters, broadband QP vibrations are found to be more efficient to improve energy harvesting performance than the periodic response.

High-order frequency response functions of Bouc-Wen model subjected to harmonic excitation

Tue.
17:00–17:20
R H. Matisse

R. de Oliveira Teloli[1], S. da Silva[2]

Universidade Estadual Paulista-UNESP, Departamento de Engenharia Mecnica, Brasil

The Bouc-Wen model is commonly used to describe the hysteretic behavior of some mechanical systems. In this model the memory effects of inelastic behavior of the restoring force depends not only the instantaneous displacement but also on the history of the previous displacement. Among different approaches that can be used to describe the hysteretic behavior, the Volterra theory could be an interesting strategy, since it represents the response of a system as a sum of linear and nonlinear components using multiple convolutions. However, the Volterra series is not able to describe non-smooth nonlinearities such as hysteresis' system. In order to overcome this technical issue the present paper proposes to rewrite the Bouc-Wen differential equation by removing the hidden state and including a time-varying parameter that can be approximated by Fourier series. Then, it is developed an identification scheme of analytical expressions to estimate the high-order frequency response functions via harmonic probing algorithm, which the time de- pendent parameters are regarded as additional inputs of the system. The high-order FRFs can be useful in applications for identification and analysis of weakly hysteretic systems, and proving an insight of how time-varying parameters affect the out-

put response. The applicability and drawback of the proposed algorithm are also deeply explored. The Bouc-Wen oscillator was solved numerically through Runge-Kutta 4th order with a variable time step subjected to a tone harmonic in- put. It was chosen the excitation frequency ! close to first resonance frequency and three different input levels of amplitude. The direct com- parison between the response obtained from numerical integration and through the Volterra model under excitation forcing shows that until a certain value of excitation amplitude level, which the hysteresis loop is almost closed, the Volterra model is able to predict the Bouc-Wen response with a desirable fit.

Energy harvesting in an excited van der Pol device using time delay in the electrical circuit

Mon.
17:20–17:40
R H. Matisse

Z. Ghouli[1], M. Hamdi[2], M. Belhaq[1]

[1] *Faculty of Sciences Aïn Chock, University Hassan II-Casablanca, Morocco*
[2] *FST-Al Hoceima, University Mohammed I Oujda, Al-Hoceima, Morocco*

This paper investigates quasi-periodic (QP) vibration-based energy harvesting (EH) in a nonlinear device consisting in an excited van der Pol oscillator coupled to a delayed piezoelectric coupling mechanism. We consider the case of primary resonance for which the frequency of the harmonic excitation is near the natural frequency of the oscillator. Analytical approximation of the QP response and the corresponding power output are obtained using the double-step multiple scales method. The effect of time delay on the EH performance is studied; It is shown that for appropriate combination of time delay parameters, QP vibration can be used to scavenge energy over a broadband of the excitation frequency away from the resonance with a significant performance. An optimum range of the system parameters where the QP vibration-based EH is maximum is determined. Numerical simulations are conducted to support the analytical predictions.

MS 2

Analytical and semi-analytical methods in nonlinear dynamics/Time delay in nonlinear systems

Organizers: *R.H. Rand* USA, *K.W. Chung* Hong Kong, *M. Belhaq* Morocco

Scheduled:

Monday	*14:00–15:40*	Royal Tulip Hotel	**Room Paul Bowles**
Monday	*16:20–18:00*	Royal Tulip Hotel	**Room Paul Bowles**

Homotopy analysis method applied for coupled time-periodic systems

Mon.
14:00–14:20
R P. Bowles

F. Dohnal
Private University for Health Sciences, Medical Informatics and Technology (UMIT), Austria

The homotopy analysis method (HAM) outlined in [1] is a semi-analytical technique to find an approximate solution of a nonlinear system of ordinary differential equations. In contrast to perturbation techniques, the method does not need an artificially small parameter for convergence. The HAM is extended to coupled time-periodic systems. The approximation is benchmarked against the approximation gained by using well-established perturbation techniques like the averaging method in [2] on a 1DOF-system in the vicinity of a parametric resonance and on a 2DOF-System in the vicinity of a parametric combination resonance [3]. The main motivation for developing this procedure is to extract an analytical estimation for the maximum vibration response during passage through resonance.

Bibliography

[1] S. Liao, Beyond perturbation, An introduction to Homotopy Analysis Method, Springer, 2004
[2] F. Verhulst, Methods and Applications of Singular Perturbations, Springer, 2005
[3] F. Dohnal and F. Verhulst, Averaging in vibration suppression by parametric stiffness excitation, Nonlinear Dynamics 54 (2008) 231-248

Homoclinic – doubling and homoclinic – gluing bifurcations in the Takens-Bogdanov normal form with D_D symmetry

Mon.
14:20–14:40
R P. Bowles

K.W. Chung[1], B.W. Qin[1], M. Belhaq[2], A.J. Rodriguez-Luis[3]

[1] *City University of Hong Kong, Hong Kong*
[2] *University Hassan II, Casablanca, Morocco*
[3] *Universidad de Sevilla, Spain*

In the detection of homoclinic bifurcation of a perturbed dynamical system, Melnikov's method is a wellestablished rigorous approach. However, this method is not able to provide an analytical approximation of a homoclinic orbit. The investigation of homoclinic bifurcation is usually resorted to the use of a continuation package such as HomCont or MatCont.
In this talk, we consider the homoclinic orbits arisen in the following Takens-Bogdanov normal form with D_4 symmetry:

$$\begin{aligned} \ddot{u} &= -\lambda u + \kappa\dot{u} + Pu^3 + Qu^2\dot{u} + Rv^2u + S\,v\dot{v}u + Tv^2\dot{u} + Uv\dot{v}\dot{u} \\ \ddot{v} &= -\lambda v + \kappa\dot{v} + Pv^3 + Qv^2\dot{v} + Ru^2v + S\,u\dot{u}v + Tu^2\dot{v} + Uu\dot{u}\dot{v} \end{aligned} \tag{2.1}$$

where u and v represent the amplitudes of two stable modes, $\lambda, ..., U$ are the system parameters and the dot stands for differentiation with respect to time. For $\lambda < 0, R = 3P < 0$ and $\kappa = Q = S = T = U = 0$, there exist three pairs of planar homoclinic orbits, namely $u = 0$, $v = 0$ and $u = \pm v$. For small perturbation of the system parameters, we apply a nonlinear time transformation (NTT) method to obtain the analytical approximations of these homoclinic orbits in the four-dimensional phase space. The NTT method is able to predict analytically the homoclinic-doubling bifurcation in which a 2- homoclinic orbit is spawned from a homoclinic orbit, giving rise to a period-doubling and a saddle-node bifurcation curves. This system also exhibits the homoclinic-gluing bifurcation where two homoclinic orbits glue together to form a new large-amplitude homoclinic orbit. Numerical simulation is performed to show the gluing of different pairs of homoclinic orbits and the existence of chaotic attractors near the codimension-2 bifurcation points.

Exact analytical solutions for longitudinal vibrations of pure cubic bars versus semi-analytical solutions for motion of chains of pure cubic oscillators

Mon.
14:40–15:00
R P. Bowles

I. Kovacic, M. Zukovic

Centre of Excellence for Vibro-Acoustic Systems and Signal Processing Faculty of Technical Sciences, University of Novi Sad, Serbia

Longitudinal vibrations of a bar with a pure cubic relationship between an axial stress and strain are considered. An exact analytical solution for modal shapes and the corresponding modal frequencies of a clamped-clamped bar as well as a clamped-free bar are obtained in terms of the Jacobi cn function and the Inverse Beta Regularized function. Some links with the semi-analytical solutions for motion of pure cubic chains of oscillators are provided in terms of their modes of vibration. In addition, the extension of the methodology to the cases with other powers of pure nonlinearity is discussed.

Infinite limit cycle bifurcation in a delayed differential equation

Mon.
15:00–15:20
R P. Bowles

S.M. Sah[1], B. Shayak[2], R.H. Rand[3]

[1] *Department of Mechanical Engineering, Technical University of Denmark*
[2] *Sibley School of Mechanical and Aerospace Engineering, Cornell University, USA*
[3] *Department of Mathematics and Sibley School of Mechanical and Aerospace Engineering, Cornell University, USA*

We investigate the occurrence of a bifurcation, which we term the "infinite limit cycle bifurcation", or ILCB for short, in the nonlinear DDE (delay-differential equation) $\frac{dx(t)^2}{dt^2} + x(t-T) + x(t)^3 = 0$, where T is the delay time. When $T > 0$, no matter how small, an infinite number of limit cycles (LCs) exist, their amplitude going to infinity as T goes to zero. Perturbation methods are used to approximate the system and investigate the nature of such a bifurcation.

Bibliography

[1] R.H. Rand, A.T. Zehnder, B. Shayak, Analysis of a simplified MEMS oscillator, Proceedings of 9th European Nonlinear Dynamics Conference (ENOC 2017), June 25-30, 2017, Budapest, Hungary.

Tuned mass damper for suppressing delay-induced vibrations

Mon.
15:20–15:40
R P. Bowles

G. Habib, G. Stepan

Dep. of Applied Mechanics, Budapest University of Technology and Economics, Hungary

Time delay in control is a major cause of instability, which is relevant for many engineering systems [1]. For instance, micro and nano electromechanical systems can experience instabilities even when time delay is very small because of their very high natural frequency [2]. Human controlled systems are subject to time delay related to human reflex, this causes the failure of high precision haptic interfaces and also causes dangerous speed wobble in bicycles and motorbikes [3]. Complex control algorithms require non negligible computational time, causing instabilities in robots [4].
The tuned mass damper (TMD) is an established solution for passively mitigating undesired vibrations and improve stability in otherwise unstable systems. It is successfully adopted for the stabilization of many engineering systems, such as slender structures subject to wind induced vibrations [5] or machine tool undergoing regenerative chatter vibrations [6].
The objective of this study is to investigate the performance of the TMD for the suppression of delay induced vibrations. Three cases are considered. Namely, a single degree of freedom resonator, a simple inerter (a mass with no restoring force) and an inverted pendulum, all subject to proportional differential position control with feedback time delay. Stability and post critical behavior are analytically studied, in order to understand the potentiality of the TMD for these applications.
Our results illustrate that the TMD can significantly improve stability properties of the system in all the three cases. However, the optimal tuning of the natural frequency of the

absorber critically depends on the control delay. This suggest that, in order to implement it in a real engineering application, either an accurate knowledge of the time delay is required, or the TMD should encompass a sort of self tuning mechanism, enabling it to operate efficiently. Alternatively, multiple TMD can be adopted, in order to improve system robustness.

Bibliography

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[5] A. Casalotti, A. Arena and W. Lacarbonara. "Mitigation of post-flutter oscillations in suspension bridges by hysteretic tuned mass dampers." Engineering Structures 69 (2014): 62-71.

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Dynamics of a system of two coupled MEMS oscillators

Mon.
16:20–16:40
R P. Bowles

R.H. Rand[1,2], A.T. Zehnder[2], B. Shayak[2]

[1] *Theoretical and Applied Mechanics, Cornell University, USA*
[2] *Department of Mathematics, Cornell University, Ithaca, USA*

A model of a simplified MEMS device which has been previously shown to support a limit cycle [1] is used to model a pair of coupled MEMS oscillators. The stability and bifurcation of in-phase and out-of-phase modes is investigated.

Bibliography

[1] R.H. Rand, A.T. Zehnder, B.Shayak, Analysis of a simplified MEMS oscillator, Proceedings of 9th European Nonlinear Dynamics Conference (ENOC 2017), June 25-30, 2017, Budapest, Hungary.

Mode coupling and effective damping in nonlinear systems with internal resonances

Mon.
16:40–17:00
R P. Bowles

A.T. Mathis[1,2], D. Quinn[2]

Department of Mechanical Engineering The University of Akron, USA

The analysis of both linear and nonlinear structural vibrations are frequently cast in terms of coordinates associated with the linear, undamped mode shapes of the system. This has the advantage of decoupling the associated linear problem so that each mode can be considered uncoupled from the remainder. However, with the introduction of mistuning in the linear system or in the presence of nonlinearities these modal coordinates become coupled together. Moreover, the identified linear characteristics of the modes, namely their natural frequencies and damping ratios, are no longer constant but depend on the response of the system as a whole. Using the method of multiple scales, this work describes the effect of mode coupling and internal resonances on systems containing non-proportional damping, linear detuning, and cubic nonlinearities. In particular the effective modal frequencies and damping ratios are shown to depend on the response of the system and the distribution of energy throughout the system. The results of the analysis tie together interpretations used by both experimentalists and theoreticians to study such systems and provides a more concrete way to interpret these phenomena.

Stabilizing and destabilizing non-resonant effects in parametrically excited systems

Mon.
17:00–17:20
R P. Bowles

A. Karev, L. De Broeck, P. Hagedorn

Dynamics and Vibrations Group, FNB, Technische Universitat Darmstadt, Germany

Dynamical systems with time-periodic coefficients, i.e. with parametric excitation, have been studied in different fields for over a hundred years. It is well known that the presence of time-periodicity acts mostly destabilizing, leading to the emergence of instability regions depending on the amplitude and frequency of excitation. In the recent decades also the phenomenon of parametric anti-resonance has received increasing attention. According to the latest finndings, properly tuned, parametric excitation is also capable of attenuating vibrations, increasing systems' stability for frequencies of excitation close to combination resonance frequencies (either sum or difference combination resonance). However, there are only few papers dealing with nonconservative (gyroscopic and circulatory) forces in the context of parametric excitation. In particular, the effects of out−of−phase excitation in nonconservative systems seem to lack attention. At the same time both of the effects (asynchronous parametric excitation as well as gyroscopic and circulatory terms) can be observed in equations of motion of technical problems. Some examples even show stabilization through time-periodic terms over a wider frequency range, which cannot be explained by the current understanding of parametric anti-resonance.

The present paper seeks to extend the understanding of in uence of parametric excitation in circulatory systems. Especially the phenomenon of parametric anti-resonance is considered: the effect of stabilization through parametric excitation seems to be wider than it was believed. In fact, under special conditions, occurring also in mechanical problems, the anti-resonance effect is not limited to a small range of excitation frequencies, but can also have a more global effect in a wide frequency range, or even for all excitation frequencies. Therefore, special attention is paid to the anti-resonance effect within the range of non-resonant excitation, i.e. for frequencies outside of the parametric resonance areas. The systems containing both circulatory terms and out-of-phase excitation are treated analytically by means of the normal form theory and also numerically via Floquet theory calculating the monodromy matrix. Stability maps are calculated for several representative examples demonstrating different effects on the stability of trivial solution. The results emphasize the role of parametric excitation in complex mechanical systems and encourage a thorough study of more general systems.

A MEMS van der Pol oscillator with 1:3 internal resonance

Mon.
17:20–17:40
R P. Bowles

S. Houri, R. Ohta, M. Asano, H. Yamaguchi

NTT Basic Research Laboratories, Kanagawa, Japan

In this work we demonstrate a MEMS-based oscillator whereby an 1:3 internal resonance between the fundamental mode and the 1st odd harmonic exist. In an open loop configuration, when the oscillator's fundamental mode is driven by an outside signal, Duffing nonlinearities result in a strong coupling between the two modes. Depending on the drive amplitude and detuning, the strong coupling can induce bifurcations and chaos. In a closed loop configuration both modes oscillate simultaneously, and depending on the phase delay and gain of the feedback loop bifurcations and chaotic oscillations are observed.

Stability analysis of a human balancing model with different feedback delays

Mon.
17:40–18:00
R P. Bowles

L. Zhang[1], G. Stepan[2]

[1] *Nanjing University of Aeronautics and Astronautics, Nanjing, China*
[2] *Department of Applied Mechanics, Budapest University of Technology and Economics,Budapest*

Considering that sensory information (position, velocity and acceleration) utilized during human balancing is associated with different conducting and processing delays, a model for human balancing with proportional-derivative-acceleration (PDA) feedback are analyzed in which the reaction delay for acceleration signals is half of the reaction delay for position and velocity signals. The stability charts are presented and compared with the results when the same feedback delay is considered.

MS 3

Nonlinear phenomena of electrical power and energy circuits and systems

Organizers: *A. El Aroudi* Spain, *E. Ponce* Spain, *L. Benadero* Spain

Scheduled:

Monday *14:00-15:40* Royal Tulip **Room Eugène Delacroix**

The Teixeira singularity in a DC-DC Converter

Mon.
14:00-14:20
R E. Delacroix

E. Ponce[1], R. Cristiano[2], M. Granzotto[2], D.J. Pagano[2]

[1] *Departamento de Matemática Aplicada II, E.T.S. Ingeniería, U. de Sevilla, Spain*
[2] *Departamento de Automaçao e Sistemas, U. F. de Santa Catarina, Brazil*

When a DC-DC boost power electronic converter is controlled by a specific sliding mode strategy, a discontinuous, piecewise linear, three-dimensional dynamical system is obtained. Its state space is divided by a plane, to be the switching manifold, separating two half-spaces. Sliding motions appear on certain subsets of the switching manifold, bounded by two straight lines of tangency points, one for each involved linear vector field. If such tangency lines intersect transversally on a invisible two-fold point then we get a Teixeira singularity.

We investigate an interesting bifurcation that occurs near the Teixeira singularity, involving both a pseudo-equilibrium point and a crossing periodic orbit. This bifurcation, known as TS-bifurcation, undergoes when a pseudoequilibrium point of the system, passes from the attractive to the repulsive sliding regions as a result of changes in parameters, so colliding with the Teixeira singularity. Simultaneously, a periodic orbit can arise from the Teixeira singularity crossing the switching manifold in two points. The TS-bifurcation on the circuit of a power electronic converter is confirmed by experimental results, to be shown.

Partial bifurcation analysis for the 4D canonical memristor oscillator

Mon.
14:20-14:40
R E. Delacroix

E. Ponce[1], J. Ros[1], A. Amador[2]

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[2] *Pontificia Universidad Javeriana-Cali, Colombia*

The dynamical richness of 4D memristor oscillators has been recently studied in several works, showing different regimes, from stable oscillations to chaos. Typically, only numerical simulations have been reported and so there is a lack of mathematical results. We focus our analysis in the existence of multi-stable oscillations in the 4D piecewise linear version of the canonical circuit proposed by M. Itoh and L. O. Chua (see [1]). This oscillator is modeled by a discontinuous piecewise linear dynamical system.

It is shown how to pass, by adding one parameter that stratifies the 4D dynamics, from the original model to a topologically equivalent 3D continuous piecewise linear dynamical system, following a similar approach to the one presented in [2,3]. Thus, some previous results on bifurcations in such reduced system, allow to detect rigorously a parametric onset for the appearance of a topological sphere in the original model, completely foliated by stable periodic orbits.

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Dynamics of a self-oscillating H-bridge switching power converter with propagation delay in the feedback loop

Mon.
14:40-15:00
R E. Delacroix

A. El Aroudi[1], L. Benadero[3], F. Torres[2], C. Olalla[3], E. Ponce[2], L. Martinez-Salamero[3]

[1] *Departament de Fisica, Universitat Politècnica de Catalunya, Barcelona, Spain*
[2] *Escuela Tèccnica Superior de Ingenieria, Universidad de Sevilla, Sevilla, Spain*
[3] *Universitat Rovira i Virgili, Tarragona, Spain*

In this paper, the dynamics of a self-oscillating H-bridge resonant power inverter are studied taking into account propagation time delay in the feedback loop and in the switching decision. The inverter is modeled as a linear system with a relay feedback and a delay block. First, limit cycle frequencies and periodic fixed points are computed exactly, using a state-space representation of the power stage dynamics. Then the relay switching surface is chosen as the Poincaré mapping surface and the existence, stability, and bifurcations of periodic solutions are studied by taking into account the delay effects. Instead of using conventional shooting methods to determine the steady-state periodic solutions of the system whose model is characterized by a vector field exhibiting discontinuities, the problem is addressed analytically taking advantage from the fact the system can be solved in closed form for each switching configuration. It will be shown that the time delay control can change the quality of the periodic solutions and their stability. Numerical simulations from the switched model confirm the theoretical predictions and finally, experimental measurements from a laboratory prototype validate the theoretical and the numerical predictions.

Fundamental energy cost of NEMS and MEMS memory devices

Mon.
15:00–15:20
R E. Delacroix

I. Neri[1], M. Lopez-Suarez[2]

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[2] *Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Barcelona, Spain*

One of the main goals of the ICT community is to develop a new generation of processors producing significantly less heat than current technologies. As a big contribution in transistors heating comes from internal currents, there is broad interest in devices where computations is not made by moving electrons but by moving mechanical parts: MEMS and NEMS are now widely investigated as possible heirs of transistors. However, changing processor technologies is not enough; physics imposes limits and boundaries to the heat that must be produced while computation takes place, setting to kBTln2 the heat produced, and thus the energy required, while resetting one bit of information (also known as Landauer limit). As this value is non-zero, it becomes important to understand the conditions, if any, under which NEMS and MEMS devices reach that value.

To address this problem we have performed molecular dynamic simulations of a graphene ribbon used as a memory device. The structure is composed by 240 carbon atoms in a ribbon, clamped on both the short edges. A constant compression is applied to the clamping regions so that the ribbon buckles in the out-of-plane direction in two possible stable states. Those are used to encode information. We have found that, if the dynamics is correctly controlled, it is possible to reach the fundamental energy limit of kBTln2 during the reset operation.

We have also realized experimentally a mechanical memory device using a non-linear microelectro- mechanical system. In such system we have experimentally measured the energy dissipation during single memory operation. We have found that, even if possible in principle, frictional phenomena prevent reaching the fundamental energy limit. However, increasing the effective temperature of the system by means of properly chosen random vibrations, it is possible to neglect the effect of internal friction. In this case we are able to experimentally measure the energy required to operate the memory device and to correlate this quantity to the probability of success of the operation.

Modal analysis of rotating viscoelastic asymmetric sandwich beams

Mon.
15:20–15:40
R E. Delacroix

F. Boumediene[1], F. Bekhoucha[2], E.M. Daya[3]

[1] *Advanced Mechanical Laboratory, USTHB, Algiers, Algeria*
[2] *Mechanical Engineering and Development Laboratory, ENP, Alger, Algeria*
[3] *Université de Lorraine, France*

In industrial fields, rotating structures such as, wind turbines, propellers and turbines can undergo significant vibrations up to resonance inducing annoying noises and damaging structures. Therefore, the precise determination of the natural frequencies of these structures is an important step in their design. In applications where the use of light structures is important, the introduction of a viscoelastic material between two elastic layers is widely used to induce a high damping inherent to the resulting multilayer structure. The rigidity of this type of structure depends on the frequency of vibration. According to our knowledge, no prior work has taken into account this dependence between stiffness and frequency in rotating sandwich beams. However, these materials have been widely studied in the case of non-rotating beams. Bilasse et al [1], for example, solved the complex nonlinear eigenvalue problems of symmetric viscoelastic non-rotating sandwich beams with a frequency-dependent Young's modulus, by coupling the homotopy technique and the asymptotic numerical method (HANM).

In our study, we use the HANM procedure to determine the dynamic parameters of rotating asymmetric viscoelastic sandwich beams with a constant uniform cross section. Our results obtained for viscoelastic sandwich rotating beams with a constant Young's modulus coincide perfectly with those obtained from literature and the software Abaqus. The originality of our work is the consideration of the dependence of Young's modulus on frequency in the study of asymmetric rotating sandwich beams. To this end, we studied the effect of angular velocity and layer thicknesses on eigenfrequencies and loss factors. Results show that, similarly to the isotropic beams, the sandwich ones gain in rigidity as the angular velocity rises inducing the increase of the eigenfrequencies and the decrease of the loss factors. Other important results observed is the fact that the dimensionless fundamental frequency does not change with damping coefficient, regardless of the angular velocity. In addition, when the angular velocity increases, the loss factor converges to the same value, regardless of the damping coefficient. From the variation of layers thicknesses, it has been noticed that the symmetrical sandwich beam is the most suitable for damping vibrations.

Bibliography

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MS 4

Linear and nonlinear vibrations of periodic and near-periodic lattices/Structural health monitoring

Organizers: *N. Kacem* France, *M. Ichchou* France, *N. Bouhaddi* France, *O. Bareille* France

Scheduled:				
	Monday	*14:00–15:40*	Royal Tulip	**Room Henri Matisse 1**
	Monday	*16:20–18:00*	Royal Tulip	**Room Henri Matisse 1**

Optimization of vibration energy localization in quasi-periodic structures

Mon.
14:00–14:20
R H. Matisse 1

M. Hbaieb[1,2], N. Kacem[1], M.A. Ben Souf[2], N. Bouhaddi[1] M. Haddar[2]

[1] *Univ. Bourgogne Franche-Comté, FEMTO-ST Institute, Besançon, France*
[2] *National Engineering School of Sfax, Tunisia*

A mechanical periodic structure in presence of component perturbations can be a seat of a localization of vibration energy. In fact, it is well known that mistuned components have larger response levels than those of perfect components. This results in a localized energy, which can be tapped via harvesting devices.

In this study, the dynamic behavior of a quasi-periodic system consisting in weakly connected linear oscillators is investigated. The studied system involves thirty oscillators coupled via linear springs while including two perturbations on two degrees of freedom (DOFs).The main objective is to optimize the mistuning parameter, the coupling stiffness and the damping coefficient in order to functionalize the imperfection, which leads to the maximization of the localized vibration energy.

The multi-objective optimization procedure consists in the maximization of the two mistuned DOF response amplitudes using NSGA algorithm and Pareto front. Several numerical simulations have been performed to validate the proposed approach and to highlight the Pareto-optimal solutions, which can be used as a decision-making tool for the design of quasi-periodic structures with well mastered energy trapping.

Benefits of energy localization on the performances of a quasi-periodic electromagnetic vibration energy harvester

Mon.
14:20–14:40
R H. Matisse 1

K. Aouali[1,2], N. Kacem[1], E. Mrabet[2], N. Bouhaddi[1], M. Haddar[2]

[1] *Univ. Bourgogne Franche-Comté, FEMTO-ST Institute, Besançon, France*
[2] *National Engineering School of Sfax, Tunisia*

The diversity of ambient sources of energy arouses researchers to made its scavenging a focus of interest. Vibration energy, in precise, is omnipresent almost everywhere and has experienced a large number of applications that could be envisaged to recover it. Many efforts have, recently, been made to look for techniques for vibration energy harvesting (VEH) based on various energy conversion mechanisms. Although energy harvesting has been achieved, energy harvesters have limitations. To overcome this issue, several techniques have been proposed such as linear, non-linear and multi-modal frequency tuning.

In the following, we are interested in energy harvesting by exploiting the multimodal approach which involves operating multiple modes in a periodic system. The harvester proposed is based on magnetic transduction. It is composed of several weakly coupled magnets guided by elastic beams. The magnetic poles are oriented in such a way that repulsive forces are created between each two adjacent magnets. These forces lead to "nonlinear magnetic stiffness". A wire-wound copper coil is wrapped horizontally around the separation distance between each two adjacent magnets. When the device is subjected to a harmonic base excitation, each moving magnet oscillates around its equilibrium position and a current is induced in each coil.

Although the manufacturing process and tools are advanced, obtaining two perfectly identical parts is difficult. These imperfections will be taken into account; their presence leads to the energy localization phenomenon. Depending on the magnitude of the disorder and the strength of the internal coupling of the system, it is possible to localize the vibration energy in regions close to the imperfections. This phenomenon will be exploited to maximize the harvested energy.

In this study, the fourth order partial differential equations of the continuum system are derived using the Hamilton principle. Then, a reduced-order model is generated by Galerkin method, transforming the system into a finite-degree-of-freedom system in terms of generalized coordinates.

Numerical simulations have been performed to highlight the benefits of the localization on the VEH in terms of normalized harvested power. Thus, the optimal imperfection can be determined in order to enhance the performances of the proposed device.

Damage detection on plate-like reinforced structures by mean of vibration based data and energy distribution inverse analysis

Mon.
14:40–15:00
R H. Matisse 1

Y. Hui, O. Bareille, C. Droz, M. Ichchou

Laboratoire de Tribologie et Dynamique des Systèmes, Ecole Centrale de Lyon, France

The identification of defects has attracted a lot of attention since there are many techniques currently available in the literature, which are referenced under the topic of Structural Health Monitoring (SHM) technologies. The definition and the efficiency assessment of a damage indicator is an important step, prior to the deployment of a practical solution. Several approaches have been applied for detecting the singularities and providing their locations. The vibration-based method is one of them, which uses the vibration proprieties of the structure like the natural frequencies, mode shapes and damping to show the difference of structure response with and without defect. In this context, a curvature-based indicator is introduced in the here reported works. This representation is comparable to the representation of the strain energy distribution. The technique is essentially applied on plate-like structures and it is numerically proven that not only the number but also the size of singularities can be retrieved. Furthermore and following these first results, experimental procedures using this principle are applied on a structured material medium. The energy distribution pattern is not only sensitive to the singularities but also emphasized by the inner structure's arrangement (like ribs and stiffeners). Singularities are, in given conditions of stress and observation, more detectable and better localized.

Wave propagation in periodic micro-rod based on the second strain gradient theory

Mon.
15:00–15:20
R H. Matisse 1

G. Zhu, C. Droz, M. Ichchou, A.M. Zine

Laboratoire de Tribologie et Dynamique des Systèmes(LTDS) École Centrale de Lyon

In conventional continuum mechanics theory, the stress in one point is assumed to depend on the strain at that point only, and the material is modeled to be continuous mass rather than as discrete particles, which lead to its failing to predict and explain the experimentally observed mechanics behaviors when the structure size is micro- or nano-scale. Therefore in recent years, many papers have studied size-dependence of material deformation behavior and developed the nonclassical continuum theories such as the couple stress theory, the non-local elasticity theory, and the strain gradient theory.
The present work investigates the wave propagation on a micro-rod based on the second strain gradient theory which is a powerful nonclassical continuum theory, and in this theory potential energy density is a function of the strain and its first and second gradients. The governing equation together with the associate boundary conditions is derived on the basis of the Hamilton principle. This proposed model is employed to study the wave propagation characteristics, and a number of essential wave propagation features are calculated and compared with the classical continuum theory. Then the second strain gradient theory-based rod model is applied to periodic nanostructures, which enable the periodic model to capture the size effect, and typical wave propagation characteristics in periodic structures to be identified.

Reliability modeling and prediction of passive controlled structures through Random Forest

Mon.
15:20–15:40
R H. Matisse 1

W. You[1], A. Saidi[1], M. Ichchou[1], A. Zine[1], X. Zhong[2]

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[2] *Shenzhen University, China*

Reliability prediction plays a significant role in risk assessment of engineering structures. Mathematically, the prediction task can be seen as a classification or regression proce-

dure. In this aspect, machine learning methods have recently shown their superior performance over others in various research domains. Random forest (RF) is distinguished for its robustness and high accuracy in modeling and prediction work. However, its application in the area of structural reliability has not been widely explored. Therefore, it is the purpose of this study to explore the feasibility of RF as well as examine its performance in modeling and prediction of structure reliability in passive control mode. A numerical example is introduced in the simulation part to evaluate performance of the proposed method in different perspectives.

Design of quasi-periodic vibration energy harvester based on electromagnetic coupling

Mon.
16:20–16:40
R H. Matisse 1

Z. Zergoune, N. Kacem, N. Bouhaddi

Univ. Bourgogne Franche-Comté, FEMTO-ST Institute, Besançon, France

Over the last few years, embedded systems have gained accuracy, reliability, robustness while becoming miniaturized but they are still limited by the life cycle of their power system. A promising alternative is to scavenge the ambient mechanical energy to ensure the energy autonomy of nomadic devices. This approach has a strong potential for innovation, miniaturization, respect for ecological issues and is part of the theme of renewable energies as well.

In our environment, diverse ambient energy sources are available and their conversion into electrical energy is a major challenge to increase the autonomy of isolated or abandoned systems. Each environment can correspond to one or more energy sources such as light, wind, thermal gradients, mechanical vibrations. For each of these sources, one or more conversion principles exist for generating electricity. Mechanical vibration sources provide potential energy that can be scavenged for charging self-powered systems. In the last decade, several design of energy harvesters, based on different conversion mechanisms, have been proposed.

The proposed study deals with the design and modeling of a novel quasi-periodic nonlinear vibration energy harvester under a harmonic base excitation. The designed harvesting devise used two fixed outer magnets and two mobile magnets which are mechanically attached to elastic suspensions which are designed and optimized to guaranty a perfect vertical displacement and to decrease the mechanical damping. These suspensions are inserted into threaded rods which have been used to vary the gap between the fixed and mobile magnets in order to functionalize the magnetic coupling. The quasiperiodicity is achieved by tuning a small mass or stiffness perturbation of one degree of freedom. The harvester involves mechanical (suspensions) and magnetic (magnets) nonlinearities.

The proposed harvester which operates at low frequencies demonstrated high performances in term of bandwidth and normalized harvested power by combining the benefits of the low mechanical damping, the effects of nonlinearities and the mode localization phenomenon.

Phase shift effects on the sound transmission loss and transition frequency of multi-layer rectangular core systems

Mon.
16:40–17:00
R H. Matisse 1

N. Guenfoud[1,2], M. Ichchou[1], O. Bareille[1], B. Pluymers[2,3], W. Desmet[2,3]

[1] *Laboratoire de Tribologie et Dynamique des Systèmes, Ecole Centrale de Lyon, Ecully, France*
[2] *Department of Mechanical Engineering, KU Leuven, Leuven, Belgium*
[3] *Member of Flanders Make*

Periodic structures have a great interest in aerospace industry since they allow a high stiffness-to-weight ratio but leading often to an unsatisfactory Sound Transmission Loss (STL). Multi-layer core topology systems are a new way to design periodic structures consisting on piling up layers made by different kind of cores (rectangular, honeycomb, auxetic). New parameters are introduced and should be investigated such as: the phase shift and the rotation between layers and geometrical parameters of each layer.

In this paper, we focus on phase shift effects on the STL and the first transition frequency of sandwich panels made with rectangular cores. This first transition frequency is a vibroacoustic indicators defined when the shear core effect becomes higher than the bending stiffness giving an information on the general acoustic behavior of the structure.

Assuming an infinite panel, real wavenumbers and structures excited only by plane waves with an angle of incidence and reflection equal, it is possible to use the Wave Finite Element Method (WFEM) to obtain the acoustic indicators. The use of the Component Modal Analysis (CMS) drastically reduces the computational cost. Besides, the first transition frequency is determined using an energetic formulation with the wavemode energy method. Both methods are combined with a Finite Element analysis and are implemented with Matlab and Ansys apdl. Moreover, considering the same rectangular core for each layer eliminates the mass effect. Nevertheless, the compression modulus of the structure is strongly altered and is kept as an indicator of mechanical performances.

The study is carried out on structures made by two and three layers. The phase shift is changed on both directions of the unit cell and results from a sandwich panel with one rectangular core through the thickness are taken as a reference. The first transition frequency and the coincidence frequency are shifted either on higher or lower frequencies and contribute to increase and decrease the STL without changing the mass of the structure.

The effect of added concentrated masses on the linear and geometrically non-linear dynamic behavior of fully clamped rectangular plates

Mon.
17:00–17:20
R H. Matisse 1

M. Hamdani, M. El Kadiriand, R. Benamar

EMI, Université Mohammed V, Rabat, Maroc

Fully clamped rectangular plates carrying concentrated masses at different locations, are encountered in many engineering applications. It is important to Know how does the presence of the added masses affect the plate frequencies and the associated mode shapes in order to estimate its effect on the forced response and the stress patterns in the plate. The theoretical model, based on Hamilton's principle and spectral analysis, previously used to examine the non-linear structural dynamic behavior of various beams, plates and shells, has been adapted here to examine the effect of added point masses on the natural frequencies and mode shapes of rectangular plates of different aspect ratios.The numerical model has been validated via satisfactory comparisons with the results available, concerned mainly with the frequencies of square plates. The non-linear formulation, involving a fourth order tensor due to the membrane forces induced by the large vibration amplitudes, has been used, to analyze the geometrically non-linear case. After preformation of the necessary change of bases from PFB (plate functions basis) to PMB (plate modal basis), the single mode approach permitted to obtain the backbone curves of many plates carrying concentrated masses at their center, at the neighborhood of the first non-linear mode. On the other hand, a parametric study has been performed and the various numerical results are given, for the dependence of the frequencies on the added mass and the plate aspect ratio. Also, tables giving the mode contributions for various values of the added mass are given. Such numerical results may be useful in engineering applications necessitating a judicious adaptation of the fundamental plate frequency in order to avoid the occurrence of undesirable resonances.

Effects of structural instability under impact-oscillatory loading of high-strength two-phase titanium alloys

Mon.
17:20–17:40
R H. Matisse 1

M.G. Chausov[1], P.O. Maruschak[2], A.P. Pylypenko[1], A. Menou[3]

[1] *National University of Life and Environmental Sciences of Ukraine, Kyiv, Ukraine*
[2] *Ternopil Ivan Pul'uj National Technical University, Ternopil, Ukraine*
[3] *International Academy of Civil Aviation, Casablanca, Morocco*

It is known that due to the pulse introduction of energy into materials of different classes (steel, aluminum alloys, armco iron, copper) under impact-oscillatory loading with a loading frequency of $1...2KHz$, structural instability occurs. Therefore, with further loading, the plastic properties of materials can be significantly improved or deteriorated. In this case, the strength properties of materials remain practically unchanged. These physical patterns are related to the self-organization of the structure under dynamic non-equilibrium processes (DNP).

In this paper, new experimental results are systematized that explain the patterns of the structural instability occurring in the impact-oscillatory loading of two-phase high-strength titanium alloys $VT23(\sigma_{us} \geq 1150MPa, \delta = 15\%)$ and $VT23M(\sigma_{us} \geq 1100MPa, \delta == 20\%)$.

The chemical composition of the alloy $VT23M$ is similar to that of the alloy $BT23$, but the range of alloying with β-stabilizing alloy elements is 33% less than the corresponding standard for $VT23M$ alloy. This fact significantly affects the improvement of the plastic properties of the alloy $VT23M$, compared with the alloy $VT23$. The percentage of α and β phases in the titanium alloys $VT23$ and $VT23M$ in the initial state was evaluated by the X-ray method.

The results of the diffractometric study showed that in the titanium alloy $VT23$ the α phase is 43% by weight and the α phase is 57%, and in the titanium alloy VT23M phase is 22% by weight and the α phase is 78%. That is, these two alloys are essentially different in structural terms. Since under impact oscillatory loading of specimens from the materials there occurred bending vibrations in addition to longitudinal vibrations, special load conditions were created in experiments, in which bending vibrations were either symmetric or asymmetric. It is established that one time, almost symmetric impact-oscillatory loading of specimens from alloys VT23 and VT23M, provided that the total stress (from the action of the initial static tension and additional pulse load) does not exceed the yield strength of alloys, reduces the plastic deformation of the alloys with repeated static stretching by approximately 10%. The strength of alloys remains practically unchanged in this case. The modes of one time, almost symmetric impact-oscillatory loading of specimens from alloys VT23 and VT23M, in which jumps of plastic strains impulse were recorded during the pulse introduction of energy in the alloys, greatly improve the plastic properties of alloys with repeated static stretching. The analysis of the experimental results obtained proves that the optimal value for the alloy VT23 is $\varepsilon_{puls} = 3.5...4.0\%$, and for the alloy VT23M the optimal value is $\varepsilon_{puls} = 0.2...1\%$. With these parameters of ε, plastic deformation of the alloy VT23 under a repeated static stretching increased by $30...35\%$. For the alloy VT23M, a significantly smaller increase in plastic deformation after the pulsed input of energy was recorded up to 5.0%. However, additional studies have shown that in this case, the impact strength of the alloy VT23M increased by 20% and its crack resistance was $13...19\%$. The fracture resistance of the alloy VT23M after various modes of loading was estimated using the original method of complete stress-strain curves.

The effect of the asymmetric impact-oscillatory loading of specimens from alloys VT23 and VT23M under the pulsed introduction of energy has been evaluated experimentally, and unexpected results have been revealed, which indicate the determining influence of the ratio between α and β phases of the titanium alloy and the course of DNP. However, they significantly affected the plastic deformation of the alloy VT23M with a lower content of the α phase. After DNP, with repeated static stretching, the plastic deformation of the alloy VT23M decreased to $8...10\%$, that is, almost 2.5 times. As a result of these experiments, it has been shown for the first time that two-phase high-strength titanium alloys VT23 and VT23M are very sensitive to impact-oscillatory loading with a loading frequency of $1...2KHz$, in which structural instability occurs in alloys.

Buildings response under railway loads - Three dimensional modelling of train-track system

Mon.
17:40–18:00
R H. Matisse 1

M. Touati, N. Lamdouar, A. Essahlaoui

EMI RABAT, Civil Engineering Department, Morocco

Buildings near railway tracks are subjected permanently to dynamic loads that are communally neglected on their design. The track irregularities impact indeed the magnitude of the loads communicated by the system train-track to those structures and may endanger their stability, especially if they are coupled to seismic loads. Therefore, the first issue is to model the train-track system. The simplest model that can be conceived in this regard is a mass supported by a spring-dashpoint unit. A two-dimensional model is obviously close to the reality when it concerns analyzing the vertical vibrations. However, if focus is to be extended to lateral vibrations which aren't to be neglected, a three dimensional analysis must be performed. The second aspect of our studies concerns the propagation of the railway loads on the ground in order to assess the frequencies and the amplitudes communicated to buildings. The results of experimental investigation of the ground will be

used like seismic refraction and H/V method. Finally, the dynamic behaviour of a building has to be computed so we can measure the impact of the railway loads on each element of the building considered. To do this, FEM will be performed on a three dimensional model of a building composed of beams. The results will allow us to identify the fatigue law as long as the railway loads are considered as repeatedly applied loads.

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MS 5

Nonliear dynamics in rotating machinery

Organizers: *J. Mahfoud* France, *P. Keogh* UK

Scheduled:

Monday *16:00-18:00* Royal Tulip **Room Eugène Delacroix**

Modelling and static experimental validation of active magnetic bearing systems based on semi-hard magnetic materials

Mon.
16:20-16:40
R E. Delacroix

S. Circosta, A. Bonfitto, A. Tonoli, N. Amati, L.M. Castellanos

Department of Mechanical and Aerospace Engineering Politecnico di Torino Turin, Italy

Semi-hard magnetic materials are of great interest for high and ultra-high speed rotor applications because of their large mechanical strength and advantageous magnetic features enabling the combination with active magnetic bearings and hysteresis electric motors. However, they are characterized by a non-linear and hysteretic behaviour which has to be taken into account in their numerical modelling. A variety of modelling approaches is available in the literature. The most common representations are classified into physics-based (Jiles-Atherton) and phenomenological models (Preisach). An additional approach exploits the generalized Maxwell-slip model, broadly used for the modelling of friction phenomena and viscoelastic behaviour of materials.

This paper describes the modelling and the experimental characterization of a radial active magnetic bearing system based on semi-hard magnetic materials. The Jiles-Atherton material representation is included in the modelling of the whole system to evaluate the performance in terms of force in static conditions. The modelling approach is experimentally validated by means of a test rig composed of a radial active magnetic bearing system whose rotor is made of FeCrCo alloy, a semi-hard magnetic material. The whole analyses are carried out with the rotor at stand still and constant values of current flowing in the electromagnet coils.

Shaftless flywheel on active magnetic bearings based on semi-hard magnetic material

Mon.
16:40-17:00
R E. Delacroix

S. Circosta[1], P. Keogh[2], C. Lusty[2], N. Amati[1], A. Tonoli[1], A. Bonfitto[1]

[1] *Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Turin, Italy*
[2] *Department of Mechanical Engineering, University of Bath, Bath, United Kingdom*

Flywheel energy storage systems (FESSs) are devices which convert electricity to kinetic energy stored in a rotating body. Their main advantages are high power rating, very long lifetime, short recharge and response time, high power density and round-trip efficiency. Furthermore, they do not need periodic maintenance, have a very low environmental impact, are zero-emissions devices and charge/discharge cycles do not degrade their storage capacity.

This paper describes the study of a novel topology of flywheel system exploiting a shaft-less layout with a rotor made of semi-hard magnetic FeCrCo alloy, suspended on active magnetic bearings and driven through a radial hysteresis electric machine.

The flywheel is shaped as a hollow cylinder and is the rotating part of the magnetic bearing system and of the electric motor/generator. This configuration allows good dynamic behaviour and advantages in terms of cost and manufacturing. Furthermore, the shaft-less topology enables a high degree of integration, namely, most of the mass of the system significantly contributes to the rotational inertia leading to higher energy density.

The paper illustrates the static and dynamic analyses conducted for the assessment of the energetic and dynamic flywheel performance along the whole speed range. Additionally, the feasibility of the magnetic suspension based on semi-hard magnetic material is assessed by means of numerical models considering the magnetic hysteresis of the rotor material as well. In fact, whereas the soft magnetic alloys, commonly employed as rotating part of standard magnetic bearings, have a very narrow hysteresis cycle which can be linearly approximated, the semi-hard magnetic alloy introduces high non-linearity. Finally, the unbalance response is carried out to evaluate the flywheel behaviour in the rotational speed range.

Base motion effects on the dynamic behavior of a rotating machine mounted on active magnetic bearings: Numerical and experimental investigations

Mon.
17:00-17:20
R E. Delacroix

C. Jarroux[1], J. Mahfoud[1], R. Dufour[1], B. Defoy[2], T. Alban[2]

[1] *Université de Lyon, CNRS, INSA-Lyon, Villeurbanne, France*
[2] *Thermodyn, GE Oil and Gas, Le Creusot, France*

The base motion generates complex rotor dynamics in particular in the presence of base rotations that could lead to parametric instabilities. At certain rotating frequencies of the support, combined with the natural frequencies of the rotor, instability zones emerge. Those zones depend on the amplitude of the rotation angle.

Particular orbit motion could be observed due to certain combinations of the rotating speed, with the effects of unbalance forces and the gyroscopic moments, and base motions. In the case of on-board rotors supported by nonlinear bearings, complex dynamics are expected. Then, this dynamic behavior should be carefully analyzed to improve the reliability and to maintain a maximal operability of the machines.

Active Magnetic Beatings (AMBs) are more and more employed in industrial applications for their several advantages (no wear due to friction, no oil system, and compact space requirement). They are inherently unstable, therefore a feedback control is needed and a PID controller is the mostly implemented.

Several studies were dedicated to the implementation of different control strategies to limit these base motions and to avoid the eventual contact with its emergency bearings that are called touchdown bearings (TDBs). The purpose is to assess the capacity of the AMBs to keep the machine in safety conditions. Few studies were dedicated to the analysis of rotor-AMB system subjected to strong base motion leading to contact of the rotor and the stator.

The paper investigates experimentally and numerically the nonlinear feature associated with a rotor supported by Active Magnetic Bearings (AMBs) and subjected to more or less severe motions from its support. The objective is to analyze the effect of the combination of mass unbalance forces, base motion excitations and contact nonlinearities on a rotor-AMB system response. The investigations were carried out numerically and experimentally on a lab-scale rotating machine. The rotor is designed to obtain the dynamic behavior of high speed turbomachinery with a rigid shaft in the operating speed range and low gyroscopic effects The aim is to assess the effectiveness of the developed augmented PID to maintain the rotor operating under severe events. To perform base motion tests, the test rig was mounted on a 6-axis hydraulic shaker. At this stage, only harmonic base motions are considered.

Finites elements model was used for the numerical calculations. Base accelerations were recorded in the three directions using tri-axial accelerometers fixed on the shaker. The displacement and current of the rotor were also recorded among each action line

It is shown that medium amplitude lead to complex periodic orbits while large amplitude generate rotor TDB interactions. The contact flatten the periodic orbits and the numerical model provides accurate results.

Modelling the behaviour of multi-member large displacement flexure joints

Mon.
17:20-17:40
R E. Delacroix

C. Lusty, N. Bailey, P. Keogh

Department of Mechanical Engineering University of Bath Bath, UK

Compliant or flexure hinges are a well-known solution to allowing relative motion between different parts of a machine or mechanism without the disadvantages associated with more traditional hinge elements which involve sliding motion (bushings, bearings etc). A compliant hinge permits motion through its own elastic deformation i.e. it is a machine component which can bend.

In current applications, is very often the case that such mechanisms only permit the flexures to undergo small magnitudes displacements. This confers the considerable advantage that the flexures can be treated in a simple linear way, and the complexities of analysing the true behaviour of the compliant member(s) can be safely disregarded without loss of significant accuracy.

The goal of this paper is to look towards opening up the field of compliant mechanism design to include hinges which undergo much larger deflections than current applications employ. The potential advantages to the design and capability of robotic systems is significant. In general, greater precision and repeatability of motion paths and contact forces naturally pave the way for increased machine performance in both new and existing applications. Large displacement compliant mechanisms may also assist in such goals as achieving more "organic" machine motion (biomimicry), creating smaller mechanisms for size critical applications (e.g. minimally invasive surgery) and designing lighter yet more reliable mechanisms for robots in space exploration technology. The potential benefits and applications are really limited only by imagination.

However, in order to retain the precision motion advantages implied by compliant mechanisms, it is vital to be able to accurately analyse (and subsequently control) flexible mechanisms undergoing these large displacements. This paper demonstrates a possible technique for such analysis.

Active magnetic bearing and active touchdown bearing control of the nonlinear dynamics rotors operating within clearance gaps

Mon.
17:40-18:00
R E. Delacroix

P. Keogh, C. Lusty, N. Bailey

Department of Mechanical Engineering, University of Bath, Bath BA2 7AY, UK

Active Magnetic Bearing (AMB) systems typically employ Touchdown Bearings (TDBs) to prevent contact between the rotor and expensive electromagnetic stator parts. However, the nonlinear rotor dynamics are then transferred to the rotor/TDB interactions. It is well-known that the rotor responses under contact conditions are arduous for the TDBs since high mechanical and thermal contact stresses are generated. During shut-down or run-down of the rotor under de-levitation it may pass through several critical speeds where the contact stresses are amplified. The accumulated damage to the TDBs may be so significant that their operational life must be specified in terms of a relatively low number of run-downs. It is therefore of interest to extend the TDB life as far as is possible if active capability remains in the overall rotor dynamic system.

Under normal operation a rotor spinning within an active magnetic bearing system will be levitated and hence a damage-free operating condition exists. However, AMBs have limited dynamic load capacity due to magnetic material field saturation. Hence large external disturbances or intermittent faults may cause clearance gaps within TDBs to close. Once initial contact has been made, rotor dynamic responses may involve initial rotor bouncing on the TDBs followed by:

(a) A return to normal levitation,
(b) Bouncing that becomes persistent,
(c) Bouncing that changes to rotor rubbing contact.

In some cases, bistable responses exist in which contact and contact-free rotor responses are possible, the latter being clearly preferable.

In this paper, cases (b) and (c) are examined with respect to using AMB and active TDB capabilities to restore contact-free rotor dynamic levitation. Feedforward and closed loop strategies are investigated. The use of AMB control is appropriate if the required control forces are within AMB saturation limits. Otherwise active TDB control may be able to destabilise persistent rotor dynamic contact conditions. Consideration is given to rigid and multi-mode rotors. This is necessary since impulsive excitation of a rotor by contact events may excite flexible rotor modes that are well above the operating rotational speed frequency. Hence the interaction of rotor modal responses with the nonlinear contact dynamics is important with respect to determining the most appropriate control action.

MS 6

Deterministic and stochastic dynamics and control of vibrating systems and their applications to engineering and science

Organizers: *J.M. Balthazar* Brazil, *A. Cunha Jr* Brazil, *P.B. Gonçalves* Brazil, *E. Jarzebowska* Poland

Scheduled:

Tuesday	*10:30–12:10*	Royal Tulip Hotel	**Room Paul Bowles**
Tuesday	*14:20–15:20*	Royal Tulip Hotel	**Room Paul Bowles**
Tuesday	*16:20–18:00*	Royal Tulip Hotel	**Room Paul Bowles**

Dynamic analysis and characterization of a nonlinear bi-stable piezo-magneto-elastic energy harvester

Tue.
10:30–10:50
R P. Bowles

J.V.L. Lopes Peterson, V. Goncalves Lopes, A. Cunha Jr
Universidade do Estado do Rio de Janeiro (UERJ)

Energy harvesting is a very promising technology to provide low levels of power for small autonomous systems, which the applicability encompass a very wide range of areas, that spans from micro/nano sensors in engineering to state of art implants in medicine. For this reason, it is a current research topic, focus of several recent works [1-3]. The present work deals with the analysis and detailed characterization of the nonlinear dynamics of the energy harvester proposed by Erturk et al. [4], which consists in a bi-stable piezo – magneto – elastic system driven by a periodic external excitation. The dynamical system is studied in depth through traditional tools of non-linear analysis (time series, bifurcation diagrams, Poincare maps and at- traction basins), and with aid of the relatively new $0-1$ test for chaos by Gottwald and Melbourne [5]. Three dimensional bifurcation diagrams provide a mapping of several configurations of the pair excitation amplitude/excitation frequency associated with high levels of energy scavenging. In particular, it is possible to note the existence of high energy orbits in the regular region of the phase space as well as embedded in the strange attractor. The level of chaoticity of the dynamical system is accessed very effeciently via the $0-1$ test for chaos, which allows mapping the presence of dense regions of chaos without the help of the Lyapunov exponents.

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Sensitivity Analysis of the optimal energy consumption to load uncertainties for open space indoor air cooling using Polynomial Chaos Expansion

Tue.
10:50–11:10
R P. Bowles

S. Ben Ayed[1], J. Borggaard[2], E. Cliff[2]

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Population growth, increased comfort levels, and the increase of indoor activities are placing more demands on the energy use from buildings across the globe. This contributes to the concerns about the exhaustion of resources and the related negative impacts on the environment. Therefore, energy efficiency in buildings is of critical interest. Since the largest contribution for a building's energy use is Heating, Ventilation, and Air Conditioning (HVAC), efforts that result in even small energy savings will be highly significant. Small to medium commercial buildings such as restaurants, stores, offices, etc., use multiple Roof Top Units (RTUs) to condition their open spaces. Interaction between these RTUs is generally difficult to simulate using a lumped indoor-air model, and needs to be addressed using Computational Fluid Dynamics (CFD) approaches. In this work, a thermal flow analysis is performed for a restaurant located in Pennsylvania, US to optimize its HVAC energy consumption. The distributed dynamic responses of temperature and moisture that correspond to perturbations of input variables are generated using a CFD analysis. The CFD model is validated with experimental data from the RTU return temperatures. To avoid the high computational cost, and provide a reliable on-line model for an optimal controller, a Reduced Order Model (ROM) is developed by approximating the responses to these perturbations using a linear time-invariant model. The resulting indoor-air model is coupled to a dynamic envelope model with longer time scales. Assuming the outside temperature distribution and the occupants' loads are known throughout the day, optimal control is applied to our coupled model to minimize the cooling power subject to local and global comfort constraints. The results show that the applied method is more efficient and achieves better comfort than the results given by the experimentally measured response of a conventional set-point control strategy.

The sensitivity of this optimal cooling cost to the variation in the input variables in a global fashion, about a reference configuration, is studied using a non-intrusive Polynomial Chaos Expansion (PCE). In PCE, any stochastic variable undergoing random fluctuations can be represented by a polynomial expansion. The polynomial coefficients are approximated through a sampling procedure of the output. The choice of the polynomial basis is highly dependent on the distribution of the random variables. For Gaussian distribution of the random variables, the Hermite polynomials can be used as basis functions. The Latin Hypercube Sampling strategy is applied to obtain a representative collection of input parameter combinations. Once the coefficients are found, the sensitivities of the operating cost to the different input parameters are computed through derivatives. The results show that the dining load is the most influential among the parameters we studied since it has the greatest sensitivity value. The results also show that this sensitivity is mostly linear when the number of studied parameters is small. However, it exhibits more non-linear behavior as the number of input parameters increases.

Bifurcation, chaotic and hysteresis phenomena of broadband tristable energy hervesters

Tue.
11:10–11:30
R P. Bowles

S. Zhou[1], J. Cao[2], G. Litak[3,4]

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[2] *School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an, China*
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Vibration energy harvesting has been expected to be a promising way to solve the challenging issue of the permanent energy supply for small sensors and MEMS devices. Among currently existing energy harvesters, the tristable energy harvester(TEH) is one of most recent energy harvesters. More importantly, the TEH was theoretically and experimentally verified that it has very good energy harvesting performance under low-frequency and low-level excitations. However, there are still missing deep investigation on the dynamic response of the TEH. Therefore, this paper explores the bifurcation, chaotic and hysteresis phenomena of broadband THEs based on simulation and experiments. In detail, the bifurcation phenomena of the TEH is analyzed by using Poincaré maps and the phase portrait topology. The responses of the TEH under linearly increasing frequency sweep excitation and decreasing frequency sweep excitation demonstrate its existing dynamical hysteresis phenomena.

Programmed task based motion analysis of robotic systems equipped with flexible links and supports

Tue.
11:30–11:50
R P. Bowles

E. Jarzêbowska[1], K. Augustynek[2], A. Urbas[2]

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[2] *University of Bielsko-Biala, Department of Mechanical Engineering Fundamentals, Poland*

Analysis of robot task based motions dedicated to work and services delivery is presented in the paper. The key contribution of the paper is in three aspects of the analysis. The first one is the possibility of constraints incorporation into the system dynamics, the second one is the special computational procedure for the constrained dynamics generation, which provides dynamic models, referred to as reference dynamics, satisfying all constraints upon them. The third contribution component of the presented research is in modeling flexibility of the system parts and supports.

Harvesting energy from environment: dynamic and thermal analyses of albatross motion

Tue.
11:50–12:10
R P. Bowles

M. Hassanalian[1], A. Stempeck[1], M. Ali[2], S. Ben Ayed[3], A. Abdelkefi[1]

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Some types of albatrosses can fly long trips of 15200Km over the oceans without any flapping motion during 46 days. Different theories have been proposed by researchers to explain how these migrating birds can fly without flapping just with extending their wings and harvest energy from the atmospheric boundary layer (ABL) above oceans. The main theory behind their long and low cost flight is their special flight mode, which is called dynamic soaring. Albatrosses are able to take advantage from wind shear to gain the most required energy for flying. Dynamic soaring occurs in four basic steps: First, the bird flies at a height where the velocity of the wind is high enough in the boundary layer, then it dives down to sea level increasing his speed due to gravity. Afterwards, the bird turns 180 degrees and flies into the wind, turning again 180 degrees and using the wind velocity to climb back to the previous altitude. Albatrosses generally have two types of movements in different scales; one is a large-scale movement that appears as a steady-state cruise of long-distance flight and another is a small scale movement which is flight maneuvers of highly dynamic nature. Previously, it was impossible to study small-scale movements of albatrosses experimentally, due to the lack of knowledge about the dynamic soaring and the physical mechanism of the energy gain of the bird from the wind. Recently, developments of GPS and tracking sensors have provided the feasibility of determination of the small-scale flight maneuver with high precision.

Various studies have been carried-out to study the dynamic soaring, flight routes, and flight profile of albatrosses, as highly performance migrating birds. One of the main important studies was that of Pennycuick in 2002, who has proposed the "gust soaring" that bird exploits structures in the wind field, such as separated boundary layers, to gain energy by climbing headed upwind and descending headed downwind across the wind shear layer. However, different factors have been ignored in the previous studies, such as the wind velocity and air temperature profiles over ocean, water wave effects, ocean tides, etc. One of the factors that have been neglected during the study of dynamic soaring of albatrosses is the thermal effect of the heat flux over the ocean on the above atmospheric boundary layer. The boundary layer of ocean is changing with time and subsequently alters the shear wind profile. Also, heat flux in boundary layer of ocean during the day and night can influence on flight characteristics of albatrosses. Generally, there is an exchange of energy between the oceans and the atmosphere. During daytime, ocean is absorbing heat through sun radiation and during night, the heat stored in the ocean water is radiated back to the atmosphere. These heat fluxes will have an effect on the local air temperature, which will change the density and viscosity of the air in the atmospheric boundary layer above the ocean. These changes in heat flux, shear wind, density and viscosity of air will affect the flight altitude of albatrosses during their soaring flight. In this paper, all the coupled effects are applied in order to get more realistic dynamic soaring model and to better understand this type of energy harvesting mechanism. This study will provide new concepts to design efficient drones that are partially powered through energy harvesting from atmosphere.

Dynamics of a bouncing ball excited by colored noise

Tue.
14:00–14:20
R P. Bowles

C. Zouabi[1], J. Perret-Liaudet[2], J. Scheibert[2]

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[2] *LTDS, UMR 5513, École Centrale de Lyon, Université de Lyon, 69134 Écully Cedex, France*

The popular bouncing ball model, which consists in a ball submitted to the gravitational field and bouncing vertically on a vibrating plate with inelastic impacts, has been widely studied in the last decades. This is due to both its simplicity and the amazing richness of its dynamics, from harmonic to chaotic, through subharmonic and quasi-periodic responses. It is now one of the paradigms for nonlinear dynamics and chaos. Most of the studies achieved to date consider harmonic vertical motion of the plate. On the contrary, few of them include random vibrations of the plate, in spite of its undeniable relevance. Moreover, the excitation induced by the plate motion at successive bounces is generally assumed to be a discrete Markovian memoryless stochastic process [1].
In this context, the main purpose of this study is centered on an updated stochastic version of the bouncing ball model. More precisely, the randomly excited bouncing ball model is revisited in the present work, by introducing the table displacement as a continuous time Gaussian random process with tunable correlation time, i.e. a colored noise. To analyze the memory effect of the excitation, we have widely investigated the dynamic behavior using numerical simulations [2]. We show that the dynamic behavior is not only governed by the restitution coefficient at impacts and the dimensionless excitation amplitude level, but also by the correlation time of the excitation process, or the bandwidth of the excitation signal [3].
More precisely, our simulations allow us to identify the pertinent parameter that controls the dynamics. It corresponds to the ratio between the characteristic Markovian mean flight time T_{flight} of the ball and the characteristic mean time T_{peak} separating two successive peaks in the plate motion. Fig. 1 demonstrates the relevance of this ratio. Introducing altitudes of take-offs H_n at impact n, it is shown in this figure the probability that H_{n+1} be smaller than H_n versus the ratio T_{flight}/T_{peak} Three regimes can clearly observed. In regime 1, the ball can easily jump over any peak of the excitation. In regimes 2 and 3, more and more jumps are required in order to climb the peaks. In other words, when the parameter is large, the Markovian approach is appropriate; but for low levels, memory effects become not negligible leading to a significant decrease of jump durations; and finally at smallest values of the ratio, chattering occurs.

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Optimal power recovery in a bi-stable energy harvester

Tue.
14:20–14:40
R P. Bowles

A. Cunha Jr

Universidade do Estado do Rio de Janeiro (UERJ)

Energy harvesting is an industrial technology with great potential to provide energetic solutions for low power autonomous systems, such as wearable electronics, network sensors, medical implants, etc, which has attracted the interest of recent studies [1,2], especially when the focus is the optimization of the energy recovery process [3]. In this sense, this work deals with the formulation and numerical solution of a robust nonlinear optimization problem which seeks to maximize the recovery of electrical power by a bistable energy harvester prototypical of Erturk et al. [4]. This robust optimization problem is formulated in terms of the response of the harvester stochastic dynamics, which considers electro-mechanical coupling parameters uncertainties, and a classifier obtained from $0-1$ test for chaos [5]. The objective function is defined as the expected value of the output power, while the nonlinear constraint is given by the 0-1 classifier function. A stochastic strategy of solution, combining penalization and cross-entropy method is proposed and tested numerically. The results illustrate the effectiveness of the proposed optimization strategy when compared to a reference solution obtained with a standard exhaustive search in a very fine grid.

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Sine-Gordon system with hysteretic bonds

Tue.
14:40–15:00
R P. Bowles

P.A. Meleshenko[1,2], A.V. Tolkachev[2], M.E. Semenov[1,2,3,4], A.V. Budanov[5]

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In the frame of this work we consider the new mechanical system which can be described in terms of the modified sine-Gordon equation. We use the standard mechanical equivalent for the sine-Gordon system proposed by Scott which can be presented as a chain of nonlinear oscillators connected by the springs. In this work we introduce also the hysteretic component in the springs. Such a hysteretic component in the links between the neighbor oscillators allows to take into account the aging of the real material. As is well known there are soliton solutions in the classical sine-Gordon system. In the modified system we also observe the soliton solution, and the properties of this solution strongly depend on the parameters of the hysteretic converters as it can be demonstrated by the numerical simulations. As a hysteretic converter we consider the backlash operator which can be modeled by the Bouc-Wen model.

Hybrid model for the diagnose of dengue in Caldas (Colombia)

Tue.
15:00–15:20
R P. Bowles

C.O. Aguirre[1], G. Olivar Tost[2]

[1] *Faculty of Engineering and Architecture, Universidad Nacional de Colombia*
[2] *Faculty of Exact and Life Sciences, Universidad Nacional de Colombia*

Several compartmental models have been suggested in the literature for modeling vector diseases such as dengue, malaria, zika, and so on. On the contrary, a small number of papers can be found on how health institutions deal with the patients, not to say a mathematical model for it. In this communication, we match a classical SIR model for dengue with an algorithmic (rule-based) model for the hospitals. Moreover, we also perform stochastic simulations with the patientąŕs treatment to check the efficiency and possible better measures in the health institutions. Thus the final model includes a hybridization of di.erential equations (for the general evolution of the disease in the population), ruled-based modeling (for the dynamics in the hospitals) and stochastic simulation (since there are many uncertainties in the diagnose procedure). Finally, we compare with the available data during a dengue outbreak in a Colombian region in 2013.

The primary purpose of present paper is focused on joining several models for each step in the modeling e.ort. Classical SIR models with di.erential equations are used to simulate the evolution of the disease outside health institutions such as hospitals. Then a rule-based algorithm model is stated for dealing with those individual patients who feel sick and go to hospitals. Getting a 100 % good diagnose is not obtained. Thus stochastic (Montecarlo) simulation is performed at this step. Parameters are obtained directly from the Health institutions in a region in Colombia, where an outbreak of dengue was observed in 2013. Then we compare numerical simulations with available data. We

found that our results almost fully agree and thus our model can be used for a better decision making.

After comparing our numerical results with those available in the data records, we checked that our model could reproduce the data with excellent agreement. Thus we are confident that the mathematical hybrid model can be used for a better decision making. Also, we aim to design a better standard procedure in the health institutions (through a new rule-based algorithm) and check with our model if this new procedure enhances the possibilities to reduce the duration and intensity of an outbreak. Also, we need, in the future, to add all serotypes of dengue to be more precise both in the disease evolution outside the hospitals and inside the hospitals.

Uncertainty analysis of skin drag reduction of albatrosses due to wings and weather characteristics

Tue.
15:20–15:40
R P. Bowles

M. Hassanalian[1], JS. Ben Ayed[2], M. Ali[3], A. Abdelkefi[1]

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Dynamic soaring and low altitude flight over water are important factors for maintaining long flights by seabirds. Dynamic soaring is a behavior in which energy is gained by repeatedly crossing the boundary between air layers with significantly different velocities. Besides dynamic soaring, wing color can be considered an effective parameter in flight performance. Many birds that implement dynamic soaring over water have black color on the dorsal (top) side of their wings and white color on the ventral (bottom) side. That is generally the case for the wandering albatross, sooty tern, Manx shearwater, and black skimmer. The black and white colors absorb heat at different rates. A black colored material is an excellent absorber and convector while a white one is an excellent reflector but very poor absorber. Therefore, the black surface of the bird wing should heat up more than the white surface. In a previous study, Hassanalian et al. considered an albatross wing as a flat plate which was insulated from the bottom side using an adiabatic boundary condition and the temperature of the top surface of the wing was calculated through an energy balance. It was found that the black colored wing top has a better drag reduction compared to the white colored one.

In this work, the idea is extended and the modeling is closer to reality since the bottom side of the wing is also considered. The thermal effects of wing color in flight is investigated in different species of birds with respect to their flight routes, migration time, and geometric and behavioral characteristics. Considering the marine and atmospheric characteristics of these flight routes, a thermal analysis of the birds wings is performed during their migration. The surrounding fluxes including the ocean flux and the sun irradiance are considered in an energy balance in order to determine the skin temperature of both sides of the wing. Applying Blasius solution for heated boundary layers, it is shown that the color configuration of these migrating birds, namely black on the top side of the wings and white on the bottom side of the wings results in a skin drag reduction, if compared to some other configurations, when both day and night are taken into consideration. This drag reduction can be considered as one of the effective factors for long endurance of

these migrating birds. It is shown that, for different arrangements of colors, when studied from an aerodynamic and thermal points of view, the drag reduction is very sensitive to the atmospheric characteristics like the sea temperature and to morphologic characteristics of the bird, like its absorptivity to thermal radiation. An uncertainty analysis is carried – out on the skin friction drag variation of the wings with respect to the proposed parameters.
This study will provide guidelines to design a new generation of efficient drones that can withstand long missions, based on biomimetics of migrating seebirds.

Dynamical analysis and control of the Malkus-Lorenz waterwheel with parametric errors

Tue.
16:20–16:40
R P. Bowles

T.C.L. Marsola[1], J.M. Balthazar[1], M.F.V. Pereira[2], A. M. Tusset[3]

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This work presents a dynamical analysis of the Malkus-Lorenz Waterwhweel, where the Lorenz equations are mapping into the waterwheel equations. With this, two types of controllers were designed for control the system’s chaotic behavior, including parametric errors. The first control is the SDRE (State Dependent Ricatti Equation) control, and the second one is a time-delay feedback control.

Numerically approximated Lyapunov exponents of quasiperiodic motions

Tue.
16:40–17:00
R P. Bowles

R. Fiedler, H. Hetzler

University of Kassel, Institute of Mechanics, Kassel, Germany

Dynamical systems excited by mechanisms with a single frequency exhibit usually periodic oscillations. As soon as a second mechanism excites the dynamical system simultaneously, oscillations of different physical origin interfere which may lead to quasiperiodic motions, unless synchronization is existent. The description of quasiperiodic motions with standard methods is due to their infinite period length disadvantageous, whereby an description with an invariant manifold is preferable which can be determined by solving a system of partial differential equations (invariance equations) [3].
This contribution assumes that an invariant manifold is calculated [2] and deals with a stability analysis of flows on invariant manifolds by calculating the Lyapunov exponent. Two characteristics of trajectories on invariant manifolds are emphasized, first if a trajectory starts on the manifold it stays on it and second a trajectory fills the manifold dense. Since the Lyapunov exponent converges if time goes towards infinity, the description using an invariant manifold for quasiperiodic motions includes all required informations on a p dimensional manifold, where p is the number of internal frequencies. For the transition of the infinite time interval to a p dimensional finite interval is the application of the mean value theorem required, which characterizes in the neighborhood of a manifold the ergodicity of semitrajectories [3]. A prerequisite for the application of the mean-value theorem is the presence of a parallel flow on the manifold, which implies constant in-

ternal frequencies. The approach is applied to a periodic and quasiperiodic motion of a forced Van der Pol equation to determine the Lyapunov exponent. To verify the calculated Lyapunov exponent a time integration based method using a continuous Gram Schmidt orthonormalization [1] is applied.

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On the hysteretic operators with stochastic parameters

Tue.
17:00–17:20
R P. Bowles

M.E. Semenov[1,2,3,4], O.I. Kanishcheva[1,2], P.A. Meleshenko[1,2], O.O. Reshetova[2], R.E. Pervezentzev[1]

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In this work we introduce the new class of hysteretic operators with stochastic parameters. Such operators are the natural model in the situation when the parameters of hysteresis carrier are under influence of stochastic, uncontrollable affections. We consider the definition of these operators in terms of the "input-output" relations, namely: for all permissible continuous inputs corresponds the output in the form of stochastic Markov process. The properties of such operators are also considered and discussed. In particular, the correctness and monotony of the introduced converters are established. Application of hysteretic operators with stochastic parameters is demonstrated on the example of simple oscillating system and the results of numerical simulations are presented.

Internal resonances of catenary–like marine risers under periodic excitation

Tue.
17:20–17:40
R P. Bowles

F.K. Alfosail, M.I. Younis

King Abdullah University of Science and Technology, Saudi Arabia

Marine risers are subjected to various environmental loads, such as vortex induced vibrations (VIV), which hinder the life of the riser by fatigue [1]. The presence of nonlinear geometric effects and static deflection makes the dynamic response of the riser structure complex involving modal interactions due to the activation of internal resonances. Although the research work in marine riser is very extensive in several aspects [2], there is little research conducted towards the influence of internal resonance on the nonlinear response of the riser structure [3-5]. Therefore, this research work aims at examining the two to – one and three – to – one internal resonances using the multiple scales (MTS) perturbation method.

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MS 7

Time series analysis methods for fault diagnosis and prognosis

Organizers: *G. Litak* Poland, *P.S. Heyns* South Africa, *C. Nataraj* USA, *C.K. Kwuimy* USA

Scheduled:			
Tuesday	*10:30–12:10*	Royal Tulip	**Room Eugène Delacroix**
Tuesday	*14:00–15:20*	Royal Tulip	**Room Eugène Delacroix**

Noise and dissipation in sliding rough surfaces

Tue.
10:30–10:50
R E. Delacroix

A. Le Bot

Laboratoire de tribologie et dynamique des systèmes, Ecole centrale de Lyon, France

The friction noise emitted when rubbing hands or small objects is a wide band noise generated by impacts between antagonist asperities of rough surfaces. Since microscopic shocks are random events, this is a problem of statistical mechanics. In this study, we propose to analyze the problem in terms of (vibrational) energy balance. A direct numerical simulation which consists in solving the elasto-dynamics equations with contact delivers crucial information on the rate and strength of impacts. While experiments give some empirical laws such as acoustical power versus sliding speed and roughness. We present an experiment which investigates the dependence of sound with the nominal contact area. It is found that in some cases, the acoustical power is proportional to the contact area while in some others, the sound is constant. This paradoxical result is explained by introducing a dissipation law of vibration at the interface of solids. In the regime where this dissipation process dominates, the sound is found to be constant.

Array of piezoelectrical sensors on-board a slider to measure local micro-impact normal forces

Tue.
10:50–11:10
R E. Delacroix

C. Gregoire[1], J. Scheibert[1], T. Durand[1], M. Guibert[1], M. Collet[1], B. Laulagnet[2], J. Perret-Liaudet[1]

[1] *Laboratoire de Tribologie et Dynamique des Systemes Ecole Centrale de Lyon, France*
[2] *Laboratoire Vibrations Acoustique, INSA Lyon, France*

An actual challenge related to dry rough sliding contacts is to get a better understanding of the dynamic forces on micro-asperities and their spatial distributions. It might permit to optimize energy efficiency, for instance by minimizing dissipation of a contact interface [1], to enhance its micro-mechanical performances, for instance by controlling deterioration at the interface and to improve its acoustic comfort, for instance by understanding the radiated energy in the audible frequency range (up to 20kHz) [2-4].

To address these issues, we designed an instrumented slider that integrates nine on-board piezoelectric sensors to get broadband, discrete and local dynamic measurements of the normal forces at a sliding contact interface. We developed a finite element model of the slider to calculate various dimensioning quantities: the eigenfrequencies, which determine the measurement bandwidth; the influence functions that relate any point force to the response of each of the nine sensors. We will summarize our dimensioning conclusions.
Once this slider was built, we added nine small asperities at the vertical of the piezoelectric sensors to create a model roughness. We rub this slider over another randomly rough surface to investigate the space-time dynamics of the micro-impacts between antagonist asperities [5]. Our first results on vibro-impacts dynamics and associated forces will be presented.

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Multi-speed multi-load bearing diagnostics using extended phase space topology

Tue.
11:10–11:30
R E. Delacroix

T. Haj Mohamad[1], C. A. Kitio Kwuimy[2], C. Nataraj[1]

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Machine condition monitoring techniques have received much attention in recent years due to their significant advantages in increasing productivity and lifespan of system components. Moreover, condition monitoring techniques decrease maintenance costs, which comprise a major part of operating costs in any industry, and hence, many industries have adopted machine condition monitoring techniques. Rotating machinery in particular are important industrially, and fail often due to rolling element bearing defects. Techniques for fault detection and diagnostics of bearings have hence gained considerable attention among researchers across the globe. Since vibration and acoustical response contain valuable information about their condition, they are the most widely used for fault diagnostics of bearings.

This paper applies a novel feature extraction method called the Extended Phase Space Topology (EPST) for bearing fault detection. The EPST method is based on characterizing the topology of density distribution of the vibration data. The density distribution of the vibration signal is approximated using Legendre polynomials, whose coefficients are then used as features. These features are ranked, and the optimal set is selected using mutual information. Finally, a support vector machine is used as the classifier to distinguish between the different bearing conditions. This method has been applied to vibrational acceleration signals of two bearings (drive end and fan end) at various defect conditions at four rotational speeds. The bearing conditions include a healthy bearing, and bearings with seeded defects in inner race, outer race, and rolling element. A dynamometer is used to apply different loads on the bearing (i.e. 0 hp, 1 hp, 2 hp, and 3 hp) at each speed.

The study demonstrates that the density distribution provides rich information about the status of the health of the bearing. Furthermore, results show that the innovative EPST procedure has outstanding performance in system condition monitoring with multiple defects. The EPST is empirically robust to noise, fast to execute, and therefore can easily be applied in an automated process.

The temperature control system during the drying process of the yeast layer

Tue.
11:30–11:50
R E. Delacroix

P. Wolszczak

Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka, Poland

The article presents the results of choosing how to control a real non-linear object. Yeast drying requires a precise temperature control due to the possibility of overheating. The object changes properties during of the process flow. Object identification was used and a mathematical model was developed. The model was used to select roboust control methods. The results were compared to the system of two PID regulators used in practice.

Fault diagnosis with a stochastic resonance model and recurrence identification

Tue.
11:50–12:10
R E. Delacroix

T. Haj Mohamad[1], C. A. Kitio Kwuimy[2], C. Nataraj[1], G. Litak[3]

[1] *Villanova Center for Analytics of Dynamic Systems (VCADS) Villanova University, Villanova, USA*
[2] *College of Engineering and Applied Science University of Cincinnati, Cincinnati*
[3] *Lublin University of Technology Faculty of Mechanical Engineering Nadbystrzycka, POLAND*

Investigations that have been carried out by and large on the application of Stochastic Resonance (SR) to mechanical system faults indicate that the method shows great promise as an advanced vibration-based condition-monitoring tool. This technique has been applied to several systems with excellent results within the linear regime of systems. However, a majority of engineering systems perform in a nonlinear regime under both healthy and defective conditions. Thus SR often give off false alarms when applied to a healthy nonlinear system. With a view to addressing this problem, researchers have been seeking to modify the SR methodology.

This paper attempts to address the issue by combining the SR method with the recurrence method which has shown promising results in the area of fault detection for both linear and nonlinear systems. The method of recurrence analysis is used to extract features in order to characterize the appearance of SR in the time response of the system. The recurrence quantification are then used as features to detect SR as signature of specific defects. The new approach will be presented for simulated data and then tested for faulty and healthy bearings in their linear and nonlinear regimes.
In the first part of the paper, the resonance model is based on the simulated data of a bistable nonlinear (stiffness nonlinearity, clearance and friction) model with an additional random signal at a low level. To detect resonance, we apply recurrences with surrogate test as a main criterion of the monitoring. The presence or absence of SR will then provide appropriate insight about the condition of the system, in particular, if it is healthy or defective. Finally, the method is applied to experimental data obtained from a bearing.

Stick-Slip phenomenon of sliding secondary components and its effect on the horizontal seismic behavior of single-story light structures

Tue.
14:00–14:20
R E. Delacroix

S.P. Challagulla[1], C. Parimi[1], P.K. Thiruvikraman[2], A. Naringe[1]

[1] *Birla Institute of Technology Science-Pilani, Hyderabad Campus, India*
[2] *Department of Physics, Birla Institute of Technology Science-Pilani, Hyderabad Campus, India*

Even though heavy components lying on a structure affect its seismic behavior, this effect is usually ignored. These heavy secondary components (non-structural) are usually considered to be part of live loads in the design of the main structure. By assuming these secondary components as rigidly attached bodies, the design of the main structure becomes too conservative. Since, there is an energy loss due to friction, the main structure vibration tends to dampen. On the other hand, the design can be unsafe if these components are completely neglected as there could be stick slip phenomenon. Due to friction or lack thereof between these non-structural components and the slab floor, a stick-slip phenomenon is possible. This phenomenon can either amplify or dampen the structural response during horizontal seismic excitation. The particular problem studied here is based on lead-shielding application in nuclear power plants. Lead-shielding in power plants is primarily provided by lead blankets simply draped on light weight scaffolding. Due to the high risk associated with the interior of the nuclear power plants, these scaffolding structures need to be designed for seismic loads. Since the lead blankets have considerable weight with respect to the light weight scaffolding structural frame and are draped on it, the friction between them affects the response of the scaffolding. For simplicity, the scaffolding is assumed to be on the ground and is assumed to be single storied.
In this study a single-story light frame is termed as primary structure (PS) and the component resting on it as secondary body (SB). Strong ground vibration causes significant inertial forces on these SBs that can cause them to slide, roll, or overturn. This paper studies the seismic behavior of PS supporting a SB with the possibility to only slide. The equations governing the motion of primary and secondary masses are developed considering Coulomb's friction model from the basic dynamic equations of the system. The equations of motion of the SB and PS were solved using numerical methods.

In this problem, the PS follows a fairly complex displacement pattern. The method is corroborated using existing studies. Various seismic excitations are applied to the scaffolding structure supporting a secondary component and a parametric study is performed to check the effect of friction on it. These studies include varying the dynamic inputs such as structural period T, frictional coefficient μ, secondary body to structure mass ratio and characteristics of input ground motion to understand the effect of SB on the PS. Based on this study, a design methodology is suggested for such structures. A parameter to quantify the effect of sliding body on the seismic response of structure is proposed and termed as Inertial Effect Ratio (IER).

Using the gottwald and Melbourne's 0-1 test and the Hugichi fractal dimension to detect chaos in defective and healthy ball bearings

Tue.
14:20–14:40
R E. Delacroix

C. A. Kitio Kwuimy[1], T. Haj Mohamad[2], C. Nataraj[2,3]

[1] *College of Engineering and Applied Science University of Cincinnati, Cincinnati*
[2] *Villanova Center for Analytics of Dynamic Systems (VCADS) Villanova University, Villanova, USA*

Time series analysis is generally referred to as the transformation of observed dynamic data into a form that provides insight for making better decisions. These data need to be characterized and analyzed in order to extract information about the system, and this has to be done in the most optimal way for specific applications. A specific and, particularly useful - characteristic of engineering systems is the inherent nonlinear properties of their time response. In fact, this is perhaps even more important when these systems are defective. This paper focuses on exploitation of this nonlinear behavior.
In particular, the paper considers the identification of chaotic behavior dynamics using data extracted from an experimental model of a spinning rotor supported on rolling element bearings. A description of the method is provided as well as an illustration using a standard dynamic map. Application of the 0-1 test for chaos and the Higuchi dimension are shown to lead to an effective tool in the identification of chaotic behavior of the system, with and without faults.
One key relevance of this work is the relative simplicity of the methods and their robustness. These two aspects are in fact the hallmark of effective fault diagnostics methods. The results hence suggest the 0-1 test for chaos and the Higuchi dimension are strong candidates for the characterization of experimental data as well as for fault analysis.

Estimating bolt tightness from measured vibrations: Influence of nonlinear boundary stiffness and damping

Tue.
14:40–15:00
R E. Delacroix

S.M. Sah[1], J.J. Thomsen[1], M. Brons[1], A. Fidlin[2], D. Tcherniak[3]

[1] *Department of Mechanical Engineering, Technical University of Denmark*
[2] *Department of Engineering Mechanics, Karlsruhe Institute of Technology, Germany,*
[3] *Brüel and Kjar Sound and Vibration Measurement, Denmark*

In this work we present a technique to assess the level of bolt tightness and to quantify the tension based on measured natural frequencies and damping ratios of the bolt. This technique is investigated experimentally and theoretically. A simple model for the bolt that consists of a pre-stressed one-dimensional beam linear equation with linear and nonlinear stiffness and damping at its boundaries is investigated to explain experimental results. At low tension the squared natural frequency rapidly increases with tension. As the bolt is gradually tightened the squared frequency starts changing approximately linearly with tension [1]. At low tension the damping ratio decreases rapidly with tension and then starts slowly decreasing for higher tension. A mathematical beam model with linear/nonlinear stiffness and damping at its boundaries is used to explain the experimental results.

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Fault diagnosis by using a fractional order derivative

Tue.
15:00–15:20
R E. Delacroix

J. Laurila[1], S. Lahdelma[1], G. Litak[2,3], J. Juuti[3]

[1] *Faculty of Technology, University of Oulu, Finland*
[2] *Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, Poland*
[3] *Faculty of Information Technology and Electrical Engineering, University of Oulu, Finland*

We propose to apply a fractional order derivative to detect faults in the time series. The most popular way of machine fault diagnosis is based on the studies of the responses of dynamical systems. In this aim one could identify the phase states. A natural way of the phase space reconstruction of a dynamical system is to define phase coordinates through higher order derivatives of the measured system response signal. They span the phase space. However not every coordinate is sensitive to faults such as unbalance, mechanical looseness, misalignment, damaged roller bearings, and others. Therefore, to reveal information about faults one can project the phase by choosing a most sensitive coordinate-derivative. Our analysis based on signal from bearing faults (see the experimental standing in Fig. 1) show that the most sensitive derivative could be of a fractional order. To support this conjecture we used several features including rms, kurtosis and recurrence rate. For better illustration and quantification of the output signal we used a concept of complex derivative $x^{(z)}$, where $z = \alpha + \beta i$ is a complex number.

MS 8
Nonlinear dynamics in spatially extended systems

Organizers: *M. Tlidi* Belgium

Scheduled:

Tuesday *14:00–15:40* Royal Tulip **Room Henri Matisse 1**

Natural convection in a horizontal porous annulus under quasi-periodic gravitational modulation

Tue.
14:00-14:20
H. Matisse 1

J. Belabid[1], K. Allali[2], M. Belhaq[3]

[1] *Royal Navy School, Sour Jdid Boulevard, Casablanca, Morroco*
[2] *University Hassan II-Casablanca, FSTM, Department of Mathematics, Morocco*
[3] *University Hassan II-Casablanca, Casablanca, Morocco*

The quasi-periodic gravitational modulation effect on natural convection in a horizontal porous annulus is studied in this paper. The model we consider includes the heat equation, the equation for the concentration and the hydrodynamics equations under Darcy law. The derived model with the stream function is solved numerically using the alternate direction implicite method. Numerical results shown that the convective instability depends on the quasi-periodic gravitational modulation frequencies ratio.

Mathematical modelling of the interplay between secondary melanoma to and the immune response in the lymph node

Tue.
14:20–14:40
R H. Matisse 1

M.A. Benchaib[1], A. Bouchnita[4], V. Volpert[2,3], A. Makhoute[1], M. Tlidi[5]

[1] *Université Moulay Ismail, Faculté des Sciences, Meknes, Marocco*
[2] *Institut Camille Jordan, University Lyon 1, Villeurbanne, France*
[3] *Institute of Numerical Mathematics, Russian Academy of Sciences, Moscow, Russia*
[4] *Department of Information Technology, Uppsala University, Uppsala, Sweden*
[5] *ULB Sciences, Département de Physique, Campus Plaine, Bruxelles, Belgium*

In the advanced stages of melanoma, some of the malignant melanocytes leave the tumor and home to neighbouring lymph nodes. The interaction between secondary melanoma in the lymph nodes and the immune response represents a complex phenomenon that needs to be fully understood in order to develop more effective immunotherapeutic startegies. In this context, dentritic cells infiltrate tumors and initiate the appropriate immune reponse for each tumor antigen. They stimulate the CD4+ and CD8+ T-cells which subsquently generate a population of helper and effector T-cells. The latter eliminate tumor cells using cell-cell contact and by secreting apoptosis inducing cytokines. On the other side, the tumor cells are able to limit the activity of T-cells using their immunosuppressive abilities. To investigate the interplay between tumor progres-

sion and the immune reponse, we develop a novel hybrid discrete-continuous model. In this models, two subtypes of cells are considered: tumor cells and the immune cells. Each cell is represented by an individual object that can move, divide, die and interact with its environment depending the different set of rules and levels of regulation. Continuous models are used to describe the intracellular and extracellular regulation of cells. We use the model to show the existence of three possible scenarios of cancer development: tumor elimination, surveillance, and escape. We developped a continious model also to compare results with our hybrid model. All simulations are done using both models. The main objectif of this work is the proof of the existence of the three interaction regimes.

The dynamics of HIV infection model with logistic growth and infected cells in eclipse phase

Tue.
14:40-15:00
R H. Matisse 1

S. Harroudi[1], K. Allali[2]

FSTM University Hassan II of Casablanca, Mohammedia, Morocco

In this paper, we study a mathematical model of human immunodeficiency virus dynamics with logistic growth and infected cells in eclipse phase. This model describes the interactions between uninfected CD4+ T cells, infected CD4+ T cells in latent stage, productively infected CD4+ T cells and free virus. The local stability of endemic equilibrium is proved and numerical simulations are also provided.

Self-organization of vegetation in semiarid ecosystems: interaction-redistribution model in the case of the Alfa (Stipa Tenacissima L.)

Tue.
15:00–15:20
R H. Matisse 1

M. Messaoudi[1], M. Khaffou[1], M. Tlidi[2], A. Makhoute[1]

[1] *UMI Sciences, Physique des Rayonnements et des interactions laser-matière, Meknès, Maroc*
[2] *ULB Sciences, Département de Physique, Campus Plaine, Bruxelles, Belgium*

We present a generic interaction-redistribution model [1] that focuses on facilitative and the competitive interactions between individual plants that are responsible for the formation of periodic vegetation patterns. In addition, we study the effect of the allometric factor on the biomass of vegetation and the formation of gap structures. When the level of the aridity increases, the uniformly vegetated cover undergoes isolated or randomly distributed vegetation spots.

Numerical spectral method to solve a nonlinear dynamical problem in heat and mass transfer: mixed convection MHD oscillatory nanofluid flow

Tue.
15:20–15:40
R H. Matisse 1

A. Wakif, Z. Boulahia, R. Sehaqui

Hassan II University, Faculty of Sciences Aïn Chock, Casablanca, Morocco

In this paper, we study numerically the unsteady mixed convection oscillatory nanofluid flow in the presence of a uniform transverse magnetic field, in the case where the flow is established vertically between two parallel plates. The governing nonlinear differential equations of the present problem are obtained by considering the Buongiorno's mathematical model, which takes into account the Brownian motion and thermophoresis effects. In this investigation, we assume that the studied nanofluid is electrically conducting and has a Newtonian behavior .The nonlinear dynamical system of partial differential equations obtained in this study constitutes an initial boundary value problem ,which is solved numerically by means of the Gear Chebyshev Gauss Lobatto collocation technique for zero nanoparticle flux and no slip impermeable conditions at the isothermal vertical plates bounding the nanofluid flow .The effects of major parameters on the dimensionless velocity, temperature and nanoparticle volume fraction are analyzed numerically via representative profiles of these variables, whereas the skin friction factor and the heat transfer rate are estimated numerically and their effective values are tabulated for different controlling parameters.

MS 9
Nonlinear PDEs and their dynamics

Organizers: *A. Azouani* Morocco, *B. Fiedler* Germany

Scheduled:

Tuesday	*16:20-18:00*	Royal Tulip	**Room Eugène Delacroix**

Flageolet harmonics on stringed instruments: the myth of the linear wave equation

Tue.
16:20-16:40
R E. Delacroix

B. Fiedler
Institute of Mathematics Free University of Berlin

Flageolet is a common technique to elicit harmonics on stringed instruments like guitars, pianos, and the violin family: the bowed or plucked string is subdivided, rationally, by just a slight touch of the finger. The standard second order wave equation of the vibrating string fails to model this phenomenon. The Dirichlet boundary condition at the finger uncouples the two parts of the string and produces tones different from the actual ageolet. Based on practical demonstrations we discuss string stiffness as a possible source for the ageolet phenomenon.

Fourier transform resolution for time-dependent linear partial differential equations with higher time order

Tue.
16:40-17:00
R E. Delacroix

M. Addam
ENSAH, Université Mohamed 1, Al Hoceima, Maroc

Let $\Omega \subset R^d$ be an open bounded domain where $d = 1$ or 2 and $[0, T]$ be a time domain where T is a time period. Let $\phi(x, t)$ be a function density at the position $x \in \overline{\Omega}$ and at the time $t \in [0, T]$. We consider the dynamical model for the density reconstruction. The density $\phi(x, t)$ was satisfied the following sth-time order partial differential equation (PDE)

$$u(x)\frac{\partial^s \phi}{\partial t^s}(x, t) - \nabla.(\kappa(x)\nabla\phi)(x, t) + \varrho(x)\phi(x, t) = f(x, t), \tag{9.1}$$

for all $(x, t) \in]a, b[\times[0, T]$ and $s \geq 1$ where μ is the evolution potential, κ is the diffusion coefficient and ϱ is the absorption coefficient.
We consider the non-homogenous boundary conditions given as

$$\beta(\xi)\phi(\xi, t) + \kappa(\xi)\frac{\partial\phi}{\partial\vec{n}}(\xi, t) = g(\xi, t), \forall(\xi, t) \in \partial\Omega \times [0, T], \tag{9.2}$$

where $\frac{\partial\phi}{\partial\vec{n}}(\xi, t) = \vec{n}.\nabla\phi(\xi, t)$ is the outward unit normal at the position ξ.

The parameters μ, κ and ϱ are bounded positives functions in $L^{\propto}(\Omega)$. There is a constants $\mu_1, \mu_2, \varrho_1, \varrho_2, \kappa_1$ and κ_2 such that

$$0 < \mu_1 \leq \mu(x) \leq \mu_2, 0 < \kappa_1 \leq \kappa(x) \leq \kappa_2, 0 < \varrho_1 \leq \varrho(x) \leq \varrho_2 \tag{9.3}$$

for all $x \in \overline{\Omega}$.
Here, we use the frequency domain method based on the Fourier transform, which leads to an intermediate differential equation in the frequency-domain. The subject of the frequency-domain approach is to simplify the time variable into frequency variable. Since the discretization of the time-variable using the finite difference scheme become very difficult in the cases for a large derivatives values s of time variable. Let p be the sampling number of the time knots points $(t_n)_{0\leq n\leq p}$ in time interval $[0, T]$ and $\Delta t = t_{n+1} - t_n$ be the uniform size distance relatively to the given time knots points In the literature, the Authors use the difference discrete notation $D^s_{\Delta t}$ to implement the operator $\frac{\partial^s}{\partial t^s}$ which imply the following discrete formula:
for $s = 1$, we have $D_{\Delta t}\phi = \frac{\phi^{n+1}-\phi^n}{\Delta t}$,
for $s = 2$, we have $D^2_{\Delta t}\phi = \frac{\phi^{n+1}-2\phi^n-\phi^{n-1}}{\Delta t^2}$, but where is the discrete formula $D^s_{\Delta t}\phi$ for large values of the operations time-order s.
So, the intermediate differential equation in the frequency-domain is solved by using Spline finite element Galerkin method. The Gauss-Hermite quadrature method is also used as computational technique to compute the time- domain solution as an inverse Fourier transform of the numerical solution in frequency-domain with respect to the time variable.

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Eigenvalue problems for $p(x)$-Kirchhoff-type equations with neumann boundary conditions

Tue.
17:00-17:20
R E. Delacroix

Z. El Allali, S. Taarabti, K. Ben Haddouch[3]
Department of Mathematics and Computer Sciences, University of Mohamed First, Oujda Morocco

This work is concerned with the existence of nontrivial weak solutions for a p(x)-Kirchhoff-type equation with Neumann boundary conditions. By using the Mountain Pass Theorem of Ambrosetti and Rabinowitz, Ekelands variational principle and the theory of the variable exponent Sobolev spaces, we establish the conditions for the existence of weak solutions.

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Blow up of p-Laplacian type heat equation with nonlinear source term

Tue.
17:20-17:40
R E. Delacroix

A. Azouani[1,2], Y. Abouelhanoune[3]

[1] *Mohemed Premier University, School of Applied Sciences Al Hoceima, Morocco*
[2] *Freie Universitat Berlin, Institute fur Mathematik I, Arnimallee 7, Berlin, Germany*
[3] *Faculty of Science and Technology Tangier, Tangier, Morocco*

The purpose of this work is to study the blow up behavior of the nonlinear heat propagation in a reactive medium with nonlinear source term

$$u_t = \Delta_p u + |u|^{q-1}\, u; \qquad x \in \mathbf{R}^N \tag{9.4}$$

where $p,\ q > 2$ and $\Delta_p u = \text{div}(|\nabla u|^{p-2}\nabla u)$ is the well known nonlinear p-laplacian operator. Our contribution is an extension of the work of Georgi [1] who considered the problem of the existence of solutions which approach the steady state solution in the strong stable manifold with some exponential rate. We apply the index theory techniques after reducing the problem to finite dimensional one to show the shape of the profiles exhibiting blow-up solutions for compatible boundary condition.

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Poster presentations

Posters Session: listed by alphabetical orders

Scheduled:

Tuesday	*15:40–16:20*	Royal Tulip Hotel
Wednesday	*10:00–10:30*	Royal Tulip Hotel

Influence of vibrations on the convective instability of a polymerization front

K. Allali, Y. Joundy, A. Taik

FSTM, Laboratory of Mathematics & Applications , University Hassan II-Casablanca, Morocco

This work is devoted to the influence of vibrations on the polymerization fronts. Vibrations are known to be among the most effective ways to affect the behavior of a fluid. Periodic oscillations of the container containing the reaction system may influence the convective instability. To study the influence of vibrations on the instability of a polymerization front, we impose a harmonic oscillation of frequency σ and λ amplitude according to the vertical direction on the container containing the liquid monomer and the solid polymer. This oscillation causes a periodic acceleration, $b(t)$, perpendicular to the liquid-solid interface. The time dependence of the instantaneous acceleration acting on the fluids is then given by $g + b(t)$, where $b(t) = gsin(t)$. We will use the Boussinesq approximation, which takes into account the dependence of density as a function of temperature only on volumetric forces. The numerical scheme is based on the meshless method (RBFM). Linear stability analysis of the problem is fulfilled, and the convective instability boundary is found depending on the amplitude and on the frequency of vibrations.

Linear modeling of 3D flexural vibrations of spinning Rayleigh beams

M.A. Aouadi , F. Lakrad

Faculty of Sciences Ain Chock University Hassan II Casablanca, Morocco

Literature survey of spinning beams works reveals the existence of various and confusing linear models. The main differences between these models come from the used assumptions, especially: (1) the used beam theory (Euler-Bernoulli, Rayleigh or Timoshenko); (2) the used reference frame (rotating or inertial) where equations are expressed; (3) the axis of spinning (fixed or relative); (4) the spinning velocity (constant or variable); and (5) the linearization scheme.

The present work investigates four linear models and discusses the effects of the linearization stage on the mathematical modeling of 3D bending vibrations of a spinning Rayleigh beam along its longitudinal axis. The spinning velocity is time dependent and equations are expressed either on the rotating or the inertial frames. It is shown that the linearization scheme influences centrifugal and Euler forces terms. Furthermore, it

is proven that the linear equations of 3D flexural vibrations of spinning Euler Bernoulli beams are independent of the linearization scheme. The outcome of these four approaches when applied to various beams boundary conditions reveals that differences in natural frequencies and critical speeds are increasing for high spinning velocities and low slenderness parameter.

Two models of atomic force microscopes subject to low frequency harmonic excitations

S. Baghdadi, F. Lakrad

Faculty of Sciences Ain Chock University Hassan II Casablanca, Morocco

Two models of atomic force microscopy (AFM) system, subject to a low harmonic frequency displacement of its base, are studied. The interactions between the AFM's cantilever tip and a sample are modeled by the Lennard-Jones forces and by the Derjaguin -Muller -Toporov (DMT) forces in the first and the second models respectively. The Galerkin method is used to obtain a fast-slow reduced order model. The invariant slow manifolds are approximated and their bifurcations are investigated. Chart of behaviors of different modes of the AFM are determined.

Numerical modeling of natural convection in a square cavity filled with nanofluid using a several types of boundary conditions

A. Bendaraa, M.M. Charafi, A. Hasnaoui

LS3M, Faculté Polydisciplinaire de Khouribga, Univ. Hassan 1, Morocco

In this work, we present a two-dimensional study based on the Finite Difference (FD) method, capable of supporting several mesh spacings. This study consists of unraveling the problem of natural convection in a partially heated cavity filled with Nanofluid (Nf) based on copper (Cu) nanoparticles. The governing equations are the Navier-Stokes equations expressed in their "Vorticity-Stream Function" formulation. The numerical modeling of the system of equations by the (FD) method has allowed us to develop a computation code which can support several cases, driven wall cavity, cavity controlled by a temperature gradient, and variable sources of temperature. Without neglecting all types of boundary conditions "Sinusoidal conditions, Dirichlet, Neumann and Newton's mixed conditions". In addition to that, our code can effectively dissect the problems of pure fluids and Nanofluids. To support all of this cases we refine our code using the Upwind scheme method to control the stability of our scheme. Subsequently, we have to perform numerical simulations based on Grashof number (Gr) ranging from 103 to 106; we evaluate the results for several values of the volume fraction between 0% and 20% in order to see the influence of this property on the temperature profile as well as the streamlines in our configuration. This work has been validated by comparing our results with simulations made in the COMSOL Multiphysics environment as well as with previous works presented in the literature, the use of our calculation code served as a tool of verification and visualization of results, and he showed a great precision, which summarizes the fineness of our code resulting from this method of calculation.

Numerical analysis of the static behavior of a rockfill dam

N. Bouhouche, B. Gourine

Centre des of spatial technics, Algeria

The safety of rockfill dams does not only depend on proper design and proper construction, but also on monitoring actual behavior, not only during construction and impoundment, but throughout the entire period of time. operation of the work. Monitoring with appropriate geodetic and geotechnical instrumentation provides a warning system for abnormal behavior of these dams. The comparison of deformation values calculated during the conception with the deformations measured using the monitoring instruments makes it possible to validate or re-evaluate the parameters used in the analyzes. Modelization of rockfill dams behavior is a complex process in which in we must consider the non-linear behavior of building materials, the interaction between the dam and the foundation soil and / or the bedrock, the influence of hydraulic load on the dam and on the foundation and the effects of saturation by water. The deformation process can be modeled using the finite element method (FEM). Among the many softwares based on the finite element method, ANSYS 15.0 is the one that makes the analysis of complex structures possible with fewer errors. The objectives assigned to this thematic are to establish a numerical analysis of dam deformation based on the finite element method (FEM) concept. A real dam was the subject of the application section which is the Altinkaya dam in Turkey ,his waterproofing is ensured by a central clay core. In order to determine the geometrical deformation of the Altinkaya dam, a monitoring network was set up. It is composed of six (06) reference points surrounding the dam area and eleven (11) target points distributed on its crest. The establishment of this network was done by GPS. All baselines were measured using static mode. The analysis of GPS movements of the survey network showed that the dam and the surrounding area have undergone horizontal and vertical displacements, during the different periods of observations that span two years (September 2000 - May 2002). The average modulus of the horizontal displacements at the points of auscultation (reference and target) is of the order of 10 mm at the maximum, during the different periods of observations. Generally, this displacement phenomenon (settlement) is the consequence of the effect of the self weight of the dam conjugated with the hydrostatic thrust, which is a normal behavior for a structure of this size.

Review on seismic behaviour of reinforced concrete frame with infill panels

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The non-linear behaviour of infilled frame under seismic loading is very complex, therefore; it is very difficult to predict it just by analytical models. Therefore, experimental studies are necessary to predict this behaviour. The presence of infill frame affects in a direct way, stiffness, strength, energy dissipation of the structure. In seismic zones, the interaction between the infill panels and bare frame influence the seismic response of the structure. The collapse of infilled reinforced concrete frames ex-posed to earthquake loading is caused in the most of the cases by the presence of infill panels and by the insufficiency of shear resisting capacity due to the lack of ductility and resistance of reinforced concrete bares. Finite element analysis can simulate the non-linear comportment of reinforced concrete elements of the model even if the non-linear response of each material has a complicated behaviour. The presence of the infill panels has an important effect on the behaviour of the bare frame; the infill alters the mechanical characteristic of the portico under seismic loading. Therefore, it is very important to know their behavior and their influence on bare frames. Many models had been proposed to understand the effect of the panels on structures. The aim of this work is to identify the effect of the presence of panels on bare frame. The diagonal stiffness and shear compression failure of the structure, the non-linear behavior of the infilled frame under axial loading and the relation between the strength, ductility and stress-strain of different previous experiments will be presented. Experimental research on the in-teraction between the steel frames and infill panels has been done to determine the behavior of steel frames with different types of infill walls. Many frames with composite panels subjected to cyclic-loading (seismic excitation) had been realized. The damping ratio, the static and dynamic response, strength and stiffness degradation of infill elements were determined. The objective of this paper is to represent and analyze the hysteretic behaviour (energy dissipation), failure modes, and the variation of different parameters of the infilled bare frame like stiffness, strength, ductility and loading displace-ment curves.

Suppression of chaos by a slow harmonic parametric excitation

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In the present work we show that small amplitudes of a slow harmonic parametric excitation may suppress chaos from large regions of control parameters. Hence, we study the chaotic dynamics caused by a resonant external harmonic excitation on a two degrees of freedom model of a shallow arch. This latter is exhibiting $1:1$ or $1:2$ internal resonances. Then, we investigate the ability of a small amplitude low frequency harmonic support displacement to suppress this chaos. It is found that the low frequency displacement can transform chaotic solutions to periodic bursting solutions for a large range of frequencies.

Global stability analysis of delay HIV model with satured infection rate

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The global dynamical behavior of delay HIV model with satured infection rate infection is investigated. We incorporate two discrete delays in the model to account for the intracellular delays in the production of productively infected cells and virus. We also derive the global properties of this two-delay model in function of the basic reproduction number R0. By using the Lyapunov functions, it is proved that the free-equilibrium point is globally asymptotically stable when R0 is smaller or equal to 1 and the endemic equilibrium point is globally asymptotically stable when R0 is greater or equal to 1. Finally, in order to support our theoretical findings we have illustrate the numerical simulations.

Acoustic Parameters of Materials BaO, CaO and SrO under high Pressure

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This work presents the effect of pressure on some mechanical parameters of the metal oxides: BaO, CaO, SrO, having the $NaCl$ structure and which can be transformed into CsC structure under the application of the high pressures. Using the theoretical technique via SAM (Scanning Acoustic Microscopy), we have determined the reflection coefficients $R(\theta)$. Next, we calculated the acoustic signatures $V(z)$ and their FFT treatments. Moreover, we calculated the Rayleigh velocity, VR, from the spatial periods, z. Finally, the influence of the pressure on the elastic moduli of Young, E, and that of shear, G was quantified according to the following equation:

$$M = M_0 + A_i P + A_j P^2$$

$M = E$ or G, M_0 is the elastic modulus at zero pressure, P means the pressure and A_i, A_j are the characterization constants.

Comparative response assessment of different frames with diagonal bracings under lateral loading

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In this study, nonlinear static analysis is performed to compare the structural response of two types of moment-resisting steel frames buildings: a) flexible Frame b) Rigid Frame with concentric diagonal braces under lateral loading. For this purpose, the existing moment-resisting frames designed according to two different stiffness levels were used as case studies. The buildings having 4 storeys consist of the same plan and three bays on both directions. Then, concentric steel braces were inserted in the middle bay of each frame. For the braced frame structures, diagonal type X configuration was utilized. The building considered in the actual study has been designed against seismic hazard according to the Moroccan code RPS2000. Capacity curve, inter-storey drift index, global damage index, Pushover curve (variation of storey displacements with height, roof displacement time history, and plastification in the frame members were evaluated for all frame systems. finally results of performance point will be discussed.

Probabilistic study of the aerodynamic around a 3D wing

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Aerodynamics can be defined as the science that deals with the manipulation of interactions between air and a structure. During this manipulation and control, numerical simulation is used as a tool for predicting the phenomena encountered in these interactions. Although dispersion and uncertainty occur naturally in all aspects of an analysis and deterministic analyses do not take it into account. Optimization and probabilistic study are essential analyses for aerodynamic manufacturers to respond to various aeronautical issues. Optimization techniques using deterministic tools have been implemented and applied at many levels, but these do not take into account any uncertain parameters. Probabilistic characterization quantifies the reliability or quality of the product by means of a statistical analysis. It combines the deterministic characterization with statistical analysis tools to address the effect of statistical variability and uncertainty influencing the products behavior. Probabilistic analysis typically involves four areas of statistical variability: the geometric shape, the material properties, the loading and the boundary conditions.

In this paper, we present the validation of a numerical simulation of a 3D transonic flow on the ONERA M6 wing for which the numerical results, realized with ANSYS FLUENT ľ, will be compared with the experimental data and the NASA CFD results. The pressure coefficient (Cp) along the surfaces of the upper and lower wing is given in the deterministic case. Then statistical distribution functions (such as Gaussian distribution, uniform distribution, etc.) are evaluated to describe the uncertain parameters relative to the fluid around the wing and determine the influence of the choose random quantities on the results of the aerodynamic analysis.

Bifurcations related to a $k\pi$ tangency in hysteretic systems of focus type

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Our goal is to study the existence of periodic orbits and their stability in two dimensional piecewise linear systems with hysteresis. We concentrate our attention on the symmetric case with equilibria of focus type. We are trying to analyze this case from a theoretical point of view in order to prove in a rigorous way the existence of chaotic behaviour. With that final objective, we start by studying simpler cases as is the existence of the so-called $k\pi$ -tangent orbits, where the position of the focus gives rise to an orbit which is tangent to both jumping lines after a certain number of half-turns around the focus. Different bifurcations of periodic orbits are detected.

A meshfree method for heat explosion problems with natural convection in inclined porous media

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This research work may be considered as a continuation of a series of investigations concerning the interaction between heat explosion and natural convection [3]. A meshless collocation method based on multiquadric radial basis functions has been applied to solve numerically the problem in an inclined two-dimensional porous media. The governing equations consist of coupling the Darcy equations in the Boussinesq approximation of low density variations to the heat equation with a nonlinear chemical source term. The numerical results obtained are in good agreement with some previous studies that consider the vertical direction [1, 2]. A complex behaviour of solutions is observed, including periodic and aperiodic oscillations. This shows that the proposed approach helps in describing the effect of the angle of inclination on thermal explosion problems with natural convection.

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Evaluation of wear and wheel tread damage impacts on railway wheelset lifetime

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In railway engineering, the estimation of the wear and damage at wheelset is an important field of study, mainly correlated to the planning of maintenance interventions and traffic safety. The evolution of profile shape deeply affects the dynamic characteristics of railway vehicles such as stability or passenger comfort and, in the worst cases, can cause a derailment. In this work, a review of the wheelset tread damage impacts on maintenance and traffic conditions is presented. The presence of defects or excessive wear on wheel tread enforces his reprofiling. Based on the tread brake wheels profile evolution due to reprofiling interventions, an estimation of a wheelset lifetime is exposed.

Energy harvesting using feedback-controlled van der Pol circuit

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This paper investigates energy harvesting performance in a feedback-controlled van der Pol electric circuit (FCvdPEC). The energy harvester is composed of a forced mechanical component coupled to an electromagnetic energy harvesting mechanism in which the feedback control is introduced in the van der Pol electric circuit. We perform that analysis near the primary resonance of the mechanical system and we use perturbation methods to approximate periodic and quasiperiodic responses and the corresponding averaged electric power amplitudes. The influence of different system parameters of FCvdPEC on the performance of the energy harvesting is examined. It is shown that for this a novel generation electrical power supply, the energy harvesting can be significantly improved at certain ranges of control parameters.

Investigation and design of continuous cow hair bio-composites against sudden loading of skull fractures

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A new bio-composite materials consist of continuous cow hair animal natural fiber and epoxy based resin were prepared by hand lay-up technique has been introduced for development the fracture properties of human skull. Three different weight fractions are respectively 5, 10, and 15 % wt of cow hair fiber were used. The impact fracture toughness and tensile properties were investigated and the effect of animal fiber fraction and orientation were analyzed. Scanning electron microscopy SEM examination were carried out. The skull bio-composite model was build up by ANSYS 16 software. The results indicated that the cow hair biocomposites fracture toughness properties is enhancement and the materials is a suitable chose for the development of skull properties against sudden loadings in comparison of traditional composite materials.

The hand-arm system vibrations: a theoretical model and experimental tests

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Vibrations are transmitted to the hand-arm system (HAS) by hand-held tools (e.g. demolition hammer, grinder, saw). The prolonged exposure of hand-arm system to mechanical vibrations can cause vascular, neurological and musculoskeletal disorders and diseases. In this work we present theoretical and experimental studies of the HAS vibrations. These studies are intended to determine the vibration transmissibility and the modal characteristics of the HAS. Thus, a new theoretical model of the HAS vibrations is developed and then compared to existing models in literature. Furthermore, experiments are conducted

to measure the transmissibility from the handle to the wrist and to the elbow. The effects of the HAS posture and its anthropometric characteristics on the vibration transmissibility are also investigated.

An improved method for bending analysis of skew thin plates having a variable stiffness

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The last three decades have witnessed a steady increase in the use of skew composite plates for structural applications. In addition to their excellent quasi-static mechanical properties such as high specific stiffness and strength, it has become essential for these composite structures to perform well under various types of loading. For example, skew plate structures play an important role as a sophisticated construction technique of bridges, as well as in aerospace industrydue to its obvious structural applications and commercial interest. The principal fibers in commercial use are various types of glass and carbon as well as Kevlar. Boron, aluminum oxide, silicon carbide and other ceramics are also employed in composite industry in limited quantities.
Fatigue strength as well as fatigue damage tolerance of fiber-reinforced composite laminated plates are excellent. For these reasons, these composite structures have emerged as a major class of structural materials substituting steel and aluminum alloys in many weight-critical components in aerospace, automotive, and other industries.This work has a broad scope and covers numerical approaches to understanding the response of continuous fibre-reinforced composites in skew composite plate with variable thickness. Bending of skew composite plate is governed by fourth-order partial differential equation with variable coefficient in w describing the transversal displacement of thin plates. The resolution of skew plates bending equation with variable thickness is about the same as for the rectangular plates. The solution of this equation can be treated by approximate and numerical methods such as, Finite Element Method, Boundary Element Methods, or Finite Difference Method. However, for simple geometries and for simple boundary conditions we can also found analytical solutions for bending problems of thin plates provided by many authors in the literature. In this work, a recent approach based on particular finite difference method developed on grids consisting of regular triangles. Thus, centered finite difference schemes on triangles are adapted to the geometry of the skew plate to obtain solutions that are more accurate.

Application of vectorcardiography and recurrence-based methods to analysis of ECG signals

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For many years, by far the greatest threat to the health and life all over the World are diseases of the circulatory system. The basic and most efficient tool used in cardiovascular diagnostic is ECG, which is so widespread that it is difficult to determine the exact number

of these tests performed each day. Despite the requirement for the efficient and reliable methods of ECG signals analysis and interpretation, in practice, almost exclusively, classical methods involving analysis of geometrical properties of the recorded waveforms in the time domain are used. The scientific works carried out recently have been focused on increasing the accuracy of ECG analysis by increasing the accuracy of finding its characteristic points. However, the accuracy limits of such a geometrical analysis have already been reached. Therefore the quest of formulating novel methods supporting classical analysis of ECG signals is still open.

In this work, in order to support classical methods of ECG analysis, vectocardiography and recurrence based methods have been used. The first method involves recording the direction and magnitude of the electrical forces of the heart by means of a continuous series of vectors that form a curving line around a center. The main idea of the second method consists in representing the ECG signals in the phase space and searching for the recurrence properties of the registered signals.

In both methods, change of analysis domain offers new, so far unreachable, opportunities for early diagnosis. In this work, discussed methods have been used for the purposes of analysis of selected ECG signals stored in the medical database The PTB Diagnostic ECG Database. Patients were selected form the group of male smoker after the age of 50. Vectocardiograms were determined on the basis of ECG signals for Farnk's leads. The further analysis was carried out with the application of the recurrence plots (RP) and RQA analysis methods. For the purposes of determining time delay mutual information function method was used. Minimal dimensions of the phase space m, making it possible to visualize the phase trajectory of the considered system, were established by means of the false nearest neighbours criterion.

Carried out research requires continuation and complementation by results of statistical analysis for various age groups and degrees of myocardial injury.

Magnetic and physical properties of the spinel CuGd2O4

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CuGd2O4 was synthesized by a nitrate route, crystallizes in the spinel structure. With metal cations distributed homogeneously throughout the matrix. The powder is calcined at tow times $600C$ and $900C$ for 3 hours for each temperature to ensure the insertion of the gadolinium and obtaining our pure phase. The oxide is a direct band-gap semiconductor with a forbidden band of $2.05eV$. The magnetic susceptibility follows a Curie-Weiss law from whicha Cu2+ concentration of 1% has been determined. The as-prepared powder of CuGd2O4 was characterized by X-ray diffraction, FT-IR, Scanning Electron Microscopy, Thermogravimetric analysis (TGA), and UV-Vis diffuse reflectance. The electrical conductivity was measured in the temperature range of 300-473 K. The photoelectrochemical study, performed for the first time for CuGd2O4, confirms p-type conduction. The flat band potential is determined by the mott-schottky relation. All these results give infor-

mation on the position of the valence band in the Cu-3d orbital. According to the band diagram the oxide will be possible to use as hydrogen photocathode.

Study of the vibrations of a circular thin disc

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In this paper the influence of circular saw blade rotational speed on its natural frequencies is investigated. First the results were obtained analytically for freely spinning circular saw blade and they are compared to those obtained using Finite Element Method. First analyses on vibrations of circular disks have been carried out by Lamb and Southwell in 1921 [1]. Also Southwell expanded the analysis on vibrations of freely spinning annular disks or disks which are clamped at center. Since then the application area has been widen from computer floppy or hard disks to turbines and circular saws [2] and [3]. The reason for that is to determine an influence of different parameters such as material, geometry, external loads, heat and rotational speed on vibrations and stability of disks. For example S. Nishio, E. Marui [4] studied the influence of slots on lateral vibrations of circular saw blade which can be approximated as centrally clamped circular disk. They've also investigated the influence of heat generated by cutting and rotational speed on vibrations of circular saw blade. In this study, based on plate theory and strain theory, the governing equation which describes the transverse vibrations of freely spinning circular disk is derived. The results obtained by this method are compared with results from analysis made using Finite Element Method. The influence of slot geometry on natural frequency and change of natural frequency versus rotational speed are also investigated.

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Effets des raidisseurs sur les modes propres d'une aile d'avion

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Some complex vibratory processes occur in the wings of aircrafts during their operation. These processes undergo the influence of several external factors including wind, shocks during landing and some abrupt manoeuvres. In order to decrease the ampleness of its undesirable effects on the wing, it is necessary to increase its rigidity and preserving its mass invariant. This work studies the structure of an airplane wing of aircraft, representing the predominant part that receives all the solicitations to which the device submitted. The purpose of this work is to determine eigen-frequencies and eigen-modes using the method of finite elements.

Dynamic delamination buckling of laminated composite stiffened curved panels under impact loading and detecting damage using lamb waves

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Laminated composite stiffened curved panels made from carbon fiber reinforced plastics (CFRP) are structures commonly used in aircraft. Up to 45% of the basic structure of the Boeing 787 consists of ground graphite-epoxy. The phenomenon of delamination may be of paramount importance when the manufactures of composite stiffened panels are concerned. In this study, the default effect the width Delamination on the dynamic buckling behavior of a composite stiffened panel is studied by implementing a numerical simulation. The common stiffened panels used in modern aircrafts have five blade-type stringers. The panel is fabricated with 8 layers and the stiffeners are made up of 16 layers, of equal thickness arranged in different orientations [1]. A complete description of the panel manufacture and dimensions can be found in [2]. Usually, these panels suffer from the presence of small lateral geometric imperfections and their strength is largely affected by the magnitudes of these defects. In this work, buckling analysis of stiffened composite panels is considered thought the nonlinear finite element modeling. The study of the effect of delamination on the dynamic buckling load capacity of such systems under the axial compression load and then a parametric study are performed to investigate the influence of delamination on size, orientation and the influence of the properties of the material. Lamb Wave fields with different glass-fiber reinforced with and without delamination are arranged. The propagation of Lamb waves in laminates and their interaction with delamination at different locations throughout the depth of the laminate is assigned to the analysis using the finite element method. The natural frequencies increase to a peak, then decrease by taking on the appearance of a half-sinusoidal arc. The dynamic analysis was performed with the Lanczos organ extract mode shapes and fundamental frequencies.

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New meshless approach for the simulation of elastic structure problems

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In this work, we present a new approach based on the meshless method interpolated by Radial Basis Functions RBFs for the simulation of elastic structure problems. The strong formulation of the problem allow us to avoid numerical integration, the mesh distortion and the tedious procedures of interrupting the analysis, performing rediscretization, mapping of current state variables and preparing the new set of boundary conditions. A study on the influence of radial function parameters (RBF) on the computation of elastic structures is provided.

Analysis of non symmetric FG sandwich plates under Thermo-mechanical loading using a novel shear deformation theory with stretching effect

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The analysis of non-symmetric functionally graded sandwich plates under thermo-mechanical loading is developed using a novel hyperbolic shear deformation theory and considering thickness stretching effects. This theory accounts for adequate distribution of the transverse shear strains in the thickness of the plate and satisfies the traction free boundary conditions on the top and bottom surface of the plates, thus a shear correction factor is not required. The governing equations of equilibrium of non symmetric functionally graded sandwich plates can be obtained using virtual work principle and the closed form solutions are obtained by using Navier technique. The accuracy of the present results is established by comparing those with well known trigonometric shear deformation theories. The results are presented for deflections and stresses of non-symmetric simply supported square plates.

Adjusted anisotropic strength model for meta-siltstones and prediction of UCS from indirect tensile tests

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Predictions of rock mass stability and load-bearing capacity of rocks should take into account the complicated non-uniformity and anisotropic strength properties which is one

of the most challenging issues in the field of rock mechanics. The direct determination of uniaxial compressive and tensile strength respecting test standards is difficult, time-consuming and requires high-quality core samples.
This paper presents an experimental investigation of anisotropic strength wich is a characteristic of volcano-sedimentary rocks,testing was used to establish the anisotropic behavior of selected meta-siltstone rocks. The effect of anisotropy on various mechanical tests (Uniaxial compressive strength, Brazilian and Point load tensile strength) was examined and their strengths were evaluated with respect to different schistosity angles, beta (i.e. $\beta = 0, 15, 30, 45, 60, 75$ and 90).
The results show that the anisotropic strength of studied meta-siltstones depend considerably on the angle between anisotropy planes and loading direction β, the maximum strength occur when the planes of anisotropy are oriented parallel to the direction of tensile load ($\beta = 0$), while the minimum tensile and compressive strengths correspond to the orientation ($\beta = 0$).
This study propose an adjusted anisotropic models of uniaxial compressive and indirect tensile strength (point-load and line-load) , the proposed expressions consist of three adjustment functions that show good agreement with experimental values and can predict the meta-siltstones strength more correctly. Based on the previous laboratory test results on meta-siltstone rock types, three practical correlations between indirect tensile and UCS test results with a low mean average percentage error were proposed.

Seismic design of buildings with base isolation systems to Eurocode 8

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The design of seismically isolated buildings in which the isolation system, incorporated below the main mass of the building structure, aims at absorbing the earthquake energy, through a decoupling the building structure from the damaging components of the earthquake input motion. Seismic isolation devices are the most widely made using laminated rubber (or elastomeric) bearings, for control of excessive base displacement. Lead rubber bearings and high damping rubber bearings are examples of this category of isolation system. The objective of the present work is to check the seismic performance of the base isolation of framed buildings when using Lead-Rubber Bearings (LRBs). To this end, a numerical investigation is carried out by isolating the fixed-base reinforced concrete reference building that was severely damaged during the 1980 Chlef earthquake, and designed according to the European seismic code (EC8). The nonlinear time history analysis was subjected to the artificial accelerograms generated so as to match the EC8 elastic response spectra. The results of the numerical investigation show that for the BI structures, the floor accelerations, interstory drifts and base shear are significantly and simultaneously reduced, therefore the performance of seismic isolation as an earthquake resistant design.

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