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G. Radons and R. Neugebauer

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Nonlinear Dynamics of Production Systems



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Nonlinear Dynamics of Production Systems

With a Foreword by Hans-Peter Wiendahl



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Editors

Prof. Dr. Günter Radons

Technische Universität Chemnitz

Institut für Physik, Theoretische Physik I

Komplexe Systeme und Nichtlineare Dynamik

Prof. Dr.-Ing. Reimund Neugebauer

Fraunhofer Institut für Werkzeugmaschinen

und Umformtechnik IWU Chemnitz

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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G. Radons, R. Neugebauer (Eds.)

**Nonlinear Dynamics of Production
Systems**

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 sub-fields 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



Participants of the "4th International Symposium on Investigations of Nonlinear Dynamic Effects in Production Systems" in Chemnitz, 8–9 April 2003

List of Contributors

Farid Al-Bender

Catholic University of Leuven
Department of Mechanical Engineering
farid.al-bender@mech.kuleuven.ac.be

Dieter Armbruster

Arizona State University
Department of Mathematics
dieter@source.la.asu.edu

Ralph T. Bailey

Babcock & Wilcox Canada, Ltd.
RTBailey@babcock.com

Michael Baune

Universität Bremen
Institut für Angewandte und Physikalische
Chemie
m.baune@uni-bremen.de

Andreas Baus

Rheinisch-Westfälische Technische Hochschule
Aachen
Werkzeugmaschinenlabor
a.baus@wzl.rwth-aachen.de

Arno Behrens

Universität der Bundeswehr Hamburg
Laboratorium Fertigungstechnik
Arno.behrens@unibw-hamburg.de

Andrzej Bodnar

Technical University of Szczecin

Ekkard Brinksmeier

Universität Bremen
Labor für Mikrozerspannung
brinksme@iwt.uni-bremen.de

Magnus Buhlert

Universität Bremen
Institut für Angewandte und Physikalische
Chemie
buhlert@uni-bremen.de

Leonid A. Bunimovich

Georgia Institute of Technology
School of Mathematics
bunimovh@math.gatech.edu

Adrienn Cser

Universität Erlangen-Nürnberg
Lehrstuhl für Fertigungstechnologie
A.Cser@lft.uni-erlangen.de

C. Stuart Daw

Oak Ridge National Laboratory
Fuels, Engines and Emissions Research Center
dawcs@ornl.gov

Berend Denkena

Universität Hannover
Institut für Fertigungstechnik und
Werkzeugmaschinen
denkena@ifw.uni-hannover.de

S. Diaz Alfonso

Instituto Superior Politecnico, Havana
Facultad de Ingenieria Chimiza

Thomas Ditzinger

Springer-Verlag, Heidelberg
Ditzinger@Springer.de

Reik Donner

Universität Potsdam
Institut für Physik
reik@agnld.uni-potsdam.de

David Engster

Universität Göttingen
III. Physikalisches Institut
D.Engster@DPI.Physik.Uni-Goettingen.de

Ronald Faassen

Technical University of Eindhoven
Department of Mechanical Engineering
r.p.h.faassen@tue.nl

Spilios D. Fassois

University of Patras
Department of Mechanical and Aeronautical
Engineering
fassois@mech.upatras.gr

Ulrike Feudel

Carl von Ossietzky Universität Oldenburg
Institut für Chemie und Biologie des Meeres
U.Feudel@icbm.de

Charles E.A. Finney

Oak Ridge National Laboratory
Fuels, Engines and Emissions Research Center
finneyc@ornl.gov

Gerhard Finstermann

Johannes Kepler Universität Linz
gerhard.finsternmann@vai.at

Thomas J. Flynn

Babcock & Wilcox Canada, Ltd.
TJFlynn@babcock.com

Michael Freitag

Universität Bremen
Planung und Steuerung produktionstechnischer
Systeme
fmt@biba.uni-bremen.de

Rudolf Friedrich

Westfälische Wilhelms-Universität Münster
Institut für Theoretische Physik
fiddir@uni-muenster.de

Michael I. Friswell

University of Bristol
Department of Aerospace Engineering
m.i.friswell@bristol.ac.uk

Timothy A. Fuller

Babcock & Wilcox Canada, Ltd.
tafuller@babcock.com

Manfred Geiger

Universität Erlangen-Nürnberg
Lehrstuhl für Fertigungstechnologie
m.geiger@lft.uni-erlangen.de

Mark Geisel

Universität Erlangen-Nürnberg
Lehrstuhl für Fertigungstechnologie
m.geisel@lft.uni-erlangen.de

Carmen Gerlach

Universität Bremen
Institut für Angewandte und Physikalische
Chemie
cgerlach@uni-bremen.de

Roland Göbel

Universität Dortmund
Lehrstuhl für Umformtechnik
Goebel@lfu.mb.uni-dortmund.de

Edvard Govekar

University of Ljubljana
Faculty of Mechanical Engineering
edvard.govekar@fs.uni-lj.si

Igor Grabec

University of Ljubljana
Faculty of Mechanical Engineering
igor.grabec@fs.uni-lj.si

Janez Gradisek

University of Ljubljana
Faculty of Mechanical Engineering
janez.gradisek@fs.uni-lj.si

Karol Grudzinski

Technical University of Szczecin
konrad@safona.tuniv.szczecin.pl

Maria Haase

Universität Stuttgart
Institut für Computeranwendungen
ica2mh@csv.ica.uni-stuttgart.de

Juergen Hahn

Texas A&M University, College Station
Department of Chemical Engineering
hahn@tamu.edu

Ernst-Christoph Haß

MIR-Chem GmbH, Bremen
Hass@mir-chem.de

Bodo Heimann

Universität Hannover
Institut für Mechanik
heimann@ifm.uni-hannover.de

Dirk Helbing

Technische Universität Dresden
Institut für Wirtschaft und Verkehr
helbing@trafficforum.de

Burkhard Heller
Universität Dortmund
Lehrstuhl für Umformtechnik
heller@lfu.mb.uni-dortmund.de

Axel Henning
Fraunhofer Institut für Produktionstechnik
und Automatisierung, Stuttgart
henning@ipa.fhg.de

Helmut J. Holl
Johannes Kepler Universität Linz
Abteilung für Technische Mechanik
helmut.holl@jku.at

Alexander Hornstein
Universität Göttingen
III. Physikalisches Institut
A.Hornstein@DPI.Physik.Uni-Goettingen.de

Tamas Inspurger
Budapest University of Technology and
Economics
Department of Applied Mechanics
inspi@mm.bme.hu

Hans Irschik
Johannes Kepler Universität Linz
Abteilung für Technische Mechanik
Hans.irschik@jku.at

Jörn Jacobsen
Universität Hannover
Institut für Fertigungstechnik und
Werkzeugmaschinen
jacobsen@ifw.uni-hannover.de

Karsten Kalisch
Universität der Bundeswehr Hamburg
Laboratorium Fertigungstechnik
Karsten.kalisch@unibw-hamburg.de

Tamás Kalmár-Nagy
United Technologies Research Center
kalmart@utrc.utc.com

Holger Kantz
Max-Planck-Institut für Physik komplexer
Systeme, Dresden
kantz@mpipks-dresden.mpg.de

Ines Katzorke
Universität Potsdam
Institut für Physik
ines@agnld.uni-potsdam.de

Matthias Kleiner
Universität Dortmund
Lehrstuhl für Umformtechnik
mkleiner@lfu.mb.uni-dortmund.de

Christian Klimmek
Universität Dortmund
Lehrstuhl für Umformtechnik
klimmek@lfu.mb.uni-dortmund.de

Fritz Klocke
Rheinisch-Westfälische Technische Hochschule
Aachen
Werkzeugmaschinenlabor
f.klocke@wzl.rwth-aachen.de

Jan Konvicka
Mikron Comp-Tec AG
jan.konvicka@mikron-ac.com

Vadim Kostykin
Fraunhofer Institut für Lasertechnik, Aachen
Vadim.kostykin@ilt.fraunhofer.de

Alexei Kouzmitchev
Westfälische Wilhelms-Universität Münster
Institut für Theoretische Physik
kuz@uni-muenster.de

Jürgen Kurths
Universität Potsdam
Institut für Physik
Jkurths@Agnld.uni-potsdam.de

Vincent Lampaert
Catholic University of Leuven
Department of Mechanical Engineering
Vincent.Lampaert@mech.kuleuven.ac.be

Erjen Lefeber
Technical University of Eindhoven
Department of Mechanical Engineering
a.a.j.lefeber@tue.nl

Regina Leopold

Fraunhofer Institut für Werkzeugmaschinen
und Umformtechnik, Chemnitz
leopold@iwu.fhg.de

Jianhui Li

Universität Bremen
Labor für Mikroerspannung
jli@lfm.uni-bremen.de

Grzegorz Litak

Technical University of Lublin
Department of Applied Physics
litak@archimedes.pol.lublin.pl

Wolfgang Marquardt

Rheinisch-Westfälische Technische Hochschule
Aachen
Lehrstuhl für Prozesstechnik
marquardt@lft.rwth-aachen.de

Hendrik Mathes

Universität Bremen
Institut für Angewandte und Physikalische
Chemie
Hendrik@uni-bremen.de

Karl Mayrhofer

Johannes Kepler Universität Linz
Institut für Anwendungsorientierte
Wissensverarbeitung
karl.mayrhofer@vai.at

Jan Michel

Fraunhofer Institut für Lasertechnik, Aachen
Jan.michel@ilt.fraunhofer.de

Martin Mönnigmann

Rheinisch-Westfälische Technische Hochschule
Aachen
Lehrstuhl für Prozesstechnik
moennigmann@lpt.rwth-aachen.de

Francis C. Moon

Cornell University, Ithaca
Sibley School of Mechanical and Aerospace
Engineering
Fcm3@cornell.edu

Alejandro Mora

Universität Stuttgart
Institut für Computeranwendungen
ica2am@csv.uni-stuttgart.de

Steffen Nestmann

Fraunhofer Institut für Werkzeugmaschinen
und Umformtechnik, Chemnitz
Steffen.nestmann@iwu.fraunhofer.de

Reimund Neugebauer

Fraunhofer Institut für Werkzeugmaschinen
und Umformtechnik, Chemnitz
Neugebauer@iwu.fhg.de

Markus Nießen

Fraunhofer Institut für Lasertechnik, Aachen
Markus.niessen@ilt.fraunhofer.de

Henk Nijmeijer

Technical University of Eindhoven
Department of Mechanical Engineering
h.nijmeijer@tue.nl

J.A.J. Oosterling

TNO Institute of Industrial Technology Enschede
Manufacturing Development

Andreas Otto

Universität Erlangen-Nürnberg
Lehrstuhl für Fertigungstechnologie
A.Otto@lft.uni-erlangen.de

Ulrich Parlitz

Universität Göttingen
III. Physikalisches Institut
U.Parlitz@DPI.Physik.Uni-Goettingen.DE

Frantisek Peterka †

Academy of Sciences of the Czech Republic,
Prague
Institute of Thermomechanics

Karsten Peters

Universität Göttingen
III. Physikalisches Institut
karsten@physik3.gwdg.de

Stefan Pfeiffer

Rheinisch-Westfälische Technische Hochschule
Aachen
Lehrstuhl für Lasertechnik

Arkady Pikovsky
Universität Potsdam
Institut für Physik
pikovsky@stat.physik.uni-potsdam.de

Peter Jörg Plath
Universität Bremen
Institut für Angewandte und Physikalische
Chemie
plath@uni-bremen.de

Thomas Rabbow
Universität Bremen
Institut für Angewandte und Physikalische
Chemie
rabbow@uni-bremen.de

Günter Radons
Technische Universität Chemnitz
Institut für Physik
Radons@physik.tu-chemnitz.de

Volker Reitmann
Max-Planck-Institut für Physik komplexer
Systeme, Dresden
reitmann@rsc.urz.tu-dresden.de

Rüdiger Rentsch
Universität Bremen
Labor für Mikrozerspannung
rentsch@lfm.uni-bremen.de

Dimitris C. Rizos
University of Patras
Department of Mechanical and Aeronautical
Engineering
Driz@mech.upatras.gr

Alejandro Rodriguez-Angeles
Technical University of Eindhoven
Department of Mechanical Engineering
a.rodriquez@tue.nl

Rafal Rusinek
Technical University of Lublin
Department of Applied Mechanics
raf@archimedes.pol.lublin.pl

Gerhard Schmidt
Fraunhofer Institut für Werkzeugmaschinen
und Umformtechnik, Chemnitz
Schmidt@iwu.fhg.de

Alf Schmieder
Universität Bremen
Planung und Steuerung produktionstechnischer
Systeme
smi@biba.uni-bremen.de

Bernd Scholz-Reiter
Universität Bremen
Planung und Steuerung produktionstechnischer
Systeme
bsr@biba.uni-bremen.de

Wolfgang Schulz
Fraunhofer Institut für Lasertechnik, Aachen
Wolfgang.schulz@ilt.fraunhofer.de

Oliver Schütte
Universität Hannover
Institut für Mechanik
schuette@ifm.uni-hannover.de

Udo Schwarz
Universität Potsdam
Institut für Physik
Uschwarz@Agnd.uni-potsdam.de

Gabor Stepan
Budapest University of Technology and
Economics
Department of Applied Mechanics
stepan@mm.bme.hu

Uwe Sydow
MIR-Chem GmbH, Bremen
sydow@mir-chem.de

Kazimierz Szabelski
Technical University of Lublin
Department of Applied Mechanics
mechstos@archimedes.pol.lublin.pl

Robert Szalai
Budapest University of Technology and
Economics
Department of Applied Mechanics
szalai@mm.bme.hu

Palaniappagounder Thangavel
Universität Bremen
Institut für Angewandte und Physikalische
Chemie
Thangavelp@yahoo.com

Hans Kurt Tönshoff
Universität Hannover
Institut für Fertigungstechnik und
Werkzeugmaschinen
toenshoff@ifw.uni-hannover.de

Ubbo Visser
Universität Bremen
Technologie-Zentrum Informatik
Visser@tzi.de

Nathan van de Wouw
Technical University of Eindhoven
Department of Mechanical Engineering
n.v.d.wouw@tue.nl

E. van Raaij
MIR-Chem GmbH, Bremen
info@mir-chem.de

Jerzy Warminski
Technical University of Lublin
Department of Applied Mechanics
jwar@archimedes.pol.lublin.pl

Frank Weidermann
Fachhochschule Mittweida
Fachbereich Maschinenbau/Feinwerktechnik
Frank.weidermann@htwm.de

A. Wessel
Universität Potsdam
Institut für Physik

Niels Wessel
Universität Potsdam
Institut für Physik
niels@agnld.uni-potsdam.de

Bert Westhoff
Universität der Bundeswehr Hamburg
Laboratorium Fertigungstechnik
Bert.westhoff@unibw-hamburg.de

Engelbert Westkämper
Fraunhofer Institut für Arbeitswirtschaft
und Organisation, Stuttgart
wke@ipa.fhg.de

Hans-Peter Wiendahl
Universität Hannover
Institut für Fabrikanlagen und Logistik
wiendahl@ifa.uni-hannover.de

Jochen Worbs
Universität Hannover
Institut für Fabrikanlagen und Logistik
worbs@ifa.uni-hannover.de

Keith Worden
University of Sheffield
Department of Mechanical Engineering
K.Worden@sheffield.ac.uk

Jens Wulfsberg
Universität der Bundeswehr Hamburg
Laboratorium Fertigungstechnik
Jens.wulfsberg@unibw-hamburg.de

Contents

I	Dynamics and Control of Production Processes	1
1	Dynamical Systems and Production Systems	5
1.1	Introduction	5
1.2	The Bucket Brigade Production System	5
1.2.1	Re-ordering	7
1.2.2	Non-constant Speeds	8
1.2.3	Bucket Brigades and Learning	11
1.3	Fluid Models of Production Networks	12
1.4	Dynamics of Supply Chains	17
1.4.1	Simulation and Control	21
	Bibliography	22
2	Method of Stabilization of a Target Regime in Manufacturing and Logistics	25
2.1	Introduction	25
2.1.1	Stabilization of a Target Regime (STR Method)	26
2.1.2	Constraints-based Hierarchy of Models	27
2.1.3	The Algorithm of the Optimal Management of the Systems in Work-sharing Manufacturing	27
2.2	The Hierarchy of Models	28
2.3	Dynamics of the Models in the Hierarchy	31
2.4	Algorithm of Stabilization of the Target Regime for OWS Models	35
2.5	Concluding Remarks	36
	Bibliography	37
3	Manufacturing Systems with Restricted Buffer Sizes	39
3.1	Introduction	39
3.2	Hybrid Models	40
3.2.1	Switched Arrival and Server Systems	41
3.2.2	Limiting Cases	43
3.2.3	Dynamics and Bifurcations	44
3.2.4	Modified Switching Rules	47
3.2.5	Manufacturing Systems with Setup Times	47
3.3	Performance of Manufacturing Systems	48
3.3.1	Evaluation of Cost Functions	49
3.3.2	Optimization and Chaos Control	50
3.4	Switched Discrete Deterministic Systems	51
3.4.1	Dynamics	51
3.4.2	Small Stochastic Disturbances	52
3.5	Conclusion	53
	Bibliography	53

4	Modeling and Analysis of a Re-entrant Manufacturing System	55
4.1	Introduction	55
4.1.1	Re-entrant Manufacturing Systems and Models	55
4.1.2	Control Policies and Their Analysis	56
4.2	“Two Products – Two Stages” Re-entrant Manufacturing System	58
4.3	Dynamical Model	59
4.4	Analysis of Dynamics	60
4.4.1	Sensitivity to Initial Conditions	60
4.4.2	Ergodicity and Stationarity	60
4.4.3	Correlations	62
4.5	Dynamical Concept for Manufacturing Control	64
4.6	Simulation Model	65
4.7	Analysis of Scheduling Policies	66
4.8	Conclusion and Outlook	67
	Bibliography	69
5	Nonlinear Models for Control of Manufacturing Systems	71
5.1	Introduction	71
5.2	Extensions to the Standard Fluid Model	72
5.2.1	A Common Fluid Model	72
5.2.2	An Extension	74
5.2.3	An Approximation to the Extended Fluid Model	75
5.2.4	A Hybrid Model	76
5.3	A New Flow Model	77
5.3.1	Introduction to Traffic Flow Theory: the LWR Model	78
5.3.2	A Traffic Flow Model for Manufacturing Flow	79
5.4	The Manufacturing Flow Model Revisited	80
5.5	Concluding Remarks	81
	Bibliography	82
6	Modeling and Optimization of Production Processes:	
	Lessons from Traffic Dynamics	85
6.1	Modeling the Dynamics of Supply Networks	85
6.1.1	Modeling One-dimensional Supply Chains	86
6.1.2	“Bull-whip Effect” and Stop-and-Go Traffic	87
6.1.3	Dynamical Solution and Resonance Effects	88
6.1.4	Discussion of Some Control Strategies	90
6.1.5	Production Units in Terms of Queueing Theoretical Quantities	91
6.1.6	Calculation of the Cycle Times	92
6.1.7	Feeding Rates, Production Speeds and Inventories	93
6.1.8	Impact of the Supply Network’s Topology	95
6.1.9	Advantages and Extensions	95
6.2	Many-particle Models of Production Processes	97
6.2.1	Learning from Pedestrians	97
6.2.2	Optimal Self-organization and Noise-induced Ordering	100

6.2.3	“Slower-is-Faster Effect” in Merging Flows	101
6.2.4	Optimization of Multi-object Flows	101
6.3	Summary and Outlook	102
	Bibliography	103

II Machine Tools and Manufacturing Processes 107

7 Nonlinear Dynamics of High-speed Milling Subjected to Regenerative Effect 111

7.1	Introduction	111
7.2	Nonlinear Dynamics of Turning	113
7.2.1	Modeling of Turning	113
7.2.2	Bifurcation Analysis of Turning	114
7.2.3	Global Dynamics of Self-interrupted Cutting	116
7.3	Nonlinear Vibrations of High-speed Milling	119
7.3.1	Modeling of High-speed Milling	120
7.3.2	Bifurcation Analysis of High-speed Milling	122
7.3.3	Global Dynamics of Parametrically Interrupted Cutting	126
7.4	Conclusions	126
	Bibliography	127

8 Mode-coupled Regenerative Machine Tool Vibrations 129

8.1	Introduction	129
8.2	Metal Cutting	130
8.2.1	Oblique Cutting	131
8.3	Three-degree-of-freedom Model of Metal Cutting	132
8.3.1	Cutting Forces	136
8.3.2	The Equations of Motion	137
8.4	Estimation of Model Parameters	138
8.4.1	Structural Parameters	139
8.4.2	Cutting Force Parameters	139
8.4.3	Model Parameters	140
8.5	Analysis of the Model	140
8.5.1	Classical Limit	142
8.5.2	Stability Analysis of the Undamped System Without Delay	142
8.5.3	Stability Analysis of the Two-degree-of-freedom Model with Delay	143
8.6	Conclusions	148
	Bibliography	149

9 Influence of the Workpiece Profile on the Self-excited Vibrations in a Metal Turning Process 153

9.1	Introduction	153
9.2	Modeling of Turning Process	154
9.3	Analytical Investigations of Primary Cutting	157

9.4	Numerical Analysis of Primary Cutting	159
9.5	Numerical Investigation of Finishing Cutting Dynamics	161
9.6	Conclusions	166
	Bibliography	166
10	Modeling of High-speed Milling for Prediction of Regenerative Chatter	169
10.1	Introduction	169
10.2	Modeling	170
10.2.1	Material Model	172
10.2.2	Machine Model	175
10.2.3	The Total Milling Model	178
10.3	Stability Analysis of the Milling System	179
10.3.1	Method of D-partition	179
10.4	Results	181
10.5	Conclusions	183
	Bibliography	185
11	Nonlinear Dynamics of an External Cylindrical Grinding System and a Strategy for Chatter Compensation	187
11.1	Introduction	187
11.2	Wheel–Workpiece Dynamics	189
11.2.1	Chatter Vibrations	189
11.2.2	Compliance	190
11.2.3	Hilbert Transform	192
11.2.4	Chatter Detection	192
11.3	Modeling of Mechanical Structure Dynamics	194
11.3.1	Model of Guideway Connection	194
11.3.2	Resonances in Guideway System	197
11.4	Feed Drive	200
11.4.1	Requirements for the Infeed Drive	202
11.4.2	Nonlinear Effects and Control Scheme	203
11.4.3	Compensation of Cogging	203
11.5	Waviness Compensation	205
11.6	Conclusions	206
	Bibliography	206
12	Problems Arising in Finite-Element Simulations of the Chip Formation Process Under High Speed Cutting Conditions	209
12.1	Introduction	209
12.2	Orthogonal Cutting Process	210
12.2.1	Description	210
12.2.2	Material Laws	210
12.2.3	Remeshing and Chip Separation	212
12.3	Simulation Results and the Comparison with Experimental Results	215
12.3.1	Process Parameters	215