

Contents

Preface.....	vii
Corporate Acknowledgments.....	ix
Institutional Acknowledgments.....	xi
Personal Acknowledgments.....	xiii
Chapter 1	
Introduction to Precision Machine Design.....	1
1.1 Introduction.....	1
1.2 Fundamentals of Economic Analysis.....	2
1.3 Project Management.....	10
1.4 The Design of a Design Engineer.....	17
1.5 Design Case Study: A High Speed Machining Center.....	31
1.6 Design Case Study: A Coordinate Measuring Machine	45
Chapter 2	
Principles of Accuracy, Repeatability, and Resolution.....	58
2.1 Introduction.....	58
2.2 Formulating the System Error Budget	61
2.3 Quasi-static Mechanical Errors.....	80
2.4 Errors Caused by Dynamic Forces	104
2.5 Design Case Study: Carriage Straightness Errors Caused by Leadscrew Misalignment	107
Chapter 3	
Analog Sensors.....	114
3.1 Introduction.....	114
3.2 Nonoptical Sensor Systems.....	120
Chapter 4	
Optical Sensor Systems.....	158
4.1 Introduction.....	158
4.2 Autocollimators.....	158
4.3 Optical Encoders	163
4.4 Fiber Optic Sensors	174
4.5 Interferometric Sensors.....	176
4.6 Laser Triangulation Sensors	206
4.7 Photoelectric Transducers	207
4.8 Time of Flight Sensors	212
4.9 Vision Systems	213
Chapter 5	
Sensor Mounting and Calibration.....	218
5.1 Introduction.....	218
5.2 Sensor Location.....	218
5.3 Sensor Alignment	222
5.4 Sensor Mounting Structure Design	224
5.5 Sensor Mounting Environment.....	227
5.6 Contact Between Curved Surfaces.....	228
5.7 Metrology Frames	236
5.8 Sensor Calibration.....	247
5.9 Effects of Sensor Output and Location Errors on Accuracy	250
5.10 Design Case Study: Design of a Laser Telemetric System.....	253

Chapter 6	
Mapping Geometric and Thermal Errors in a Turning Center	268
6.1 Introduction.....	268
6.2 Assembling the HTM Model of the Superslant™	274
6.3 Machine Tool Metrology	279
6.4 Calibration Measurement Results	286
6.5 Compensating for the Measured Errors	296
6.6 Real-time Implementation of the Error Compensation System.....	298
6.7 Summary and Conclusions.....	302
Chapter 7	
System Design Considerations.....	304
7.1 Introduction.....	304
7.2 Manufacturing Considerations.....	305
7.3 Materials	332
7.4 Structural Design	340
7.5 Joint Design.....	365
7.6 Support Systems.....	393
7.7 Kinematic Coupling Design.....	401
7.8 Design Case Study: A Unique Machine for Grinding Large, Off-axis Optical Components	412
Chapter 8	
Bearings with Mechanical Contact between Elements	421
8.1 Introduction.....	421
8.2 Sliding Contact Bearings	425
8.3 Rolling Element Bearings.....	444
8.4 Rolling Element Rotary Motion Bearings.....	460
8.5 Rolling Element Linear Motion Bearings.....	479
8.6 Flexural Bearings	521
8.7 Design to Limit Thermal Effects on Bearing Performance	539
8.8 Case Study: Measurement of a Spindle's Error Motions.....	543
Chapter 9	
Bearings without Mechanical Contact between Elements	551
9.1 Introduction.....	551
9.2 Hydrostatic Bearings	551
9.3 Aerostatic Bearings.....	580
9.4 Magnetic Bearings.....	625
Chapter 10	
Power Generation and Transmission.....	640
10.1 Introduction.....	640
10.2 Dynamic Matching of Components	640
10.3 Linear and Rotary Electric Servomotors	650
10.4 Limited Range of Motion Electromagnetic Actuators	663
10.5 Piezoelectric Actuators	666
10.6 Fluid Power Systems	674
10.7 Rotary Power Transmission Elements.....	683
10.8 Linear Power Transmission Elements.....	699
10.9 Design Case Study: Increasing Axial Stiffness Through Control	739
Index.....	745