Nonlinear Dynamic Phenomena in Mechanics

SOLID MECHANICS AND ITS APPLICATIONS
Volume 181

Series Editor: G.M.L. GLADWELL
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Waterloo, Ontario, Canada N2L 3GI

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Springer

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ISBN 978-94-007-2472-3
e-ISBN 978-94-007-2473-0

DOI 10.1007/978-94-007-2473-0

Library of Congress Control Number: 2011936650

Typeset & Cover Design: Scientific Publishing Services Pvt. Ltd., Chennai, India.

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

Preface

Nonlinear phenomena should play a crucial role in the design and control of engineering systems and structures as they can drastically change the prevailing dynamical responses. For example, bifurcations or transitions to irregularity (chaos) may completely alter intuitively expected behaviour. Dealing with nonlinear dynamic phenomena requires special analytical treatment and dedicated control techniques to harness the effects of unpredictable behaviour. In many cases, formulating an appropriate *nonlinear mathematical model* of a real structure or system would be essential to obtain a broad knowledge of the relevant response and the influence of its parameters.

Nonlinear mechanics is classical in origin, however its applications are modern and they are vast in science and engineering. In spite of the fact that linear models are in common use, in many practical problems certain key effects can be explained only by exploration of nonlinear models.

The origin of this book is a series of lectures given in the frame of the Transfer of Knowledge Project led by Prof. Tomasz Sadowski of Lublin University of Technology on 'Modern Composite Materials Applied in Aerospace, Civil and Sanitary Engineering: Theoretical Modelling and Experimental Verification' (contract MTKD-CT-2004-014058) and the FP7 Project 'Centre of Excellence for Modern Composites Applied in Aerospace and Surface Transport Infrastructure' (CEMCAST, FP7-REGPOT-2009 1, grant agreement No: 245479). The mentioned projects accommodated two groups of researchers: one, working in the field of modern materials mechanics, and the other, working in nonlinear dynamics, bifurcation, chaos theory and control. Some of the results obtained by the latter are included in this book, whose scope covers theoretical and applications-based problems of *nonlinear dynamics*. In the presented chapters the newest methods of nonlinear mechanics are applied to elucidate a rich variety of features of system response and the latest control techniques are used to enhance the dynamics or to reduce undesired responses. Besides composite structures and systems with controllable and adaptive properties, flexible structures and non-smooth problems are addressed, paying proper attention to real applications.

So called *small nonlinearities* very often result in large qualitative and quantitative changes in structural dynamics. As a classical example we may mention *pendulum-like systems* addressed in Chap. 1. In practice, a pendulum can be used as a dynamic absorber mounted in high buildings, bridges or chimneys. Swings of the pendulum can suppress oscillations of the primary structure which then oscillates with a very small amplitude or not at all. However, geometrical nonlinearities introduced by pendulum motion may change the system dynamics, and instead of the expected response we can observe a rapid increase of the oscillations of both the pendulum and the structure, leading to full pendulum rotation or chaotic dynamics. The reason for such behaviour is related to autoparametric coupling resulting in the occurrence of instability zones. To avoid such dangerous situations the proper selection of parameters or the introduction of semi-active *magnetorheological damping* is proposed. On the basis of the analytical solutions of a nonlinear two DOF model the resonance and instability regions are detected, and then chaotic oscillations, bifurcation points and transition paths from regular to chaotic vibrations are determined by numerical techniques. Theoretical results are validated by real experimental tests.

Nonlinear mechanics also has to be used to explain undesired response in *slender footbridges*. Motivation for research in this topic was the famous example of the *London Millenium Bridge* event. Strong horizontal vibrations, caused by synchronisation of pedestrian motions, were induced on its opening day. The problem of pedestrian induced lateral vibrations may occur in bridges of various structural types and materials. The parametric study presented in Chap. 2 allows a better understanding of the structural mechanics and also the detection of regions of increasing vibration. The observed phenomena can be explained by an analytical *nonlinear discrete-time model* based on the stroboscopic Poincaré map which then enables the location of instability regions and the prediction of the number of pedestrians required to trigger synchronisation of the structure. The analytical formula gives reliable values which are in good qualitative and quantitative agreement with real examples and observations.

Smart active or semi-active elements, like for example: magnetorheological dampers, piezoelectric patches or shape memory alloys actuators embedded inside the structure, together with robust control algorithms, may eliminate regions of dangerous behaviour. Also we may take advantage of the nonlinear phenomena to design an active structure to work more effectively. *Shape memory alloys* (SMAs) exhibits very interesting nonlinear thermo- mechanical properties such as the *shape memory effect* and *superelasticity*. Methodologies for integrating shape memory alloy elements are based on *active property tuning* (APT) and *active strain energy tuning* (ASET). Chapter 3 presents details of the modelling of the SMA effect and applications for SMA wires embedded in mechanical structures to control their dynamics. SMA elements integrated within composite beams or plates can be used for active modification of structure properties e.g. by affecting their natural frequencies. It is shown that the resonant characteristics of such hosts can be significantly altered by activation of the embedded elements. This concept is extended to shell-like structures, specifically tubular bearing housings used to locate flexible rotors, and also to more complex plate geometries in which the SMA is arranged in a periodic and repeating structure in order to control *multiple modes of vibration*.

Recent advancements in the theoretical and experimental research on the finite amplitude, resonant, forced dynamics of *sagged, horizontal or inclined, elastic cables* are presented in Chap. 4, by considering modelling, analysis, response, and, in particular, nonlinear/nonregular phenomena. Asymptotic solutions and a rich variety of features of *nonlinear multimodal interaction* occurring in various resonance conditions are comparatively discussed. Dynamical and mechanical characteristics of some of the principal, experimentally observed, responses are summarized, along with the relevant robustness, spatio-temporal features, and dimensionality. Challenging issues arising in the characterization of involved *bifurcation scenarios* resulting in transition to *complex dynamics* are addressed, and hints for proper *reduced-order modelling* in cable nonlinear dynamics are obtained based on both asymptotic solutions and experimental investigations, in the perspective of a profitable cross-validation of the observed nonlinear phenomena.

The importance of *non-smooth dynamical systems*, which are very common in engineering practice is discussed in Chap. 5. Mathematically, such systems can be considered as locally smooth and therefore the global solution is obtained by *stitching* local solutions, which can be determined by standard methods. If the dynamical system is piecewise linear then an implicit global analytical solution can be given, however the occurrences of non-smoothness have first to be determined. This leads to the necessity of solving a set of nonlinear algebraic equations. To illustrate non-smooth problems and the methodology for solving them, three mechanical engineering examples are studied: (i) a *vibro-impact system* in the form of a moling device, (ii) the influence of the opening and closing of a *fatigue crack* on the host system dynamics, and (iii) nonlinear interactions between a *rotor* and snubber ring system. The theoretical results have been obtained from the developed mathematical models and confirmed by experimental tests, with a good degree of correlation.

This book is aimed at a wide audience of engineers and researchers working in the field of nonlinear structural vibrations and dynamics, and undergraduate and postgraduate students reading mechanical, aerospace and civil engineering.

Lublin, Ancona, Glasgow, Roma, Aberdeen
December 2010

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Acknowledgements

”The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013), FP7 - REGPOT - 2009 - 1, under grant agreement No:245479”.

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