Introduction. Experimental nonlinear dynamics of solids

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Nearly six decades ago, Stoker in the introduction to his seminal book on nonlinear vibrations (Stoker 1950) pointed out, 'It is perhaps worth while to consider for a moment the reasons why one should be interested particularly in the nonlinear problems in mechanics. Basically the reason is, of course, that all of the problems in mechanics are nonlinear from the outset, and the linearizations commonly practiced are an approximating device which is often a confession of defeat in the challenge presented by nonlinear problems as such'. This powerful statement is echoed in the celebrated book on nonlinear oscillators (Andronov et al. 1966), which provides a very comprehensive source of the theoretical foundations and applications in the area of nonlinear oscillations. The concepts of slow and fast oscillations, small and large terms in solutions, and periodicity have been clearly introduced in this book by solving various dynamical problems. In more recent works (Guckenheimer & Holmes 1983; Thompson & Stewart 1986), one can find a systematic approach to model and analyse nonlinear systems exhibiting chaos.

Since the invention of digital computers, the interest in the area of nonlinear mechanics, and nonlinear dynamics in particular, has grown nearly in an exponential manner. Currently, we have in excess of 40 journals that publish nonlinear dynamics results. However, there is a huge disproportion between numbers of theoretical and experimental papers. A very conservative estimate would account for approximately 5% of experimental articles. Experiments are vital to confirm new theories, make viable predictions and ultimately to establish firm foundations for developments in science and technology.

The main aim of arranging and compiling this theme is to perhaps address in a small but powerful way the misbalance mentioned above. The theme comprising a total of 12 papers has two issues, ‘Experimental nonlinear dynamics I. Solids’ and ‘Experimental nonlinear dynamics II. Fluids’.

This issue comprises seven contributions written by world experts in the area of nonlinear and chaotic dynamics, who undertake experimental studies. The selection of papers was chosen to reflect the active research areas of experimental nonlinear dynamics of solids.

The issue is opened with a paper by Ing et al. (2008), where extensive experimental investigations of an impact oscillator with one-sided elastic
constraint are undertaken. These studies are focused on the experimental stability analysis discussing the bifurcation scenarios near grazing. The mass acceleration is used to effectively detect grazing incidence with the secondary spring. The most typical recorded scenario is when a non-impacting periodic orbit bifurcates into an impacting one through the grazing mechanism. The resulting orbit can be stable, but in many cases it loses stability. The evolution of the attractor is governed by a complex interplay between smooth and non-smooth bifurcations, where in some cases the occurrence of coexisting attractors is manifested through discontinuous transition from one orbit to another through boundary crisis. The stability of non-impacting and impacting period-1 orbits is then studied using a newly proposed experimental procedure. The results are compared with the theoretical predictions obtained from standard theoretical stability analysis, and a good correspondence between them is shown for different stiffness ratios.

Green et al. (2008) investigates dynamics of a multi-ball, automatic dynamic balancing mechanism for eccentric rotors. In the paper an analytical and experimental investigation is applied into the dynamics of an automatic dynamic balancer (ADB) designed to quench vibration in eccentric rotors. This fundamentally nonlinear device incorporates several balancing masses that are free to rotate in a circumferentially mounted ball race. An earlier study into the steady state and transient response of the device with two balls is extended to the case of an arbitrary number of balls. Using bifurcation analysis allied to numerical simulation of a fully nonlinear model, the question is addressed of whether increasing the number of balls is advantageous. It is found that it is never possible to perfectly balance the device at rotation speeds comparable with or below the first natural bending frequency of the rotor. When considering practical implementation of the device, a modification is suggested where individual balls are contained in separate arcs of the ball race, with rigid partitions separating each arc. Simulation results for a partitioned ADB are compared to those from an experimental rig. A close qualitative and quantitative match is found between the theory and experiment, confirming that for sub-resonant rotation speeds, the ADB at best makes no difference to the imbalance and can make things substantially worse.

In the paper on ‘Reconstructing slow-time dynamics from fast-time measurements’, Chelidze & Liu (2008) consider a dynamical system subjected to damage evolution in variable operating conditions to illustrate the reconstruction of slow-time (damage) dynamics using fast-time (vibration) measurements. Working in the reconstructed fast-time phase space, phase space warping-based feature vectors are constructed for slow-time damage identification. A subspace of the feature space corresponding to the changes in the operating conditions is identified by applying smooth orthogonal decomposition (SOD) to the initial set of feature vectors. Damage trajectory is then reconstructed by applying SOD to the feature subspace not related to the changes in the operating conditions. The theory is validated experimentally using a vibrating beam, with a variable nonlinear potential field subjected to fatigue damage. It is shown that the changes in the operating condition (or the potential field) can be successfully separated from the changes caused by damage (or fatigue) accumulation and SOD can identify the slow-time damage trajectory.

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The next article by Wojewoda et al. (2008) reviews the hysteretic effects of dry friction and their influence on dynamics of mechanical systems. In particular, the phenomena associated with the hysteretic behaviour of friction force observed in experiments such as non-reversibility, frictional memory, contact compliance, varying break-away force and Stribeck effect are discussed. These phenomena demonstrate the complexity and difficulty of dry friction description and modelling. In the paper, a new friction classification is proposed; a frictional characteristics can be classified into a group either insensitive or sensitive on the system dynamics. On the basis of the reported experimental results, a simple but robust friction model is proposed. It enables to simulate with a good accuracy various frictional phenomena including contact compliance, frictional memory, non-reversibility, varying break-away force and Stribeck effect.

The paper by the late Prof. Karl Popp and his co-workers (Kröger et al. 2008) discusses the experimental investigation to avoid self-excited vibrations caused by stick-slip phenomenon in mechanical systems. First, the main excitation mechanisms, including decreasing friction force characteristics as a function of the sliding velocity, fluctuating normal loads and various geometrical effects, are explained. Then, the practical relevance of self-excited friction-induced vibrations is shown through three example systems, namely an axial seal, a tread block of a tyre and a disc brake. The main focus of this work to acquire a good understanding of the excitation mechanisms is to introduce robust design countermeasures, which are important to solve practical problems. Finally, passive and active subsystems are proposed and validated experimentally.

Transient tumbling chaos and damping identification for parametric pendulum are investigated by Horton et al. (2008). The main aim of this study is to provide a simple, yet effective and generally applicable technique for determining a damping for a parametric pendulum. The proposed model is more representative of system dynamics because the numerical results well describe the qualitative features of experimentally exhibited transient tumbling chaotic motions. The assumption is made that the system is accurately modelled by linear viscous and Coulomb damping and a parameter identification procedure is developed from this basis. The results of numerical and experimental time history of free oscillations are compared with the model produced from parameters identified by the classical logarithmic decrement technique. The merits of the present method are discussed before the model is verified against experimental results, which incorporate parametric forcing. Finally, emphasis is placed on the close corroboration between experimental and theoretical transient tumbling chaotic trajectories.

The issue on nonlinear dynamics of solids is closed with a paper on distributed friction damping of travelling wave vibration in rods by Tangpong et al. (2008). Depending on the frequency range, wavenumber and level of preload, vibration of the base structure can be effectively and passively attenuated by friction that develops along the interface between it and the damper. The assembly is modelled as two rods that couple in longitudinal vibration through spatially distributed hysteretic friction, with each rod having periodic boundary conditions in a manner analogous to an unwrapped ring and disc. The system is driven by a travelling wave disturbance, and for that form of excitation, the
responses of base structure and damper are determined without the need for computationally intensive simulation. The damper’s performance can be optimized with respect to normal preload, and its effectiveness is insensitive to variations in preload or the excitation’s magnitude when its natural frequency is substantially lower than that of the base structure in the absence of contact.

In closing this preface, I would like to express my thanks to the Editor, Prof. J. M. T. Thompson FRS for his support and encouragement. Of course, I am deeply grateful to all the authors and Dr Helen Ross, the publishing editor, for her patience and flexibility. At the end, I would like to reiterate the growing importance of nonlinear problems as more and more nonlinearities or nonlinear interactions are being deliberately used in science and technology.

References