G. Radons, R. Neugebauer (Eds.)

Nonlinear Dynamics of Production Systems

With a Foreword by Hans-Peter Wiendahl

WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

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Cover picture
The photograph shows a working finger milling tool with spiral chips formed. The state space trajectories of the insert visualize the nonlinear dynamics of regenerative chatter which may perturb such machining operations. Courtesy: Gabor Stépán, Budapest.

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Foreword

Since the 1980s both a distinct acceleration and an increasing interlinkage of technical and logistic manufacturing processes can be observed worldwide. This has led to phenomena which are often graphically described as "turbulent". Conventional linear models and approaches obviously no longer suffice to control the corresponding sudden and apparently unforeseeable process changes.

Prompted by works on chaos research in the mathematics and physics, a group of colleagues at the German Academic Society for Production Engineering (Wissenschaftliche Gesellschaft für Produktionstechnik WGP) posed the question whether the theories propounded by "chaos researchers" to describe non-linear dynamic systems might not also contribute to a deeper understanding of the behaviour of high-precision manufacturing processes, complex production facilities and cross-linked logistic processes.

To assess the need for action, a workshop on "Potentials of chaos research in manufacturing sciences" sponsored by the Volkswagen Foundation was staged in Hanover in 1994. About 30 participants from the manufacturing sciences, natural sciences and industry took part. The evaluation of this workshop and contacts with other scientists led to a joint proposal by Professors Wiendahl (Hanover), Weck (Aachen) and Lierath (Magdeburg) to initiate research with focus on the "Investigation of non-linear dynamic effects in production technology systems".

In the summer of 1995, the board of trustees of the Volkswagen Foundation agreed to set up this research program, which came to a conclusion at the end of 2001. The Foundation funded a total of 33 joint projects with up to six research groups involved. An important condition for the funding of a project was the collaboration of physicists and/or mathematicians with engineers. The Foundation granted a total sum of 13 mill. Euro for projects with this research focus, with 7.6 mill. Euro to go to the engineering sciences, 3.9 mill. Euro to physics and 1.5 mill. Euro to mathematics. In April 2003, the fourth and final symposium took place in Chemnitz.

This book contains selected and edited contributions to this symposium. The spectrum of the topics dealt with ranges from the modelling and optimisation of classical manufacturing processes, such as cutting, milling or grinding, to the development of innovative control processes for complex manufacturing machines and logistic analysis and modelling of production technology systems. These can now be better understood as regards their structure and dynamics, in particular their irregular behaviour and their characteristic complexity. Building on this, new concepts for their planning, design and control were designed.

In retrospect, it is clear that the initiative succeeded not only in gaining important scientific insights within the projects and on workshops, but also in promoting and strengthening the ongoing co-operation between engineers, physicists and mathematicians in this new field of manufacturing science.

The initiators and researchers involved would like to thank the Volkswagen Foundation for its generous funding of the projects, symposia and the publication of this book, and are also indebted to Dr Claudia Nitsch and Dr Franz Dettenwanger for their competent and helpful support.

Hans-Peter Wiendahl

Hannover, August 2003

Preface

After more than two decades of intense fundamental research in nonlinear dynamics, time has come to reap the fruits of this field. Applications in the area of production systems are possibly the most important and challenging ones. To enable progress in applying nonlinear dynamics to production systems, one needs the input from theoreticians, who are often affiliated with physics or mathematics departments, and from experts in the engineering sciences. Only a close cooperation between these groups can solve the many problems that arise from the ubiquitous presence of nonlinearities inherent in production processes and manufacturing techniques. This has been recognized clearly almost ten years ago by the initiators of the priority area "Investigations of Non-Linear Dynamic Effects in Production Systems" and the responsible persons at VolkswagenStiftung, the funding organization of this project.

Due to these efforts we are now in the lucky position to report on the progress and the many facets of this new research field. On occasion of the fourth and final symposium of this priority area held on 8–9 April 2003 in Chemnitz, Germany, we asked the members of the priority area and internationally renowned experts in the field to contribute to a book on "Nonlinear Dynamics of Production Systems". The response was overwhelming and enthusiastic and resulted in the current volume. This is the first book covering nonlinear dynamic effects in the broad field of production systems in such a comprehensive way. Of course, not every problem arising in one of the many different manufacturing techniques or production processes can be solved with the aid of nonlinear dynamics. And of the many cases where the inherent complexity and nonlinearity calls for such methods, we can only present a prototypical selection.

The content of this book is divided into five parts corresponding to different aspects or subfields of production systems. Part I is devoted to the dynamics and the optimal organization of whole production lines and general production systems. Classically, such problems have been topics in operations research. Recently, however, with the need for more flexibility and stability of production processes, the central importance of nonlinear dynamic effects has been recognized. Thereby a new field is emerging and the chapters in this part give an overview over these approaches. The aspects that arise are of interest for both the scientist who seeks interesting fields of research and the manager who wants to optimize his workshop. The largest section, Part II, is concerned with various mechanical manufacturing techniques. It reports on recent advances for the long-standing problem of machine chatter appearing in turning, milling, grinding and other mechanical machining operations, but also on new forming techniques. In addition, it treats various other important methods used nowadays to improve quality and performance of these techniques, such as the coating of tools. In a way this and the next part may be regarded as an update and an extension of the previously published Wiley book on "Dynamics and Chaos in Manufacturing Processes", edited by Francis C. Moon in 1998. Part III deals with certain aspects of the dynamics of machines and robots, which are relevant for or closely related to manufacturing processes. These range from nonlinear vibrations in forming machines and drives to the control of mechanical coordination tasks and the experimental identification of the friction dynamics in mechanical systems. This part also contains an obituary for one of our authors, František Peterka, who died unexpectedly while we were editing this book. In Part IV, non-conventional manufacturing methods, such as water-jet or laser-jet cutting and laser welding are treated. In many respects these advanced techniques complement the more traditional mechanical processes. It turns out, however, that the nonlinear dynamic phenomenon of pattern formation causes some problems in otherwise advantageous operating regimes. Possible solutions or at least new insights into these problems are provided. Pattern formation also plays a central role for many industrial chemical and electro-chemical processes which are treated in Part V. Often these processes are too complex to be understood in detail, but nevertheless the appearance and identification of certain patterns often helps to determine and control the state of the system, be it in a coal burner, or in an etching process or in a lead battery. This part also reveals that bifurcation and catastrophe theory are valuable tools in designing and controlling chemical processes.

In our opinion the contributions in this book demonstrate very convincingly the ubiquity of nonlinear dynamic effects in almost all aspects of production systems. As a consequence the understanding of such effects becomes an increasingly important pre-requisite for the further development of production techniques and systems. For the nonlinear-dynamics scientist this implies a continuing challenge from interesting real-world problems, and to the engineer it shows that nonlinear dynamics can provide promising approaches for the solution of his problems.

We want to thank all persons who made the publication of this book possible. First we thank the authors who cooperated so constructively and reliably also in our cross-refereeing procedure. Next, also in the name of all authors, we wish to express our gratitude towards the VolkswagenStiftung, Hannover, which funded not only much of the research presented here, but also the symposium in Chemnitz and previous ones from which this book emanated, and which in addition made it possible for this book to appear in color printing. Finally we thank Vera Palmer and Ulrike Werner from Wiley-VCH for their smooth and engaged cooperation, which made the editing of this volume a pleasant endeavor.

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Chemnitz, September 2003

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