IUTAM Symposium on Chaotic Dynamics and Control of Systems and Processes in Mechanics
Aims and Scope of the Series

The fundamental questions arising in mechanics are: Why?, How?, and How much? The aim of this series is to provide lucid accounts written by authoritative researchers giving vision and insight in answering these questions on the subject of mechanics as it relates to solids.

The scope of the series covers the entire spectrum of solid mechanics. Thus it includes the foundation of mechanics; variational formulations; computational mechanics; statics, kinematics and dynamics of rigid and elastic bodies: vibrations of solids and structures; dynamical systems and chaos; the theories of elasticity, plasticity and viscoelasticity; composite materials; rods, beams, shells and membranes; structural control and stability; soils, rocks and geomechanics; fracture; tribology; experimental mechanics; biomechanics and machine design.

The median level of presentation is the first year graduate student. Some texts are monographs defining the current state of the field; others are accessible to final year undergraduates; but essentially the emphasis is on readability and clarity.

For a list of related mechanics titles, see final pages.
IUTAM Symposium on
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**Dynamic Vibration Absorber for Friction Induced Oscillations**

*K. Popp and M. Rudolph*

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**Control of Limit Cycle Oscillations**

*W. Schiehlen and N. Guse*

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**Optimal Control of Retrieval of a Tethered Subsatellite**

*A. Steindl, W. Steiner, and H. Troger*

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**Passive Vibration Control by Nonlinear Energy Pumping: Theoretical and Experimental Results**

*A.F. Vakakis, D.M. McFarland, L. Bergman, L.I. Manevitch, and O. Gendelman*

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PREFACE

The interest of the applied mechanics community in chaotic dynamics of engineering systems has exploded in the last fifteen years, although research activity on nonlinear dynamical problems in mechanics started well before the end of the Eighties. It developed first within the general context of the classical theory of nonlinear oscillations, or nonlinear vibrations, and of the relevant engineering applications. This was an extremely fertile field in terms of formulation of mechanical and mathematical models, of development of powerful analytical techniques, and of understanding of a number of basic nonlinear phenomena. At about the same time, meaningful theoretical results highlighting new solution methods and new or complex phenomena in the dynamics of deterministic systems were obtained within dynamical systems theory by means of sophisticated geometrical and computational techniques.

In recent years, careful experimental studies have been made to establish the actual occurrence and observability of the predicted dynamic phenomena, as it is vitally needed in all engineering fields. Complex dynamics have been shown to characterize the behaviour of a great number of nonlinear mechanical systems, ranging from aerospace engineering applications to naval applications, mechanical engineering, structural engineering, robotics and biomechanics, and other areas.

The International Union of Theoretical and Applied Mechanics grasped the importance of such complex phenomena in the Eighties, when the first IUTAM Symposium devoted to the general topic of nonlinear and chaotic dynamics in applied mechanics and engineering was held in Stuttgart (1989). Starting with that meeting, mechanics people began thinking of nonlinear vibration problems within the more modern framework of Nonlinear Dynamics. Two successive IUTAM Symposia in the same fields were held in London (1993) and Ithaca, NY (1997). Though these three Symposia dealt with a variety of more and more intriguing problems in nonlinear and chaotic dynamics of mechanical systems, one could say, at the risk of being

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too schematic, that their respective focuses were on computational techniques (Stuttgart), geometrical tools (London), and experimental investigations (Ithaca), reflecting the interests and the specific expertise developed in the Schools of the symposium organizers.

Today, it seems generally accepted that nonlinear vibration problems should be cooperatively addressed through the combined use of analytical, computational, geometrical and experimental approaches, each of them giving fundamental and complementary contributions to the overall understanding of the problem.

Further important related issues have attracted the attention of the mechanics community in the last decade. First, the interaction between nonlinear dynamics and control, which plays an important role in advanced engineering systems in order to obtain desired dynamic behaviour and improved reliability during operation. It was the subject of a IUTAM Symposium held in Eindhoven (1996). Second, topics related to methods and applications of control of chaos, which primarily developed within the physics and dynamical systems communities but have recently received increasing attention by the nonlinear mechanics community.

This volume evolves from a further international event in the field, namely the IUTAM Symposium on Chaotic Dynamics and Control of Systems and Processes in Mechanics, held in Rome, Italy, on 8–13 June 2003. It was aimed at diving deep both into theory and recent applications to mechanics of nonlinear and chaotic dynamics, and into their control, by at the same time furthering the exchange of scientific ideas within the group of scholars – as well as friends – from various research teams, that had been established in the last fifteen years.

By now, the new and revolutionary dynamic phenomena of some years ago have become increasingly popular in the scientific community, as witnessed even by the overabundance of chaos software and pictures available on books and websites; they are known to characterize many theoretical systems and engineering applications. So, what is the present research framework in the field?

One can identify two main general issues: (i) the need to overcome the limitations inherent in the archetypal single- or few-degree-of-freedom systems mostly considered in the past, and (ii) the increased interest towards control of chaos – or more generally – of nonlinear dynamics in mechanical systems. The aim is to develop more reliable models for the analysis of high-dimensional systems and processes encountered in most technical applications; to obtain further meaningful hints from experimental investigations; to generalize techniques for the analysis of new complex behaviours; to explore implications of chaos in design and operating conditions of advanced systems, as well as needs and features for their
control. It is important to remember how difficult and involved is the passage from simple models to actual engineering systems.

For the Symposium, an International Scientific Committee was appointed by the Bureau of IUTAM with the following members: G. Rega (Italy, Chair), F. Vestroni (Italy, Co-Chair), F. L. Chernousko (Russia), E. Kreuzer (Germany), F. C. Moon (USA), G. Stepan (Hungary), J. M. T. Thompson (UK), H. Troger (Austria) and D. H. van Campen (The Netherlands). This Committee selected the papers to be presented at the Symposium and 51 papers were presented in lecture and poster-discussion sessions. There were 63 registered participants from engineering, physics and applied mathematics communities regularly attending the Technical Sessions; they came from 20 different countries according to the following geographical distribution: Austria (1), Brazil (1), Canada (1), Czech Republic (1), China (1), Denmark (1), Germany (6), Greece (3), Hungary (2), Israel (1), Italy (13), Japan (1), Morocco (1), Poland (1), Russia (5), Serbia-Montenegro (1), the Netherlands (2), Turkey (1), U.K. (8), U.S.A. (12). A number of Italian PhD students and University scientists also attended some scientific sessions.

Papers derived from nearly all of the Symposium presentations are now published in the present volume, after undergoing review by members of the Scientific Committee, or other participants to the Symposium, aimed at achieving a standard of Proceedings comparable to that of refereed journals in the field.

Though most papers are related to more than one topic, it seemed suitable to group them within 7 main areas:

I. Bifurcation, Chaos and Control
II. Mechanical Systems
III. Structural Systems
IV. Nonsmooth Dynamics
V. Delay and Random Systems
VI. Control of Systems and Processes
VII. Chaos Control and Synchronization.

Meaningful scientific achievements are highlighted mostly as regards the following topics:

(i) Complex systems and processes for classical and innovative applications
(ii) Features of nonlinear interactions in mechanical systems
(iii) Patterns of novel bifurcations, with special emphasis on nonsmooth systems
(iv) Dimensionality and reduced-order models of continuous systems
(v) Exploitation of dynamical system properties for applications
(vi) Implications of chaos for design and operating conditions
(vii) Control of spatio-temporal dynamics.
The four keynote lectures of the Symposium, and the relevant lectures and poster presentations, are indicated in the Table of Contents.

We thank both the participants to the Symposium and the authors of the papers for their valuable contributions.

The Symposium was held in the 15th-century cloister of the Faculty of Engineering of the University of Rome “La Sapienza”, in the very centre of the city. The opening remarks were given by G. Rega, F. Vestroni (Head, Structural Engineering Department), T. Bucciarelli (Faculty Dean), and W. Schiehlen (Vice President, IUTAM). Within a rich cultural and social programme, we also took the opportunity to recognize the contributions to the area of nonlinear dynamics and control of three world class scientists, Professors Felix Chernousko, Werner Schiehlen, and Michael Thompson, by celebrating their respective 65th birthdays during the Symposium banquet.

The success of the Symposium would not have been possible without the work of the local Organizing Committee established at the Department of Structural and Geotechnical Engineering of the University of Rome “La Sapienza”, whose members were as follows: G. Rega (Chair), F. Vestroni (Co-Chair), F. Romeo (Secretary), D. Bernardini, P. Casini, W. Lacarbonara, R. Masiani, A. Paolone.

A special acknowledgment has to be given to Dr. Francesco Romeo for his hard and valuable effort, and the continuous care spent for the success of both the Symposium and this Proceedings volume.

The financial support of the University of Rome “La Sapienza”, of the IUTAM, and of a significant number of Italian companies from the area of civil engineering is most gratefully acknowledged.

Finally, many thanks are due to Kluwer Academic Publishers, especially to Ms. Nathalie Jacobs, for their support and efficient cooperation with this Proceedings volume.

Giuseppe Rega
Fabrizio Vestroni
University of Rome “La Sapienza”, Italy
July 2004
WELCOME ADDRESS
BY THE VICE-PRESIDENT OF IUTAM

Professor Bucciarelli, Professor Vestroni
Dear Professor Rega,
Dear Colleagues from all over the world,
Ladies and Gentlemen,

It is my honor and pleasure to welcome all of you on behalf of the International Union of Theoretical and Applied Mechanics, here in Italy. As we have learnt, the University of Rome “La Sapienza” (which means “Wisdom”) is the oldest university in town, founded in 1303 by Pope Boniface the Eighth. Today, the university is well-known within the mechanics community due to its outstanding academic and scientific strength in nonlinear dynamics. Further, most of us know also the International Journal of the Italian Association of Theoretical and Applied Mechanics, published by Kluwer and called simply MECCANICA. This Journal is edited by Professor Giuseppe Rega here at the Department of Structural and Geotechnical Engineering.

Let me use this Opening Ceremony for a short look on the past and present activities of IUTAM. Organized meetings between scientists in the field of mechanics were initiated 80 years ago, namely in 1922, when Professor Theodore von Kármán from Germany and Professor Tullio Levi-Civita from Italy organized the world's first conference in hydro- and aero-mechanics. Two years later, in 1924, the First International Congress was held in Delft, The Netherlands, encompassing all fields of mechanics, that means analytical, solid and fluid mechanics, including their applications. From then on, with exception of the year 1942, international congresses on mechanics have been held every four years.

The disruption of international scientific cooperation caused by the Second World War was deeper than that caused by the First World War, and the need for re-knotting ties seemed stronger than ever before, when the
mechanics community reassembled in Paris for the Sixth Congress in 1946. Under these circumstances, at the Sixth Congress in Paris, it seemed an obvious step to strengthen bonds by forming an international union, and as a result IUTAM was created and statutes were adopted. After one year, in 1947, the Union was admitted to ICSU, the International Council for Science. This council coordinates activities among various other scientific unions to form a tie between them and the United Nations Educational, Scientific and Cultural Organization, well known as UNESCO.

Today, IUTAM forms the international umbrella organization of more than 50 national Adhering Organizations representing mechanics in many nations around the globe. Each Adhering Organization of IUTAM, like the Italian Association of Theoretical and Applied Mechanics, is represented by a number of scientists in IUTAM's General Assembly. In particular, the Italian representatives are:

Professor Carlo Cercignani and Professor Giulio Maier, from the Politecnico di Milano,
Professor Paolo Podio-Guidugli, from the University of Rome “Tor Vergata”, and
Professor Furio Vatta, from the Politecnico di Torino.

Furthermore, a large number of international scientific organizations of general or more specialized branches of mechanics are connected with IUTAM as Affiliated Organizations. As a few examples, let me mention: the European Mechanics Society (EUROMECH), the International Association of Computational Mechanics (IACM), and the International Association for Vehicle System Dynamics (IAVSD).

Within IUTAM, the only division used so far is related to solid and fluid mechanics as indicated by our two Symposia Panels. But last year the General Assembly of IUTAM approved and established Working Parties devoted to specific areas of mechanics. These areas are:

- Non-Newtonian Fluid Mechanics and Rheology,
- Dynamical Systems and Mechatronics, which is our topic, too,
- Mechanics of Materials,
- Material Processing,
- Computational Fluid and Solid Mechanics.

And in addition, with potential links to other International Unions the following subjects were chosen:

- Biomechanics,
- Nano- and Microscale Phenomena in Mechanics,
- Geophysical and Environmental Mechanics,
- Education in Mechanics and Capacity Building.

These Working Parties may be developed into Standing Scientific Committees, too, in the future.
Since 1949 there have been held more than 260 IUTAM symposia worldwide. Out of them, 6 symposia were organized in Italy, but our symposium is the first one to be held in Rome. It is worthwhile to mention that the second IUTAM Symposium ever held took place in Pallanza, Lago Maggiore back in 1950 with 27 participants from 11 countries.

The present Symposium is exceptionally interesting because it deals with new developments in dynamics. IUTAM found that the proposal of Professors Rega and Vestroni for such a symposium was not only very timely, but also very well founded in the outstanding research carried out in this field at the University of Rome “La Sapienza”. Thus, the proposal for the Symposium was readily accepted and granted by the General Assembly of IUTAM in the year 2000. There is no doubt that IUTAM considers nonlinear dynamics as an important field of mechanics. Successful IUTAM symposia on chaos and control have been held since 1989 in Stuttgart, London, Eindhoven and at Cornell. Nevertheless, IUTAM does not offer series of symposia. Thus, the titles are always adapted to the latest developments.

As I mentioned before, IUTAM organizes not only symposia but also international congresses in all part of the world. These quadrennial congresses are also considered as the Olympics of Mechanics. With 1500 participants the Chicago Congress was the central millennium event in mechanics to celebrate the turn of the century, too. The Twenty-first International Congress of Theoretical and Applied Mechanics will be held in Warsaw, Poland, from 15 to 21 August 2004, which means in one year’s time. Announcements of this forthcoming congress will be widely distributed and published in many scientific journals. Please visit also IUTAM’s very informative website designed and maintained by the Secretary-General Dick van Campen, who is with us this week, too.

On behalf of IUTAM, I wish to express my sincere thanks to the Department of Structural and Geotechnical Engineering, and in particular to Professor Giuseppe Rega, for the invitation to host this significant scientific event. I thank all participants for their readiness to come and to contribute to the Symposium with presentations, posters and scientific discussions.

It is up to you now, Ladies and Gentlemen, to harvest the fruits of the Organizers’ work. Contribute your share to make this IUTAM Symposium a meeting that will be long remembered. On behalf of IUTAM, I greet you all and wish you a symposium crowned by success!

Werner Schiehlen
Professor of Mechanics
University of Stuttgart, Germany
OBITUARY

It is very sad to note that one of the contributors to this volume, Professor František PETERKA, died just three months after attending the IUTAM Symposium in Rome, due to an unexpected and incredible event.

With his important and updated research activity in the field of nonlinear impacting dynamics, Professor Peterka was an assiduous protagonist of a great number of scientific events that occurred in the last decade in the general area of mechanical applications of nonlinear and chaotic dynamics.

For his scientific work, as well as for being a man of great humanity, mildness, tolerance and generosity, Professor Peterka was credited with great esteem, appreciation and friendship within the overall group of scholars in nonlinear dynamics who interacted with him during the years.

I believe I fully interpret the feelings of all of his scientific friends and colleagues from different countries by including in this volume, which is one of the very last volumes he contributed to, a short résumé of Professor Peterka’s scientific activity kindly prepared by his colleague Professor Ladislav Pust.

Giuseppe Rega

Ing. František PETERKA, Dr. Sc., was born on November 26, 1939 in Týn nad Vltavou in South Bohemia. From his mother, a teacher of mathematics, he inherited a talent for the natural and technical sciences. In 1962, he graduated with honour in applied mechanics from the Faculty of Mechanical Engineering of the Czech Technical University, Prague. Thereafter he began his scientific activity at the Institute of Thermomechanics of the Czechoslovak Academy of Sciences. His research was focused on the dynamics of mechanical systems, particularly on the problems of dynamics of strongly nonlinear systems with impacts. In 1968, he defended his PhD thesis Theory of dynamical impact damper with two degrees of freedom.
He was the author and co-author of more than 150 papers and lectures, and five books. Using both theory and analogue computer simulation he studied the problems of periodic and chaotic impact motions, and the optimisation of parameters of impact systems with viscous and dry friction. He was one of the first researchers who discovered chaotic phenomena in nonlinear mechanical systems. He worked also on the experimental verification of theoretical results by means of physical models of mechanical impact-systems. His last larger contribution to the theory of vibration is the chapter *Vibration Impact Systems* in the *Encyclopedia of Vibration*, published by Academic Press, London in 2001. With industrial enterprises he collaborated on the development of mechanical hammers for metal scrap compacting equipment, pneumatic drill hammers, and on the modelling of the oscillation of the nuclear reactor fuel rods under aeroelastic and seismic excitation. He elaborated a new principle of forming impact machines. However, the prototype of the patented forming machine remains unfinished.

He was the Head of the Laboratory of Non-linear Systems Dynamics in the Institute of Thermomechanics, Academy of Sciences of the Czech Republic. His scientific work was supported from 1991 in five grant projects by Grant Agency of the AS CR, Grant Agency of the CR and by the Ministry of the Education, Youth and Sport of the CR within the European action COST P-4. He was the Chairman of the Czech National Committee of the IFToMM (International Federation for the Theory of Machines and Mechanisms) and the Secretary of the IFToMM Technical Committee *Non-linear Oscillations*. He was the member of the permanent Euromech (European Society for Mechanics) Non-Linear Oscillations Conferences Committee. As a secretary of the 2nd European Nonlinear Oscillations Conference (ENOC ‘96) in Prague 1996, he contributed to a great degree to its success.

His spare time he devoted mainly to his family, a daughter, two sons and four grandchildren, and to music; he played violin and sang in the church orchestra and choir.

_Ladislav Pust_

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