CONTENTS

VOLUME 1

PR	PREFACE		xxiii
CO	CONTRIBUTORS		xxvii
PART I CIVIL AND ENVIRONMENTAL ENGINEERING		1	
1		and Emerging Technologies in Structural Health Monitoring Enckell, Jacob Egede Andersen, Branko Glisic, and Johan Silfwerbrand	3
	1.1	Introduction, 5	
	1.2	Background, 6	
	1.3	New and Emerging Technologies, 8	
	1.4	Fiber-Optic Technology, 16	
	1.5	Acoustic Emission, 24	
	1.6	Radar Technology, 27	
	1.7	Global Positioning System, 31	
	1.8	Corrosion Monitoring Systems, 33	
	1.9	Weigh-in-Motion (WIM) Systems, 35	
	1.10	Components of Structural Health Monitoring System, 37	
	1.11	Structural Health Monitoring System Design, 41	
	1.12	System Procurement and Installation, 44	
	1.13	Application of Structural Health Monitoring Systems, 47	

	1.14 Discussion, 67 1.15 Conclusion, 69 Acknowledgments, 70 References, 71	
2	Applications of GIS in Engineering Measurements	79
	Gary S. Spring	
	 2.1 Introduction, 79 2.2 Background, 80 2.3 Basic Principles of GIS, 81 2.4 Measurement-Based GIS Applications, 96 	
	2.5 Implementation Issues, 97 2.6 Conclusion, 100 References, 102	
3	Traffic Congestion Management	105
,	Nagui M. Rouphail	105
	 3.1 Introduction and Background, 105 3.2 Scope of the Chapter, 106 3.3 Organization of the Chapter, 107 3.4 Fundamentals of Vehicle Emission Estimation, 107 3.5 Inventory of Traffic Congestion Management Methods, 112 3.6 Assessing Emission Impacts of Traffic Congestion Management, 119 3.7 Summary, 128 Acknowledgments, 129 References, 129 	
4	Seismic Testing of Highway Bridges Eric V. Monzon, Ahmad M. Itani, and Gokhan Pekcan	133
	 4.1 Introduction, 133 4.2 Similitude Requirements, 134 4.3 Specimen Fabrication, 141 4.4 Input Motion, 148 4.5 Instrumentation, 150 4.6 Data Acquisition and Processing, 155 4.7 Results, 157 References, 158 	
5	Measurements in Environmental Engineering Daniel A. Vallero	159
	 5.1 Introduction, 159 5.2 Environmental Sampling Approaches, 166 5.3 Laboratory Analysis, 169 5.4 Measurement Uncertainty, 183 	

	 5.5 Measurement Decision Making, 186 5.6 Environmental Indicators, 191 5.7 Extending Measurement Data Using Models, 199 5.8 Summary, 200 Nomenclature, 200 References, 202 	
6	Hydrology Measurements Todd C. Rasmussen	205
	 6.1 Introduction, 206 6.2 Precipitation, 209 6.3 Evapotranspiration, 212 6.4 Surface Flow, 216 6.5 Groundwater, 219 6.6 Soil Water, 223 6.7 Water Quality, 226 Suggested Readings, 231 	
7	Mobile Source Emissions Testing Mohan Venigalla	233
	7.1 Testing for Regulatory Compliance, 234 References, 240	
PA	RT II MECHANICAL AND BIOMEDICAL ENGINEERING	241
PA) 8	RT II MECHANICAL AND BIOMEDICAL ENGINEERING Dimensions, Surfaces, and their Measurement Mikell P. Groover	241 243
	Dimensions, Surfaces, and their Measurement	
	Dimensions, Surfaces, and their Measurement Mikell P. Groover 8.1 Dimensions, Tolerances, and Related Attributes, 244 8.2 Conventional Measuring Instruments and Gages, 245 8.3 Surfaces, 254	

10	Force Measurement Patrick Collins	301
	 10.1 Introduction, 302 10.2 Force Transducers, 303 10.3 Universal Testing Machines, 306 10.4 The Strain Gauge Sensor, 307 10.5 Resonant Element Transducers, 311 10.6 Surface Acoustic Wave Transducers, 314 10.7 Dynamometers, 317 10.8 Optical Force Transducers, 317 10.9 Magneto-Elastic Transducers, 320 10.10 Force Balance Transducers, 321 10.11 Force Transducer Characteristics, 321 10.12 Calibration, 323 10.13 Conclusion, 329 Glossary of Terms, 329 References, 340 	
11	Resistive Strain Measurement Devices Mark Tuttle	343
	 11.1 Preliminary Discussion, 343 11.2 Resistance Metal Strain Gages, 349 11.3 Semiconductor Strain Gages, 363 11.4 Liquid Metal Strain Gages, 365 References, 366 	
12	Vibration Measurement Sheryl M. Gracewski and Nigel D. Ramoutar	367
	 12.1 Introduction, 367 12.2 One-Degree-of-Freedom System Response, 369 12.3 Multi-Degree-of-Freedom Systems and the Frequency Response Function, 373 12.4 Vibration Measurement Equipment and Techniques, 388 12.5 Experimental Modal Analysis, 405 12.6 Applications of Vibration Measurement, 423 Nomenclature, 428 References, 431 	
13	Acoustical Measurements Brian E. Anderson, Jonathan D. Blotter, Kent L. Gee, and Scott D. Sommerfeldt	433
	 13.1 Introduction, 434 13.2 Fundamental Measures, 436 13.3 Microphones, 445 13.4 Sound Pressure Level Measurements, 451 13.5 Measurement of Sound Isolation, 454 13.6 Room Acoustics Measurements, 457 	

	 13.7 Community and Environmental Noise, 463 13.8 Sound Intensity Measurements, 465 13.9 Sound Power Measurements, 472 13.10 Sound Exposure Measurements, 476 References, 479 	
14	Temperature Measurement Peter R. N. Childs	483
	Summary, 484 14.1 Introduction, 484 14.2 Selection, 487 14.3 Invasive Temperature Measurement, 489 14.4 Semi-Invasive Methods, 511 14.5 Noninvasive Methods, 514 14.6 Conclusions, 519 Nomenclature, 519 References, 521	
15	Pressure and Velocity Measurements Richard S. Figliola and Donald E. Beasley	527
	 15.1 Pressure Concepts, 528 15.2 Pressure Reference Instruments, 530 15.3 Pressure Transducers, 536 15.4 Pressure Transducer Calibration, 543 15.5 Pressure Measurements in Moving Fluids, 544 15.6 Modeling Pressure and Fluid Systems, 548 15.7 Design and Installation: Transmission Effects, 548 15.8 Fluid Velocity Measuring Systems, 552 Nomenclature, 563 References, 564 	
16	Luminescent Method for Pressure Measurement Gamal E. Khalil, Jim W. Crafton, Sergey D. Fonov, Marvin Sellers, and Dana Dabiri	567
	 16.1 Introduction, 567 16.2 Principles of Pressure-Sensitive Paint, 569 16.3 Pressure-Sensitive Luminescent Dyes, 571 16.4 PSP Polymer and Binder, 572 16.5 Measurement Methods, 574 16.6 Pressure-Sensitive Paint Measurements, 588 Acknowledgments, 611 References, 612 	
17	Flow Measurement Jesse Yoder	615
	 17.1 New-Technology and Traditional Technology Flowmeters, 616 17.2 Trends in Flow Measurement, 627 Further Readings, 628 	

18	Heat Flux Measurement Thomas E. Diller	629
	 18.1 Introduction, 630 18.2 Important Issues, 631 18.3 Gages Based on Spatial Temperature Difference, 634 18.4 Gages Based on Temperature Change with Time, 643 18.5 Gages Based on Active Heating Methods, 648 18.6 Calibration and Errors, 653 References, 655 	
19	Heat Transfer Measurements for Nonboiling Two-Phase Flow Afshin J. Ghajar and Clement C. Tang	661
	 19.1 Introduction, 661 19.2 Experimental Setup for Horizontal and Slightly Inclined Pipes, 662 19.3 Instruments for Measurement and Data Acquisition, 666 19.4 Heat Transfer Experiment Procedures, 667 19.5 Verifying the Functionality of the Experimental Setup, 670 19.6 Experimental Results of Two-Phase Flow, 673 19.7 Concluding Remarks, 682 Nomenclature, 683 References, 684 	
20	Solar Energy Measurements Tariq Muneer and Yieng Wei Tham	687
	20.1 Introduction, 688 20.2 Measurement Equipment, 694 20.3 Equipment Error and Uncertainty, 703 20.4 Operational Errors, 704 20.5 Diffuse Radiation Data Measurement Errors, 704 20.6 Types of Sensors and their Accuracy, 711 20.7 Modern Developments, 711 20.8 Data Quality Assessment, 714 20.9 Statistical Evaluation of Models, 716 20.10 Outlier Analysis, 722 Acknowledgments, 722 References, 723	
21	Wind Energy Measurements Peter Gregg	727
	 21.1 Introduction, 728 21.2 Concepts, 728 21.3 Measurements, 731 21.4 Evaluation, 739 References, 747 	

	C	ONTENTS	xiii
22	Human Movement Measurements Rahman Davoodi		749
	 22.1 Introduction, 749 22.2 Characterization of Human Movement, 750 22.3 Optical Motion Capture Systems, 751 22.4 Magnetic Motion Capture Systems, 754 22.5 Inertial Motion Capture Systems, 756 22.6 Discussion, 761 Acknowledgment, 762 References, 762 		
23	Flow Measurement Arnold A. Fontaine, Keefe B. Manning, and Steven Deutsch		765
	23.1 Introduction, 76523.2 Flow Measurement Applications, 768References, 799		
PA	RT III INDUSTRIAL ENGINEERING		803
24	Statistical Quality Control Magd E. Zohdi		805
	 24.1 Measurements and Quality Control, 805 24.2 Dimension and Tolerance, 805 24.3 Quality Control, 806 24.4 Interrelationship of Tolerances of Assembled Products, 812 24.5 Operation Characteristic (OC) Curve, 812 24.6 Control Charts for Attributes, 812 24.7 Acceptance Sampling, 815 24.8 Defense Department Acceptance Sampling by Variables, 817 Further Readings, 817 		
25	Evaluating and Selecting Technology-Based Projects <i>Hans J. Thamhain</i>		819
	 25.1 Management Perspective, 819 25.2 Quantitative Approaches, 821 25.3 Qualitative Approaches, 826 25.4 Recommendations, 828 Variables and Abbreviations, 831 References, 831 		
26	Manufacturing Systems Evaluation Walter W. Olson		833
	 26.1 Introduction, 833 26.2 Components of Environmentally Conscious Manufacturing, 8 26.3 Manufacturing Systems, 835 	334	

xiv	CONTENTS

	 26.4 System Effects on ECM, 838 26.5 Assessment, 840 26.6 Summary, 844 References, 845 	
27	Measuring Performance of Chemical Process Equipment <i>Alan Cross</i>	847
	 27.1 Introduction, 847 27.2 Direct Fired Heater Measurement and Process Control Instrumentation, 848 27.3 Crushing and Grinding Equipment Measurements, 851 References, 858 	
28	Industrial Energy Efficiency B. Gopalakrishnan, D. P. Gupta, Y. Mardikar, and S. Chaudhari	859
	 28.1 Introduction, 860 28.2 Literature Review, 863 28.3 Data Analysis of Energy Efficiency Measures, 864 28.4 Energy Efficiency Measures in Major Energy Consuming Equipment, 872 28.5 Case Studies of Development of Energy-Efficiency Measures, 879 28.6 Conclusion, 881 Acknowledgments, 881 References, 881 	
29	Industrial Waste Auditing C. Visvanathan	885
	 29.1 Overview, 885 29.2 Waste-Minimization Programs, 886 29.3 Waste-Minimization Cycle, 888 29.4 Waste Auditing, 890 29.5 Conclusion, 909 Further Readings, 910 	
30	Organizational Performance Measurement Jennifer A. Farris, Eileen M. Van Aken, and Geert Letens	911
	30.1 Introduction, 911 30.2 Summary, 940 References, 940	
INI	DEX	I-1

VOLUME 2

PRI	PREFACE CONTRIBUTORS		xxiii
CO			xxvii
PAI	RT IV	MATERIALS PROPERTIES AND TESTING	945
31	Ann M 31.1 31.2 31.3 31.4 31.5	Viscosity Background, 947 Common Units of Viscosity, 949 Major Viscosity Measurement Methods, 959 ASTM Standards for Measuring Viscosity, 974 Questions to Ask When Selecting a Viscosity Measurement Technique, 976 ences, 979	947
32	32.1 32.2 32.3 32.4 32.5 32.6 32.7 32.8 32.9	Introduction, 982 Measurement of Surface Roughness, 983 Measurement of Friction, 988 Measurement of Wear, 992 Measurement of Test Environment, 994 Measurement of Material Characteristics, 998 Measurement of Lubricant Characteristics, 1001 Wear Particle Analysis, 1004 Industrial Measurements, 1005 Summary, 1006	981
33	933.1 33.2 33.3	Osion Monitoring R. Roberge What is Corrosion Monitoring?, 1007 The Role of Corrosion Monitoring, 1008 Corrosion Monitoring System Considerations, 1010 ences, 1116	1007
34		Introduction, 1121 Surface Properties, 1122 Microstructural Analysis, 1125	1121

vvi	CONTENTS

34.7 34.8	Compositional Analysis, 1128 Phase Analysis, 1130 Mechanical Testing, 1131 Corrosion Properties, 1141 Standards for Surface Engineering Measurement, 1145 ences, 1147	
	mal Conductivity of Engineering Materials en Blumm	1151
35.1 35.2	Introduction, 1151 Stationary Methods for Measurement of the Thermal Conductivity, 1157	
35.3	Transient Methods for the Measurement of the Thermal Conductivity, 1163	
35.4 Refer	Test Results on Various Engineering Materials, 1173 ences, 1188	
_	cal Methods for the Measurement of Thermal Conductivity bakar R. Bandaru and Max S. Aubain	1189
36.3 36.4 36.5 36.6 36.7 Ackn	Thermal Boundary Resistance May Limit Accuracy in Contact-Based Thermal Conductivity (κ) Measurements, 1189 Optical Measurements of κ May Avoid Contact-Related Issues, 1192 Thermoreflectance (TR), 1196 Characteristics of Thermoreflectance from Si Thin Films—Modeling and Calibration, 1199 Experimental Procedures, 1202 Results and Discussion, 1204 Summary and Outlook, 1208 owledgments, 1209 ences, 1209	
	tion of Metals for Structural Design	1213
	Introduction, 1214 Common Alloy Systems, 1215 What are Alloys and What Affects their Use?, 1215 What are the Properties of Alloys and How are Alloys Strengthened?, 1218	
	Manufacture of Alloy Articles, 1221 Alloy Information, 1221 Metals at Lower Temperatures, 1231 Metals at High Temperatures, 1233 Melting and Casting Practices, 1236 Forging, Forming, Powder Metallurgy, and Joining of Alloys, 1242 Surface Protection of Materials, 1245	
	Postservice Refurbishment and Repair, 1248	

	37.13 Alloy Selection: A Look at Possibilities, 1249 37.14 Level of Property Data, 1252 37.15 Thoughts on Alloy Systems, 1252 37.16 Selected Alloy Information Sources, 1259 Further Readings, 1261		
. 38	Mechanical Properties of Polymers Daniel Liu, Jackie Rehkopf, and Maureen Reitman	1263	
	 38.1 Microstructure and Morphology of Polymers—Amorphous Versus Crystalline, 1264 38.2 General Stress—Strain Behavior, 1265 38.3 Viscoelasticity, 1271 38.4 Mechanical Models of Viscoelasticity, 1272 38.5 Time—Temperature Dependence, 1274 38.6 Deformation Mechanisms, 1274 38.7 Crazing, 1277 38.8 Fracture, 1279 38.9 Modifying Mechanical Properties, 1284 38.10 Load-Bearing Applications: Creep, Fatigue Resistance, and High Strain Rate Behavior, 1285 References, 1290 		
39	Electrical Properties of Polymers Evaristo Riande and Ricardo Diaz-Calleja	1291	
	 39.1 Introductory Remarks, 1291 39.2 Polarity and Permittivity, 1292 39.3 Measurements of Dielectric Permittivity, 1293 39.4 Polarization and Dipole Moments in Isotropic Systems, 1297 39.5 Thermostimulated Depolarization Currents, 1316 39.6 Conductivity in Polyelectrolytes and Polymer-Electrolytes as Separators for Low Temperature Fuel Cells and Electrical Batteries, 1318 39.7 Semiconductors and Electronic Conducting Polymers, 1324 39.8 Ferroelectricity, Pyroelectricity, and Piezoelectricity in Polymers, 1328 39.9 Nonlinear Polarization in Polymers, 1331 39.10 Elastomers for Actuators and Sensors, 1333 39.11 Electrical Breakdown in Polymers, 1336 References, 1338 		
40	Nondestructive Inspection Robert L. Crane and Jeremy S. Knopp	1343	
	40.1 Introduction, 1344 40.2 Liquid Penetrants, 1347 40.3 Radiography, 1351 40.4 Ultrasonic Methods, 1361		

xviii	CONTENTS
AVIII	CONTENTS

 40.5 Magnetic Particle Method, 1370 40.6 Thermal Methods, 1373 40.7 Eddy Current Methods, 1375 References, 1410 	
Testing of Metallic Materials Peter C. McKeighan	1413
 41.1 Mechanical Test Laboratory, 1414 41.2 Tensile and Compressive Property Testing, 1418 41.3 Creep and Stress Relaxation Testing, 1420 41.4 Hardness and Impact Testing, 1422 41.5 Fracture Toughness Testing, 1425 41.6 Fatigue Testing, 1429 41.7 Other Mechanical Testing, 1433 41.8 Environmental Considerations, 1434 Acknowledgments, 1436 References, 1436 	
Ceramics Testing Shawn K. McGuire and Michael G. Jenkins	1437
42.1 Introduction, 1437 42.2 Mechanical Testing, 1438 42.3 Thermal Testing, 1451 42.4 Nondestructive Evaluation Testing, 1458 42.5 Electrical Testing, 1460 42.6 Summary, 1461 References, 1461	
Plastics Testing Vishu Shah	1463
43.1 Introduction, 1464 43.2 Mechanical Properties, 1464 43.3 Thermal Properties, 1481 43.4 Electrical Properties, 1484 43.5 Weathering Properties, 1488 43.6 Optical Properties, 1492 Further Readings, 1496	
Testing and Instrumental Analysis for Plastics Processing: Key Characterization Techniques Maria del Pilar Noriega	1499
 44.1 FTIR Spectroscopy, 1499 44.2 Chromatography (GC, GC-MSD, GC-FID, and HPLC), 1500 44.3 DSC and Thermogravimetry (TGA), 1510 44.4 Rheometry, 1518 References, 1527 	
	40.6 Thermal Methods, 1373 40.7 Eddy Current Methods, 1375 References, 1410 Testing of Metallic Materials Peter C. McKeighan 41.1 Mechanical Test Laboratory, 1414 41.2 Tensile and Compressive Property Testing, 1418 41.3 Creep and Stress Relaxation Testing, 1420 41.4 Hardness and Impact Testing, 1422 41.5 Fracture Toughness Testing, 1425 41.6 Fatigue Testing, 1429 41.7 Other Mechanical Testing, 1433 41.8 Environmental Considerations, 1434 Acknowledgments, 1436 References, 1436 Ceramics Testing Shawn K. McGuire and Michael G. Jenkins 42.1 Introduction, 1437 42.2 Mechanical Testing, 1438 42.3 Thermal Testing, 1451 42.4 Nondestructive Evaluation Testing, 1458 42.5 Electrical Testing, 1460 42.6 Summary, 1461 References, 1461 Plastics Testing Vishu Shah 43.1 Introduction, 1464 43.2 Mechanical Properties, 1464 43.3 Thermal Properties, 1481 43.4 Electrical Properties, 1484 43.5 Weathering Properties, 1488 43.6 Optical Properties, 1488 43.6 Optical Properties, 1488 43.6 Uptical Properties, 1488 43.6 Optical Properties, 1492 Further Readings, 1496 Testing and Instrumental Analysis for Plastics Processing: Key Characterization Techniques Maria del Pilar Noriega 44.1 FTIR Spectroscopy, 1499 45.2 Chromatography (GC, GC-MSD, GC-FID, and HPLC), 1500 44.3 DSC and Thermogravimetry (TGA), 1510 44.4 Rheometry, 1518

45	Prop	Analytical Tools for Estimation of Particulate Composite Material Properties		
	Tarek	I. Zohdi and Magd E. Zohdi	,	
	45.2 45.3 45.4	,,,,,		
PA	RT V	INSTRUMENTATION	1539	
46	Instrument Statics Jerry Lee Hall, Sriram Sundararajan, and Mahmood Naim		1541	
	46.1 46.2 46.3 Refer	,		
47	Input and Output Characteristics Adam C. Bell			
	47.1 47.2 47.3 47.4 47.5 47.6 47.7 47.8 Refer	Introduction, 1574 Familiar Examples of Input–Output Interactions, 1575 Energy, Power, Impedance, 1578 Operating Point of Static Systems, 1586 Transforming the Operating Point, 1598 Measurement Systems, 1602 Distributed Systems in Brief, 1607 Concluding Remarks, 1609 rences, 1610		
48	-	ge Transducers	1611	
	Patri	ck L. Walter		
		Terminology, 1612 Flexural Devices in Measurement Systems, 1612 The Resistance Strain Gage, 1615 The Wheatstone Bridge, 1625 Resistance Bridge Balance Methods, 1634 Resistance Bridge Transducer Measurement System Calibration, 1636 Resistance Bridge Transducer Measurement System Considerations, 1646 AC Impedance Bridge Transducers, 1655		
	Refe	rences, 1660		
	Furth	er Readings, 1661		

49	Signal Processing John Turnbull	1663
	 49.1 Frequency-Domain Analysis of Linear Systems, 1663 49.2 Basic Analog Filters, 1666 49.3 Basic Digital Filter, 1672 49.4 Stability and Phase Analysis, 1680 49.5 Extracting Signal from Noise, 1682 References, 1683 	
50	Data Acquisition and Display Systems Philip C. Milliman	
	 50.1 Introduction, 1686 50.2 Data Acquisition, 1687 50.3 Process Data Acquisition, 1688 50.4 Data Conditioning, 1691 50.5 Data Storage, 1699 50.6 Data Display and Reporting, 1704 50.7 Data Analysis, 1707 50.8 Data Communications, 1708 50.9 Other Data Acquisition and Display Topics, 1712 50.10 Summary, 1715 References, 1715 	
PAI	RT VI MEASUREMENT STANDARDS	1717
PA1	RT VI MEASUREMENT STANDARDS Mathematical and Physical Units, Standards, and Tables Jack H. Westbrook	1717 1719
	Mathematical and Physical Units, Standards, and Tables	
	Mathematical and Physical Units, Standards, and Tables Jack H. Westbrook 51.1 Symbols and Abbreviations, 1720 Bibliography for Letter Symbols, 1731 Bibliography for Graphic Symbols, 1737 51.2 Mathematical Tables, 1742 51.3 Statistical Tables, 1765 51.4 Units and Standards, 1775 Bibliography for Units and Measurements, 1802 51.5 Tables of Conversion Factors, 1802 51.6 Standard Sizes, 1833	

53	Meas	urements	
	E. L. I	Hixson and E. A. Ripperger	
	53.1	Standards and Accuracy, 1927	
	53.2	Impedance Concepts, 1930	
	53.3	Error Analysis, 1935	
	Refer	ences, 1942	

xxi

1927

I-1