Contents

List of Contributors xvii

1 Introduction 1
1.1 Scope of the Subject 1
1.2 Scientific and Technological Challenges and Needs 2
1.3 Emerging Trends 4
References 6
2 Basic Concepts and Theory 7
2.1 Introduction 7
2.2 Loop Stiffness within the Machine-tool-workpiece System 7
2.2.1 Machine-tool-workpiece Loop Concept 7
2.2.2 Static Loop Stiffness 8
2.2.3 Dynamic Loop Stiffness and Deformation 9
2.3 Vibrations in the Machine-tool System 10
2.3.1 Free Vibrations in the Machine-tool System 10
2.3.2 Forced Vibrations 13
2.4 Chatter Occurring in the Machine Tool System 15
2.4.1 Definition 15
2.4.2 Types of Chatters 16
2.4.3 The Suppression of Chatters 16
2.5 Machining Instability and Control 17
2.5.1 The Conception of Machining Instability 17

2.5.2 The Classification of Machining Instability 19
Acknowledgements 19
References 19
3 Dynamic Analysis and Control 21
3.1 Machine Tool Structural Deformations 21
3.1.1 Machining Process Forces 22
3.1.2 The Deformations of Machine Tool Structures and Workpieces 30
3.1.3 The Control and Minimization of Form Errors 39
3.2. Machine Tool Dynamics 43
3.2.1 Experimental Methods 43
3.2.2 The Analytical Modelling of Machine Tool Dynamics 47
3.3. The Dynamic Cutting Process 54
3.3.1. Mechanic of Dynamic Cutting 55
3.3.2. The Dynamic Chip Thickness and Cutting Forces 59
3.4. Stability of Cutting Process 63
3.4.1 Stability of Turning 64
3.4.2. The Stability of the Milling Process 68
3.4.3. Maximizing Chatter Free Material Removal Rate in Milling 74
3.4.4. Chatter Suppression-Variable Pitch End Mills 79
3.5. Conclusions 82
References 83
4 Dynamics Diagnostics: Methods, Equipment and Analysis Tools 85
4.1 Introduction 85
4.2 Theory 86
4.2.1 An Example 88
4.2.2 The Substructure Analysis 90
4.3 Experimental Equipment 92
4.3.1 The Signal Processing 92
4.3.2 Excitation Techniques 93
4.3.3 The Measurement Equipment 93
4.3.4 Novel Approaches 94
4.3.5 In-process Sensors 96

4.3.6 Dynamometers 96
4.3.7 The Current Monitoring 97
4.3.8 The Audio Measurement 97
4.3.9 Capacitance Probes 97
4.3.10 Telemetry and Slip Rings 98
4.3.11 Fibre-optic Bragg Grating Sensors 98
4.4 Chatter Detection Techniques 98
4.4.1 The Topography 100
4.4.2 The Frequency Domain 100
4.4.3 Time Domain 105
4.4.4 Wavelet Transforms 109
4.4.5 Soft Computing 110
4.4.6 The Information Theory 111
4.5 Summary and Conclusions 111
Acknowledgements 112
References 112
5 Tool Design, Tool Wear and Tool Life 117
5.1 Tool Design 118
5.1.1 The Tool-workpiece Replication Model 118
5.1.2 Tool Design Principles 120
5.1.3 The Tool Design for New Machining Technologies 123
5.2 Tool Materials 124
5.2.1 High Speed Steel 124
5.2.2 Cemented Carbide 124
5.2.3 Cermet 125
5.2.4 Ceramics 125
5.2.5 Diamond 126
5.2.6 Cubic Boron Nitride 127
5.3 High-performance Coated Tools 127
5.3.1 Tool Coating Methods 128
5.3.2 The Cutting Performance of PVD Coated Tools 129
5.3.3 The Cutting Performance of CVD Coated Tools 132

5.3.4 Recoating of Worn Tools 133
5.4 Tool Wear 133
5.4.1 Tool Wear Classification 134
5.4.2 Tool Wear Evolution 136
5.4.3 The Material-dependence of Wear 138
5.4.4 The Wear of Diamond Tools 139
5.5 Tool Life 142
5.5.1 The Definition of Tool Life 142
5.5.2 Taylor's Tool Life Model 142
5.5.3 The Extended Taylor's Model 144
5.5.4 Tool Life and Machining Dynamics 145
References 148
6 Machining Dynamics in Turning Processes 151
6.1 Introduction 151
6.2 Principles 151
6.2.1 The Turning Process 153
6.3 Methodology and Tools for the Dynamic Analysis and Control 154
6.4 Implementation Perspectives 155
6.5 Applications 156
6.5.1 The Rigidity of the Machine Tool, the Tool Fixture and the Work Material 156
6.5.2 The Influence of the Input Parameters 162
6.6 Conclusions 164
References 164
7 Machining Dynamics in Milling Processes 167
7.1 Introduction 167
7.1.1 Forced Vibration 167
7.1.2 Self-excited Vibration 168
7.1.3 The Scope of This Chapter 169
7.1.4 Nomenclature in This Chapter 170
7.2 The Dynamic Cutting Force Model for Peripheral Milling 171
7.2.1 Oblique Cutting 172

7.2.2 The Geometric Model of a Helical End Mill 173
7.2.3 Differential Tangential and Normal Cutting Forces..... 174
7.2.4 Undeformed Chip Thickness 175
7.2.5 Differential Cutting Forces in X and Y Directions 178
7.2.6 Total Cutting Forces in X and Y Directions 180
7.2.7 The Calibration of the Cutting Force Coefficients..... 181
7.2.8 A Case Study: Verification 186
7.3 A Dynamic Cutting Force Model for Ball-end Milling 186
7.3.1 A Geometric Model of a Ball-end Mill..... 186
7.3.2 Dynamic Cutting Force Modelling 188
7.3.3 The Experimental Calibration of the Cutting Force Coefficients 194
7.3.4 A Case Study: Verification 198
7.4 A Machining Dynamics Model 200
7.4.1 A Modularisation of the Cutting Force 200
7.4.2 Machining Dynamics Modelling..... 203
7.4.3 The Surface Generation Model..... 205
7.4.4 Simulation Model..... 207
7.5 The Modal Analysis of the Machining System 207
7.5.1 The Mathematical Principle of Experimental Modal Analysis 208
7.5.2 A Case Study 209
7.6 The Application of the Machining Dynamics Model 213
7.6.1 The Machining Setup..... 213
7.6.2 Case 1: Cut 13..... 214
7.6.3 Case 2: Cut 14..... 219
7.7 The System Identification of Machining Processes..... 224
7.7.1 The System Identification 225
7.7.2 The Machining System and the Machining Process 226
7.7.3 A Case Study 227
7.7.4 Summary..... 231
References 231
8 Machining Dynamics in Grinding Processes..... 233
8.1 Introduction 233

8.2 The Kinematics and the Mechanics of Grinding 236
8.2.1 The Geometry of Undeformed Grinding Chips 236
8.3 The Generation of the Workpiece Surface in Grinding 242
8.4 The Kinematics of a Grinding Cycle 248
8.5 Applications of Grinding Kinematics and Mechanics 253
8.6 Summary 259
References 261
9 Materials–induced Vibration in Single Point Diamond Turning 263
9.1 Introduction 263
9.2 A Model-based Simulation of the Nano-surface Generation 264
9.2.1 A Prediction of the Periodic Fluctuation of Micro-cutting Forces 265
9.2.2 Characterization of the Dynamic Cutting System 269
9.2.3 A Surface Topography Model for the Prediction of Nano-surface Generation 271
9.2.4 Prediction of the Effect of Tool Interference 275
9.2.5 Prediction of the Effect of Material Anisotropy 277
9.3 Conclusions 278
Acknowledgements 279
References 279
10 Design of Precision Machines 283
10.1 Introduction 283
10.2 Principles 284
10.2.1 Machine Tool Constitutions 284
10.2.2 Machine Tool Loops and the Dynamics of Machine Tools 288
10.2.3 Stiffness, Mass and Damping 290
10.3 Methodology 293
10.3.1 Design Processes of the Precision Machine 293
10.3.2 Modelling and Simulation 295
10.4 Implementation 298
10.4.1 Static Analysis 298
10.4.2 Dynamic Analysis 298
10.4.3 A General Modelling and Analysis Process Using FEA 300

10.5 Applications 303
10.5.1 Design Case Study 1: A Piezo-actuator Based Fast Tool Servo System 303
10.5.2 Design Case Study 2: A 5-axis Micro-milling/ grinding Machine Tool 313
10.5.3 Design Case Study 3: A Precision Grinding Machine Tool 317
Acknowledgements 320
References 320
Index 323