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Guest Editorial

Special issue on Geometrically non-linear vibrations of structures—EUROMECH 483

Vibrations with large amplitude displacements, i.e. geometrically non-linear vibrations, often emerge in structural dynamics. They occur in important applications, including aerospace and aeronautic engineering, biomechamics, bridge dynamics, micro-electromechanical devices, musical instruments, and rotating blades. With the development of computational and experimental capabilities, the field of geometrically non-linear vibrations of structures has known consistent progress over the last decades.

This issue is constituted by extended versions of some of the papers presented at the EUROMECH colloquium 483, *Geometrically non-linear vibrations of structures*, which was held at the Faculty of Engineering, University of Porto, Portugal, from 9 to 11 July 2007. The issue comprises 24 contributions, which give a picture of the current research in geometrically non-linear vibrations. Several aspects are addressed, including the following: vibrations of structural elements—cables, beams, plates, and shells; internal resonances; bifurcations; chaotic vibrations; vibration control; modal coupling; targeted energy transfer (TET) (energy pumping); and fluid structure interactions.

The first three papers are concerned with vibrations of cables. In the paper by A. Luongo, D. Zulli, and G. Piccardo, galloping instability, which is an aeroelastic instability, of a sagged suspended cable is tackled using a curved cable-beam model, geometrically non-linear and able to torque. Numerical and analytical approaches are employed and the role of torsion is investigated. In the second paper, by N. Srinil and G. Rega, finite differences are applied in space and time to investigate the geometrically non-linear forced dynamics of suspended cables, in order to validate analytical predictions based on the multiple scales method. The third paper is authored by L. Demeio and S. Lenci, and presents an asymptotic solution of a moving-boundary problem which describes the non-linear oscillations of semi-infinite cables resting on an elastic substrate, subjected to a constant distributed load and to a harmonic displacement applied to the finite boundary. Second-order terms in a small parameter are considered. This paper is not exactly in geometrically non-linear vibrations, since small vibration amplitudes are considered, but will be of interest to researchers on this field.

A railway catenary system consists of a contact and a messenger wire, droppers, supporting brackets, and registration arms. In the paper by Y. Cho, a finite element (FE) formulation for the pantograph-catenary dynamics, including a non-linear dropper model and contact is proposed. The wires are modelled using Euler–Bernoulli beam elements. After validation of the formulation, the dynamic responses of the catenary system to a moving pantograph are investigated. It is found that the increase of the uplift force applied to the pantograph can reduce the variation of the contact force, unless the wave reflection becomes a major cause for loss of contact. Stronger wave reflection at the dropper is found to cause larger variation of the force acting on the dropper. The properties of the dynamic strain on the contact wire are discussed.

The ensuing four papers involve vibration of beam structures. The paper by P. Barthels and J. Wauer addresses slidable systems of structural components with clearances. The system components are modelled as connected geometrically non-linear beams, with clearance in the contact areas. S. Rizzi and A. Przekop develop a procedure to choose a modal basis for reduced order non-linear simulation. The method employs

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proper orthogonal decomposition to identify non-linear system dynamics, and the modal assurance criterion to relate proper orthogonal modes to the normal modes used as the basis functions. The technique is applied to analyse a planar beam and a shallow arch. In the paper by J. Warminski, M. Cartmell, and M. Bochenski a coupled structure that forms an "L" shaped beam is analysed. The differential equations of motion and associated boundary conditions are given up to the third-order approximation. Results of preliminary experimental tests and numerical simulations for out of plane motion, modal interactions and their influence on the structure's response are presented. R. Bebiano, N. Silvestre, and D. Camotim study local-plate, distortional and global vibration behaviour of thin-walled steel channel members subjected to compression and/or non-uniform bending. A generalised beam theory (GBT) formulation, which takes into account the geometrically non-linear stiffness reduction caused by the presence of (i) longitudinal stress gradients and (ii) the ensuing shear stresses, is employed. The effect of the applied load and bending moment gradient on the vibration behaviour of the loaded members is analysed. The work is of interest to this issue because the geometrically non-linear effects that stem from the presence of applied loads are considered, but the vibrations analysed are small amplitude.

S. Stoykov and P. Ribeiro study the free vibrations of clamped circular plates using a multidegree of freedom (mdof) model that accounts for symmetric and antisymmetric modes. The principle of virtual work and an expansion with hierarchical sets of spatial functions are employed to obtain the ordinary differential equations of motion, which are transformed into algebraic equations by the harmonic balance method. Internal resonances are found and multimodal oscillations described. H. Park and W. Lee re-investigate the asymmetric vibrations of a clamped circular plate under a harmonic excitation, where the frequency of excitation is near one of the natural frequencies. The authors discover that there exist at most five stable steady-state responses: one standing wave and four travelling waves. Two of the travelling waves lose their stability by Hopf bifurcations and experience a sequence of period-doubling bifurcations leading to chaos. The basin boundaries of the attractors are examined.

The first work on rectangular plates is by O. Thomas and S. Bilbao, and is devoted to the analysis of properties of the von Kármán equations. An intrinsic formulation of the local partial differential equations in terms of the transverse displacement and an Airy stress function as unknowns is provided. Classical homogeneous boundary conditions are defined in terms of the Airy stress function in the case of a boundary of arbitrary geometry. A property, thought to be important for some energy conserving numerical schemes and called "triple self-adjointness", is derived. E. Manoach and I. Trendafilova study the sensitivity of non-linear vibration response parameters to the presence of damage. The geometrically non-linear version of the Mindlin plate theory is used and damage is represented as a stiffness reduction in a small area of the plate. Damage influences the vibration response, as shown by the time-history diagrams and in the Poincaré maps. A criterion and a damage index for detecting the presence and the location of the damage are proposed.

S. Maruyama, K. Nagai, and Y. Tsuruta present experimental and numerical results on chaotic vibrations of a shallow double-curved open shell subjected to gravity and periodic excitation. Modal interactions in the chaotic responses are discussed. In the experiments, time histories of the chaotic responses at spatial multiple positions of the shell-panel are measured to examine modal interactions. The Donnell–Mushtari–Vlasov theory and the Bobnov–Galerkin procedure are applied to obtain ordinary differential equations of motion. Periodic responses are calculated by the harmonic balance method and chaotic responses are obtained numerically. P. Ribeiro and E. Jansen analyse the vibrations of open composite laminated shallow shells under the simultaneous action of thermal fields and mechanical excitations. A model based on an efficient p-version first-order shear deformation FE, with hierarchical basis functions, is employed. Parametric studies are carried out in order to study the influence of temperature change, initial curvature, panel thickness and fibre orientation on the shells dynamics. P. Gonçalves, F. Silva, and Z. Prado discuss the derivation of discrete low-dimensional models for the non-linear vibration analysis of thin cylindrical shells. Donnell's non-linear shallow shell theory is followed and a perturbation procedure is used to derive an expression for the non-linear vibration modes. The discretized equations of motion are obtained by the Galerkin method and the model is reduced via the Karhunen–Loève expansion. The relative importance of each mode is investigated and it is proposed that rather low-dimensional models can describe with good accuracy the response of the shell up to large vibration amplitudes.

O. Bendiksen and G. Seber consider non-linear aeroelastic stability problems, where geometric non-linearities in the structure interact with aerodynamic non-linearities caused by moving shocks. Examples include transonic panel flutter and flutter of transonic wings. Neglecting either the structural or the fluid non-linearities can lead to completely erroneous stability predictions in these non-linear fluid–structure problems. The results presented illustrate the rich flutter behaviours of transonic wings, and the limitations of the von Kármán plate model in strongly non-linear fluid–structure interaction problems of this type.

M. Keber and M. Wiercigroch investigate the effect of structural non-linearity on the dynamical behaviour of a vertical offshore riser subjected to vortex-induced vibration. The riser dynamics is coupled with the flow of the surrounding fluid by attaching a wake oscillator to a reduced model of the structure. By comparing the free responses of the linear and the non-linear structures, it is found that the structural non-linearity has a stiffening effect on the oscillation of the riser, which becomes more pronounced when the internal flow is incorporated into the model.

The following group of papers is devoted to vibration isolation. When a mass is supported by a vertical linear spring on a rigid foundation the lower the static stiffness, the wider the region where the isolator provides efficient vibration attenuation. However, low static stiffness causes a large static deflection. I. Kovacic, M. Brennan, and T. Waters advocate adding two non-linear pre-stressed oblique springs in order to improve the static characteristics of a mechanism, simultaneously producing a smaller stiffness at larger displacements. The device is a type of quasi-zero stiffness (QZS) mechanism, designation applied because of the potential capacity of reaching zero dynamic stiffness. A dynamical analysis of the isolator is performed to quantify the undesirable effects of the non-linearities and chaotic behaviour is found. The following paper is also concerned with improving the efficiency of a vibration isolator. The solution studied by A. Carrella, M. Brennan, and T. Waters consists in incorporating a negative stiffness element in the isolator, such that the dynamic stiffness is much less than the static stiffness. The device is referred to as a high-static-low-dynamic-stiffness (HSLDS) mount, which is also a QZS mechanism. A theoretical and experimental study is carried out. Although the HSLDS suspension system is non-linear, it is advocated that for small oscillations it can be considered to be linear. L. Virgin, S. Santillan, and R. Plaut use a highly deformed, slender beam, to reduce the motion of a supported mass. The slender beam, or strip, is bent so that the two ends are clamped together, forming a loop. A study of the equilibrium shapes of this loop with varying static loads and lengths reveals a large degree of stiffness tunability. Experiments using polycarbonate strips are conducted to verify equilibrium and dynamic behaviour.

The TET in a two dof system consisting of primary linear oscillator and a non-linear energy sink (NES) with non-polynomial potential is analysed by O. Gendelman. It is demonstrated that a technique designated as ''complexification—averaging'' can be extended to these cases. The procedure is illustrated by examples involving softening (non-polynomial) and piecewise—linear (non-analytic) NES. O. Gendelman and Y. Starosvetsky also investigate a linear oscillator with an attached NES, considering external forcing near the main resonance. Local bifurcations of the periodic regimes are described. An analytical approach to predict strongly modulated response is presented. Possibilities of coexistence of distinct response regimes are predicted analytically and demonstrated numerically.

Stabilisation control methods for non-linear phenomena and utilizations of non-linear phenomena for amplitude and motion control are discussed by H. Yabuno. It is indicated that slowly varying components in the dynamics play important roles. Focusing on these components, stabilization control methods for two non-linear phenomena are dealt with. Afterwards, the amplitude control of the cantilever probe of an atomic force microscope is proposed by increasing the non-linearity in the system. Also, the motion control of a two link manipulator with a free link and an active link is considered by controlling bifurcations produced under high-frequency excitation. The issue closes with a paper of J. Sieber and B. Krauskopf about hybrid testing. This type of testing couples physical experiments and computer simulations bidirectionally and in real time. The delays in the coupling between simulation and experiment are discussed for a pendulum that is vertically excited by coupling it to a simulated linear mass–spring–damper system. A small delay in the coupling can give rise to an essential instability. To overcome this, the authors introduce an approach based on feedback control and Newton iterations.

As a final word, we would like to thank all those who helped to turn the EUROMECH colloquium 483 a success, the authors of the papers in this special issue and the referees. A grateful acknowledgment is also due to Mrs. Marjorie Hookham and to Professor Christopher Morfey for their assistance in the creation of this issue.

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