SOLID MECHANICS AND ITS APPLICATIONS

H. Ulbrich and W. Günthner (Eds.)

IUTAM Symposium on

Vibration Control of Nonlinear Mechanisms and Structures

Springer

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Vibration Control of Nonlinear Mechanisms and Structures

Proceedings of the IUTAM Symposium held in Munich, Germany, 18–22 July 2005

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Springer

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN-10 1-4020-4160-8 (HB)
ISBN-13 978-1-4020-4160-0 (HB)
ISBN-10 1-4020-4161-6 (e-book)
ISBN-13 978-1-4020-4161-7 (e-book)

Published by Springer,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

www.springeronline.com

Printed on acid-free paper

Printed in the Netherlands.

IUTAM Symposium on Vibration Control of Nonlinear Mechanisms and Structures

SOLID MECHANICS AND ITS APPLICATIONS
Volume 130

Series Editor: G.M.L. GLADWELL
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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.

DEDICATION

Contributions of the IUTAM Symposium on Vibration Control of Nonlinear Mechanisms and Structures are dedicated to Professor Friedrich Pfeiffer on the occasion of his seventieth birthday, which he celebrated on 22 February 2005.

Friedrich Pfeiffer originated from Wiesbaden, where he was awarded his university-entrance diploma from the Realgymnasium in 1955 as the best of his class. Afterwards, he studied mechanical engineering at the Technische Hochschule Darmstadt from 1955 to 1961, supported by a scholarship from the "Studienstiftung des deutschen Volkes". From 1961 to 1965, he was a research assistant at the TH Darmstadt Institute for Aeronautics, under the supervision of Professor Günther Bock. He received his Dr.-Ing. summa cum laude in 1965 based on his doctoral thesis "Abwindkorrekturen für Flügel beliebiger Pfeilung in offenen und geschlossenen kreisrunden Windkanälen mit Bodenplatte".

This was the foundation of his storybook career in industry. In the year 1966 he started as a development engineer at the department of aerospace of Bölkow GmbH in Ottobrunn, where he soon became project manager, then department manager, head of the department, and finally a member of the company management. There he was responsible for research and development, supervising about 1000 employees and with annual sales of approximately 100 million Euro.

During his 16 years at the company, Professor Pfeiffer was always at the top of the ongoing current research in the field of the dynamics of rockets and satellites. When he was appointed to a professorship at the newly founded "Bundeswehrhochschule Hamburg" in 1973 he declined the offer. But almost 10 years later he was eventually attracted to university life and became a full professor for mechanics at the "Technische Universität München – Lehrstuhl B für Mechanik", where he was the successor of Professor Magnus.

Professor Pfeiffer has educated many thousands of students in the basic principles of mechanics and in the field of multi-body dynamics of robots and walking robots. He was very popular among students, who respected him as an excellent teacher. And as an outstanding researcher, it was easy for him to inspire his research and teaching assistants, of which more than 80 did their Ph.D. under his supervision.

More than 200 papers in international journals and five books demonstrate Professor Pfeiffer's exceptional talents in research and teaching, especially his remarkable ability to put complex theory into engineering practice. He focused his scientific research mainly on dynamics and control of large mechanical systems with friction and clearance but also always kept an eye on the mechanical fundamentals and worked on different problems from industry. The name Pfeiffer is primarily linked to groundbreaking work about non-smooth dynamics of multi-body systems with unilateral constraints and biological oriented walking robots, for which he was awarded the "Körber Preis". Professor Pfeiffer is editor and co-editor of many internationally renowned journals in the area of non-linear dynamics and robotics. For many years he was active on different committees, among those the board of "Studienstiftung des deutschen Volkes", member of the senate of the DFG (German Research Foundation), dean of the Faculty of Mechanical Engineering, a member of the senate of the "Technische Universität München" and, since 2000, president of the Society of Applied Mathematics and Mechanics ("Gesellschaft für Angewandte Mathematik und Mechanik, GAMM"). He has received numerous honours of which only a few are listed here: honorary doctorate (Dr. h. c. and Dr.-Ing. E. h.) from the universities of Moscow and Dresden, "Bundesverdienstkreuz am Bande", and the appointment as an IEEE fellow and ASME fellow.

Students, colleagues, and fellow scientists wish him first of all health, happiness, and vitality. We hope that he continues being active and giving advice in the years to come.

Munich, July 2005 Heinz Ulbrich

PREFACE

During the last decades, the growth of micro-electronics has reduced the cost of computing power to a level acceptable to industry and has made possible sophisticated control strategies suitable for many applications. Vibration control is applied to all kinds of engineering systems to obtain the desired dynamic behavior, improved accuracy and increased reliability during operation. In this context, one can think of applications related to the control of structures' vibration isolation, control of vehicle dynamics, noise control, control of machines and mechanisms and control of fluid-structure-interaction. One could continue with this list for a long time.

Research in the field of vibration control is extremely comprehensive. Problems that are typical for vibration control of nonlinear mechanisms and structures arise in the fields of modeling systems in such a way that the model is suitable for control design, to choose appropriate actuator and sensor locations and to select the actuators and sensors.

The objective of the Symposium was to present and discuss methods that contribute to the solution of such problems and to demonstrate the state of the art in the field shown by typical examples. The intention was to evaluate the limits of performance that can be achieved by controlling the dynamics, and to point out gaps in present research and give links for areas of future research. Mainly, it brought together leading experts from quite different areas presenting their points of view.

The book evolved from the International Symposium on Vibration Control of Nonlinear Mechanisms and Structures, held in Munich, Germany, from 18 to 22 July 2005. This Symposium was initiated by the International Union of Theoretical and Applied Mechanics. The main topics of the Symposium were:

- Control of machines and mechanisms
- Control of vehicles
- Active control of noise and vibration in structures
- Active vibration isolation of mechanisms
- Control of nonsmooth dynamics
- Actuators and sensors
- Vibration control of fluid-structure interaction

- Numerical methods in real-time-control

A Scientific Committee was appointed by the Bureau of IUTAM with the following members:

- Heinz Ulbrich, Munich, Germany (Chairman)
- Sunil K. Agrawal , Delaware, USA
- Steven R. Bishop, London, UK
- Felix L. Chernousko, Moscow, Russia
- Mikio Horie, Yokohama, Japan
- Ali H. Nayfeh, Blacksburg, USA
- Werner Schiehlen, Stuttgart, Germany
- Gábor Stépán, Budapest, Hungary

This committee selected the participants to be invited and the papers to be presented at the Symposium. As a result of this procedure, more than 60 active scientific participants from 14 different countries followed the invitation. There were three key lectures selected to give an overview of the different fields to be covered by the Symposium followed by 31 papers. All the papers presented at the Symposium are included in this book.

Since many of the presentations are related to more than one of these topics, the papers in this book are arranged in alphabetical order with respect to the family name of the first author, starting at the beginning with the three key papers. The papers cover a wide range of engineering applications of the vibration control of nonlinear mechanisms and structures. The presentations and discussions during the Symposium will certainly stimulate further theoretical and experimental investigations in the related research fields.

The editors wish to thank both the participants of this IUTAM Symposium and the authors of the papers for their valuable contributions to the important field of vibration control of nonlinear mechanisms and structures. Special thanks are given to the invited lecturers, all the lecturers and the sessions chairmen for making this Symposium a success.

The organizer gratefully acknowledges the financial support and/or effective help in the preparation of the Symposium

- Deutsche Forschungsgemeinschaft (German Research Foundation)
- International Union of Theoretical and Applied Mechanics (IUTAM)
- BMW Research Group
- Bayerisches Staatsministerium für Wissenschaft und Kunst (Bavarian Ministry of Science and Arts)
- Technical University of Munich (TUM)

The main contribution to the success of the Symposium was the great help and excellent work of the staff of the Institute of Applied Mechanics of the TUM and the Local Organizing Committee.

Special thanks are given to Dipl.-Ing. Sandor Riebe and to Dipl.-Ing. Wolfgang Günthner, they did an excellent job, as well as to Ms. Rita Schneider and Ms. Manuela Müller-Philipp for their great administrative help.

In addition, many thanks are due to Springer (formerly Kluwer Academic Publishers) and Karada Publishing Services for their efficient cooperation.

Munich, July 2005 Heinz Ulbrich

WELCOME ADDRESS

Magnifizenz Professor Schilling, Chairman Professor Ulbrich,
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, and its President Professor Ben Freund from Brown University. 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 83 years ago, namely in 1922, when Professor Theodore von Kármán and Professor Tullio Levi-Civita 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 the exception of the year 1942, International Congresses in Mechanics have been held every four years.

In particular, when the mechanics community reassembled in Paris for the Sixth Congress in 1946, out of the Congress series an international union was formed, 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 about 50 national Adhering Organizations of mechanics from nations all over the world. 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), the International Association for Vehicle System Dynamics (IAVSD), and the International Commission of Acoustics (ICA).

Within IUTAM the only division used so far is related to solid and fluid mechanics as indicated by our two Symposia Panels. But more recently nine

Working Parties with up to five members each have been established by the General Assembly of IUTAM devoted to specific areas of mechanics. These areas are:

- Non-Newtonian Fluid Mechanics and Rheology,
- Dynamical Systems and Mechatronics,
- Mechanics of Materials,
- Materials Processing,
- Biomechanics,
- Nano- and Micro-Scale Phenomena in Mechanics,
- Geophysical and Environmental Mechanics,
- Education in Mechanics and Capacity Building.

The terms of reference of the Working Parties include to make recommendations to the General Assembly regarding timely subjects for IUTAM Symposia, to maintain contact with the relevant Affiliated Organizations and sister International Unions, to identify important growth areas of the field, and to assist the Bureau and the General Assembly in discussions on position statements. Professor Friedrich Pfeiffer whom I am greeting too, is Chairman of the Working Party on Dynamical Systems and Mechatronics.

IUTAM carries out an exceptionally important task of scientific cooperation in mechanics on the international scene. Each national Adhering Organization of IUTAM, like the German Committee for Mechanics (DEKOMECH), is represented by a number of scientists in IUTAM's General Assembly. In particular, the German delegates with IUTAM are

Professor Ulrich Gabbert, Otto von Guericke University of Magdeburg;
Professor Christian Miehe, University of Stuttgart;
Professor Wolfgang Schröder, Rheinisch-Westfälische Technische Universität Aachen (RWTH Aachen);
Professor André Thess, Ilmenau University of Technology.

Mechanics is a very well developed science in Germany represented at most universities and some national laboratories. Since 1949 there has been held more than 280 IUTAM symposia worldwide. Out of them 31 symposia where organized in Germany with two symposia in Munich.

In 1977, just 28 years ago, the first IUTAM Symposium was held at the Technical University of Munich under the chairmanship of Professor Kurt Magnus. This first Munich Symposium was devoted to the Dynamics of Multibody Systems with the result that a new branch of mechanics called "Multibody Dynamics" was created.

Twenty-one years later in 1998 a second IUTAM Symposium took place here in Munich. Professor Friedrich Pfeiffer was chairman of the Symposium on Unilateral Multibody Contacts which was very successful again. Since that time contact problems are considered as an attractive research field in multibody dynamics, too.

As I mentioned before, IUTAM organizes not only symposia but also international congresses all over the world. Last year the 21st International Congress of Theoretical and Applied Mechanics was held in Warsaw, Poland. With 1515 participants the Warsaw Congress was a major event in mechanics also described as the Olympics of Mechanics. The Twenty-second International Congress of Theoretical and Applied Mechanics will be held in Adelaide, Australia, from 24th to 30st August 2008, which means in three years from now. Announcements of this forthcoming congress will be widely distributed and published in many scientific journals. The German members elected to the standing Congress Committee of IUTAM are Professor Edwin Kreuzer, Technical University Hamburg-Harburg, and Professor André Thess, Ilmenau University of Technology.

The present Symposium is exceptionally interesting because it deals with new developments in mechanics. The Symposium covers important approaches:

- Control of machines and mechanisms,
- Active control of vibration in structures,
- Control of multibody dynamics,
- Sensors and observers,
- Applications to cranes and robots.

IUTAM found that the proposal of Professor Ulbrich for such a symposium was not only very timely, but also well justified in the outstanding research carried out in this field at the Technical University of Munich. Thus, the proposal for the Symposium was readily accepted and granted by the General Assembly of IUTAM. There is no doubt that IUTAM considers vibration control of nonlinear systems as an important field of mechanics.

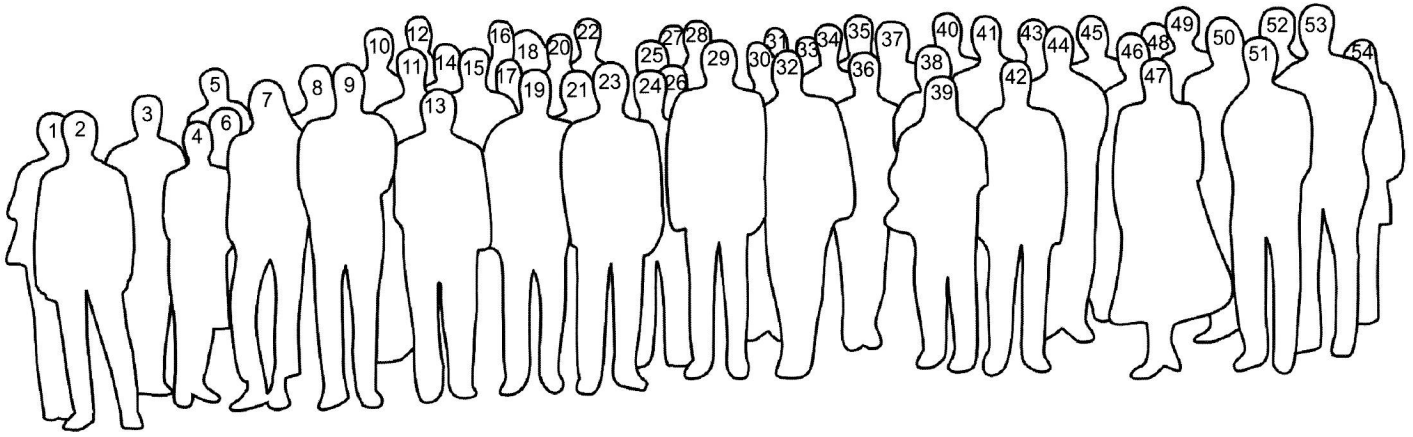
Finally, I would like to mention that to sponsor a scientific meeting is one thing, but to organize one is another. A heavy burden is placed on the shoulders of the Chairman and his associates who are in charge of the scientific program and the practical local arrangements. All who have tried this before know very well how much work has to be done in organizing a meeting like this one.

Thus, we should be thankful, not only to the International Scientific Committee, but also to the Chairman, Professor Heinz Ulbrich, and his associates who assisted him in carrying the heavy load and responsibility.

It is up to you now, Ladies and Gentlemen, to harvest the fruits of the Organizer's work. Contribute your share to make this IUTAM Symposium a meeting that will be long remembered as a very successful one!

On behalf of IUTAM, I greet you all and wish you great success!

Werner Schiehlen
Past President of IUTAM, University of Stuttgart, Germany



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