

# CONTENTS

<b>Preface</b>	<b>xxv</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Digital Technology, 1	
1.2 Smaller Is Better, 2	
1.3 Medical Marvels, 5	
1.4 Improving Shuttle Safety, 6	
1.5 Airport Security, 9	
1.6 Process Control, 9	
1.7 Instrument Synchronization with PXI, 10	
1.8 PCI vs. PXI, 11	
1.9 60,000-Mile-High Elevator, 11	
1.10 Proliferation of Information, 12	
<b>2 Acoustic Emissions</b>	<b>15</b>
2.1 Principles and Theory, 15	
2.2 Signal Propagation, 16	
2.3 Physical Considerations, 16	
2.4 The AE Process Chain, 17	
2.5 Time Considerations, 18	
2.6 AE Parameters, 18	
2.7 The AE Measurement Chain, 20	
2.7.1 Coupling Agents, 21	
2.7.2 AE Sensors, 21	

- 2.7.3 Sensor Attachment, 22
- 2.7.4 Sensor to Preamplifier Cable, 22
- 2.7.5 AE Preamplifier, 23
- 2.7.6 Preamplifier to System Cable, 23
- 2.8 Vallen AMSY-5 High-Speed AE System, 24
  - 2.8.1 Frequency Filter, 24
  - 2.8.2 The A/D Converter, 25
  - 2.8.3 Feature Extraction, 25
  - 2.8.4 Transient Recorder, 25
  - 2.8.5 Data Buffer, 26
  - 2.8.6 Personal Computer and Software, 26
  - 2.8.7 Sensor Coupling Test (Autocalibration), 26
- 2.9 Location Calculation and Clustering, 27
  - 2.9.1 Location Calculation Based on Time Differences, 27
  - 2.9.2 Clustering, 29
  - 2.9.3 Sample Analysis Screen, 30
  - 2.9.4 Visualization of Measurement Results, 32
- 2.10 Advantages and Limitations of AE Testing, 32
  - 2.10.1 Advantages, 32
  - 2.10.2 Advantages of Using Operating Medium (Gas or Liquid), 32
  - 2.10.3 Advantages Compared to Other NDT Methods, 33
  - 2.10.4 Limitations, 33
  - 2.10.5 Location Errors, 33
- 2.11 AMSY-5 Main Features, 34
- 2.12 AE Transducers, 34
- 2.13 Kistler Piezotron<sup>®</sup> Acoustic Emission Sensors and Couplers, 35
- 2.14 AE Sensor Construction, 35
- 2.15 Summary of AE Sensor Features, 36
- 2.16 Technical Specifications—8152B2 Sensor, 36
- 2.17 AE Coupler Features, 36
- 2.18 Technical Specifications—5125B Coupler, 38
  - 2.18.1 Input, 38
  - 2.18.2 Output, 38
- 2.19 Acoustic Emission Technology, 38
- 2.20 AE Applications, 39
- 2.21 AE Theory, 39
- 2.22 Applications, 41
  - 2.22.1 Behavior of Materials—Metals, Ceramics, Composites, Rocks, Concrete, 41
  - 2.22.2 Nondestructive Testing During Manufacturing Processes, 41
  - 2.22.3 Monitoring Structures, 41
  - 2.22.4 Special Applications, 41

- 2.23 Advanced Equipment, 42
  - 2.23.1 PCI-2 AE Unit, 42
  - 2.23.2 Key Features, 42
  - 2.23.3 PCI-8, 16-Bit, 8-Channel AE Unit, 43
  - 2.23.4 MicroSAMOS™, Budget, Compact AE System, 44
  - 2.23.5 DiSP Systems, 45
  - 2.23.6 PCI/DSP-4 Card, 45
  - 2.23.7 Features of PCI/DSP-4 System Board, 47
  - 2.23.8 PCI/DSP-4 Board Operation and Functions, 47
  - 2.23.9 DiSP System Block Diagram, 49
  - 2.23.10 Other Company Products, 50
- 2.24 Codes, Standards, Practices, Guidelines, and Societies, 50
  - 2.24.1 Sheer Numbers, 52
  - 2.24.2 Terminology, 52
  - 2.24.3 Common Term Definitions, 52
  - 2.24.4 General Principles, 53
  - 2.24.5 Measurement Techniques and Calibration, 53
  - 2.24.6 Areas of Opportunity, 53
- 2.25 Application and Product-Specific Procedures, 54
- 2.26 Impact-Echo Method, 54
  - 2.26.1 Background, 54
  - 2.26.2 Finite Element Code, 55
  - 2.26.3 Ball Bearing–Generated Stress, 55
  - 2.26.4 Impact-Echo Transducer Development, 56
  - 2.26.5 Frequency Domain Analysis, 56
  - 2.26.6 Theory of Operations, 56
  - 2.26.7 Propagation of Waves, 57
  - 2.26.8 Impact-Echo Instrumentation, 59
    - 2.26.8.1 System Components, 59
    - 2.26.8.2 Heavy-Duty Carrying Case, 60
    - 2.26.8.3 Computer Recommendations, 60
- 2.27 Technical Specifications, 61
  - 2.27.1 Hand-Held Transducer Unit, 61
  - 2.27.2 A/D Data Acquisition System, 62
  - 2.27.3 Windows-Based Software, 63
- 2.28 Applications, 64

### **3 Electromagnetic Testing Method**

65

- 3.1 Eddy Current Theory, 66
  - 3.1.1 Surface Mounted Coils, 66
  - 3.1.2 Encircling Coils, 71
- 3.2 Magnetic Flux Leakage Theory, 73
- 3.3 Eddy Current Sensing Probes, 79

- 3.4 Flux Leakage Sensing Probes, 83
  - 3.4.1 Induction Coils, 83
  - 3.4.2 Hall Effect Sensors, 84
- 3.5 Factors Affecting Flux Leakage, 87
- 3.6 Signal-to-Noise Ratio, 88
- 3.7 Test Frequency, 88
- 3.8 Magnetization for Flux Leakage Testing, 90
- 3.9 Coupling, 95
- 3.10 Eddy Current Techniques, 95
- 3.11 Instrument Design Considerations, 96
- 3.12 UniWest US-454 EddyView™, 98
  - 3.12.1 E-Lab Model US-450, 101
  - 3.12.2 ETC-2000 Scanner, 102
- 3.13 Institut Dr. Foerster, 103
- 3.14 Magnetic Flux Leakage Testing, 106
- 3.15 Applications, 108
  - 3.15.1 General Eddy Current Applications, 108
  - 3.15.2 Specific Eddy Current Applications, 110
  - 3.15.3 General Flux Leakage Applications, 111
  - 3.15.4 Specific Leakage Flux Applications, 111
- 3.16 Use of Computers, 112
- 3.17 Barkhausen Noise/Micromagnetic Testing, 112
  - 3.17.1 Introduction, 112
- 3.18 Early Applications, 113
- 3.19 Principles of Measurement, 114
- 3.20 Equipment, 115
- 3.21 Technical Specifications, 117
- 3.22 Calibration and Testing, 117
- 3.23 Current Applications, 120
  - 3.23.1 Applications in Aircraft/Automotive/Marine Industries, 120
- 3.24 General Applications, 121
  - 3.24.1 Pipe/Tubing/Sheet/Plate Manufacturing, 121
- 3.25 Electromechanical Acoustic Transducers (EMATs), 121
  - 3.25.1 EMATs Advantages Over Piezoelectric Transducers, 122
- 3.26 Basic Theory of Operation, 122
- 3.27 Recent Applications and Developments, 123
- 3.28 Alternating Current Field Measurement (ACFM) Method, 124
- 3.29 ACFM Principles of Operation, 125
  - 3.29.1 Bx and Bz Components, 126
  - 3.29.2 Butterfly Plot, 127
- 3.30 Probe Design, 127
- 3.31 Applications, 128

**4 Laser Testing Methods****131**

- 4.1 Introduction, 131
- 4.2 Disadvantages, 132
- 4.3 Main Advantages, 132
- 4.4 Laser Theory, 132
- 4.5 Laser Safety, 133
- 4.6 Laser Classification, 133
- 4.7 Training, 134
- 4.8 Profilometry Methods, 134
  - 4.8.1 Stylus Profilometry, 135
  - 4.8.2 Optical Profilometry, 135
  - 4.8.3 White Light Interferometry, 135
- 4.9 Basic TV Holography/ESPI Interferometry, 136
  - 4.9.1 Single Laser Operation, 136
  - 4.9.2 Camera Operation, 136
  - 4.9.3 Applications, 137
  - 4.9.4 Thermal Stresses, 139
  - 4.9.5 Quantitative Aspects of Mechanical Stress, 140
  - 4.9.6 Qualitative Aspects, 141
- 4.10 Nanometric Profiling Measurements, 141
  - 4.10.1 Introduction, 141
  - 4.10.2 Autofocus Principle, 142
  - 4.10.3 Specifications, 142
    - 4.10.3.1 Sensor, 142
    - 4.10.3.2 Camera, 142
- 4.11 Conoscopic Holography, 143
  - 4.11.1 Theory, 143
  - 4.11.2 Specifications, 143
- 4.12 Confocal Measurement, 144
  - 4.12.1 Specifications, 144
    - 4.12.1.1 Sensor, 144
    - 4.12.1.2 Camera, 144
- 4.13 NanoSurf Confocal Microscopy, 145
  - 4.13.1 Introduction, 145
  - 4.13.2 Standard Components, 146
  - 4.13.3 Options, 146
- 4.14 3D Confocal Microscopy, 146
  - 4.14.1 Principle of Operation, 146
  - 4.14.2 Advantages, 146
  - 4.14.3 Specifications, 146
- 4.15 Nanometric Profiling Applications, 147
- 4.16 Scanning Laser Profilometry, 147
  - 4.16.1 Optical Principle, 148
  - 4.16.2 Probes, 149

- 4.16.3 3D Profiler, 149
- 4.16.4 LP-2000™ Control Unit, 150
- 4.17 Laser-Scanned Penetrant Inspection (LSPI™-Patent Pending), 152
  - 4.17.1 Applications, 154
- 4.18 Advanced Techniques, 154
- 4.19 Natural and External Excitation, 154
- 4.20 Strain/Stress Measurement, 155
  - 4.20.1 Theory of Operation, 155
  - 4.20.2 Technical Data, 156
- 4.21 Longer Range 3D Speckle Interferometry System, 157
  - 4.21.1 Technical Data, 158
  - 4.21.2 Hardware and Software Options, 158
  - 4.21.3 Applications for 3D-ESPI Systems, 158
  - 4.21.4 Technical Data, 160
- 4.22 Nondestructive Testing (NDT), 161
- 4.23 Shearography, 161
  - 4.23.1 Principle of Laser Shearography, 161
  - 4.23.2 Compact Shearography System, 162
  - 4.23.3 Technical Data, 163
- 4.24 Portable Shearography System, 164
  - 4.24.1 Technical Data, 164
  - 4.24.2 Other Applications, 165
- 4.25 Feltmetal Inspection System, 166
  - 4.25.1 Setup and Technique, 166
  - 4.25.2 Technical Data, 166
- 4.26 Optional Applications, 168
- 4.27 Optical Inspection Systems, 168
  - 4.27.1 ARAMIS, 168
  - 4.27.2 Industry-Specific Applications, 170
  - 4.27.3 Measuring Procedure, 170
  - 4.27.4 Measurement Results, 170
  - 4.27.5 Measurement Advantages, 170
  - 4.27.6 Comparison of ESPI and 3D Image Correlation, 171
  - 4.27.7 ARAMIS HR Specifications, 172
- 4.28 ARGUS, 172
- 4.29 TRITOP, 174
  - 4.29.1 Photogrammetric Offline System, 174
  - 4.29.2 Measurable Object Size, 174
  - 4.29.3 Digital Photogrammetry Functionality, 174
- 4.30 System Advantages, 175
- 4.31 Portable Measuring System Technique, 175
- 4.32 Dynamic TRITOP, 177
- 4.33 Other Laser Methods, 177
  - 4.33.1 Measurement of Hot Spots in Metal/Semiconductor Field-Effect Transistors, 177

**5 Leak Testing Methods****179**

- 5.1 Introduction, 179
- 5.2 Fundamentals, 180
- 5.3 Ultrasonic Leak Testing, 180
  - 5.3.1 Ultrasonic Leak Detectors, 180
- 5.4 Bubble Leak Testing, 183
- 5.5 Dye Penetrant Leak Testing, 183
- 5.6 Pressure Change Leak Testing, 183
- 5.7 Helium Mass Spectrometer Leak Testing, 184
- 5.8 Mass Spectrometer Leak Detector, 184
- 5.9 MSLD Subsystems, 184
  - 5.9.1 Spectrometer Tube, 185
  - 5.9.2 Vacuum Systems, 186
- 5.10 Vacuum System Configurations, 186
  - 5.10.1 Conventional (Direct) Flow, 186
  - 5.10.2 Contraflow (Reverse) Flow, 187
  - 5.10.3 Midstage Flow, 188
  - 5.10.4 Multiple Flow, 188
- 5.11 Electronics, 189
  - 5.11.1 I/O Functions, 190
- 5.12 Methods of Leak Detection, 190
- 5.13 Vacuum Testing Method (Outside-In), 191
  - 5.13.1 Locating Leaks, 191
  - 5.13.2 Measuring Leaks, 192
- 5.14 Pressure Test Method (Inside-Out), 192
  - 5.14.1 Locating Leaks, 192
  - 5.14.2 Measuring Leaks, 193
- 5.15 Accumulation Testing Method, 194
- 5.16 Vacuum Systems, 194
- 5.17 Pressurized Systems, 195
- 5.18 MSLD Configurations, 196
  - 5.18.1 “Wet” or “Dry” Pumps, 196
  - 5.18.2 Cabinet or Workstation Models, 196
  - 5.18.3 Portable Units, 197
  - 5.18.4 Component or Integratable Units, 197
- 5.19 Calibration, 197
  - 5.19.1 Calibrated Leaks, 198
- 5.20 Radioisotope Tracer Leak Testing, 198
- 5.21 Bubble Leak Testing, 199
  - 5.21.1 Leak Detector Solution, 199
  - 5.21.2 Vacuum Box Bubble Tracer Leak Testing, 199
  - 5.21.3 Pressure Bubble Leak Testing, 200
  - 5.21.4 Indications, 201
- 5.22 Pressure Change Leak Testing, 202

- 5.22.1 Principles, 202
- 5.22.2 Terminology, 202
- 5.22.3 Equipment, 203
- 5.22.4 Pressurizing Gases, 204
- 5.23 Pressure Change Measurement Testing, 205
  - 5.23.1 Reference System Technique, 207
- 5.24 Leakage Rate and Flow Measurement Testing, 207
- 5.25 Nuclear Reactor Systems, 208
- 5.26 Halogen Diode Leak Testing, 209
  - 5.26.1 Principles, 209
  - 5.26.2 Terminology, 210
  - 5.26.3 Gases and Equipment, 210
  - 5.26.4 Calibration, 210
- 5.27 "Sniffer" Techniques, 212
  - 5.27.1 Equipment Operation and Servicing, 212
  - 5.27.2 Normal Operation, 212
- 5.28 VIC MSLD Leak Detectors, 213
- 5.29 MSLD Subsystems, 216
  - 5.29.1 Spectrometer Tube, 217
  - 5.29.2 Vacuum System, 218
- 5.30 Operating Sequence (MS-40 and MS-40 Dry), 219
- 5.31 Calibration Sequence (MS-40 and MS-40 Dry), 220

## 6 Liquid Penetrant Tests

221

- 6.1 Introduction, 221
- 6.2 Processing, 222
- 6.3 Test Methods, 224
  - 6.3.1 Water Washable Fluorescent Penetrant Process, 224
  - 6.3.2 Post-Emulsification Fluorescent Process, 226
  - 6.3.3 Reverse Fluorescent Dye Penetrant Process, 227
  - 6.3.4 Visible Dye Penetrant Process, 227
  - 6.3.5 Water Emulsifiable Visible Dye Penetrant Process, 228
  - 6.3.6 Water Washable Visible Dye Penetrant Process, 228
  - 6.3.7 Post-Emulsifiable Visible Dye Penetrant Process, 229
  - 6.3.8 Solvent Clean Visible Dye Penetrant Process, 229
- 6.4 Advantages and Disadvantages of Various Methods, 230
- 6.5 Test Equipment, 231
- 6.6 Penetrant Materials, 236
- 6.7 System Comparisons, 238
- 6.8 Applications, 239
- 6.9 Measurement of UV and Visible Light, 242
- 6.10 Automatic and Semiautomatic Penetrant Testing Methods, 245



**7 Magnetic Particle Testing****247**

- 7.1 Magnetic Principles, 247
- 7.2 Magnets and Magnetic Fields, 249
- 7.3 Discontinuities and Defects, 252
- 7.4 Induced Magnetic Fields, 254
- 7.5 Circular and Longitudinal Fields, 257
- 7.6 Selection of Magnetizing Method, 262
- 7.7 Commercial Equipment, 263
- 7.8 Wet and Dry Particle Inspection, 264
- 7.9 MT Improvements, 267
  - 7.9.1 Remote Magnetic Particle Inspection, 269
  - 7.9.2 Probe Power, 269
  - 7.9.3 Lightweight UV Lamps, 270
  - 7.9.4 Dual Light (UV/Visible and Visible) Particle Indications, 270
- 7.10 Applications, 270
- 7.11 Residual Fields and Demagnetization, 273
- 7.12 Magnetic Flux Strips, 275
- 7.13 Hall Effect Gaussmeter, 276
- 7.14 The Hysteresis Curve, 277
- 7.15 Selection of Equipment, 280
- 7.16 Advantages and Disadvantages of the Method, 285
- 7.17 Magnetic Rubber Inspection, 285
  - 7.17.1 Introduction, 285
  - 7.17.2 Inspection Principles, 285
  - 7.17.3 Advantages of MRI, 286
  - 7.17.4 Formulations, 287
- 7.18 Underwater MRI, 288
  - 7.18.1 Technique, 288
  - 7.18.2 Disadvantages, 288
- 7.19 Magnetic Penetrators, 289
- 7.20 Automatic and Semiautomatic Inspection, 289
- 7.21 Magwerks Integrated System Tracking Technology, 290
  - 7.21.1 Basic Operation, 290
    - 7.21.1.1 Basic Operation—Automatic Mode, 291
    - 7.21.1.2 Applications, 295
- 7.22 Discontinuities and Their Appearances, 296
- 7.23 Nonrelevant Indications, 297

**8 Neutron Radiographic Testing****301**

- 8.1 Introduction, 301
- 8.2 Physical Principles, 303
- 8.3 Neutron Radiation Sources, 304

- 8.4 Neutron Activation Analysis, 304
- 8.5 Ward Center TRIGA Reactor, 307
- 8.6 Radiation Hazards and Personal Protection, 309
- 8.7 Radiation Detection Imaging, 311
  - 8.7.1 Conversion Screens, 312
  - 8.7.2 Indirect Transfer Method, 312
  - 8.7.3 Direct Transfer Method, 312
  - 8.7.4 Fluorescent Screens, 313
- 8.8 Electronic Imaging, 313
- 8.9 Nonimaging Detectors, 313
- 8.10 Neutron Radiographic Process, 313
- 8.11 Interpretation of Results, 315
- 8.12 Other Neutron Source Applications, 316
- 8.13 Neutron Level Gauges, 320
- 8.14 Californium-252 Sources, 321
- 8.15 Neutron Radioscopic Systems, 321
  - 8.15.1 Introduction, 321
  - 8.15.2 Neutron Imaging System Components, 322
  - 8.15.3 Online Inspection Systems, 323
  - 8.15.4 Characteristics of Aluminum Corrosion, 323
  - 8.15.5 Thermal Neutron Inspection System Requirements, 324
  - 8.15.6 Conclusions, 324

## **9 Radiographic Testing Method**

**325**

- 9.1 Industrial Radiography, 325
  - 9.1.1 Personnel Monitoring, 325
  - 9.1.2 Selected Definitions, 326
  - 9.1.3 Survey Instruments, 327
  - 9.1.4 Leak Testing of Sealed Sources, 329
  - 9.1.5 Survey Reports, 331
- 9.2 Work Practices, 331
- 9.3 Time—Distance—Shielding—Containment, 332
- 9.4 Regulatory Requirements, 335
- 9.5 Exposure Devices, 335
- 9.6 State and Federal Regulations, 337
- 9.7 Basic Radiographic Physics, 338
  - 9.7.1 Introduction—Isotope Production, 338
- 9.8 Fundamental Properties of Matter, 339
- 9.9 Radioactive Materials, 340
  - 9.9.1 Stability and Decay, 341
  - 9.9.2 Activity, 341
  - 9.9.3 Half-Life, 342
- 9.10 Types of Radiation, 343
- 9.11 Interaction of Radiation with Matter, 346

- 9.12 Biological Effects, 348
- 9.13 Radiation Detection, 352
  - 9.13.1 Survey Instruments, 354
- 9.14 Radiation Sources, 356
  - 9.14.1 Isotope Sources, 356
- 9.15 Portable Linear Accelerators, 359
- 9.16 Special Radiographic Techniques, 360
- 9.17 Standard Radiographic Techniques, 361
  - 9.17.1 Introduction, 361
  - 9.17.2 Basic Principles, 363
  - 9.17.3 Screens, 364
  - 9.17.4 Film Composition, 365
- 9.18 The Radiograph, 365
  - 9.18.1 Image Quality, 370
  - 9.18.2 Film Handling, Loading, and Processing, 374
  - 9.18.3 High-Intensity Illuminators, 376
- 9.19 Fluoroscopy Techniques, 377
- 9.20 Flat Panel Digital Imaging Systems, 378
- 9.21 Flat Panel Systems vs. Fuji Dynamix CR Imaging System, 379
  - 9.21.1 Resolution, 379
  - 9.21.2 Ghost Images, 380
  - 9.21.3 Image Lag, 380
  - 9.21.4 Dark Current Noise, 381
  - 9.21.5 Portability, 381
  - 9.21.6 Temperature Sensitivity, 381
  - 9.21.7 Flexibility, 381
  - 9.21.8 Fragility, 381
  - 9.21.9 Advantages, 381
- 9.22 Industrial Computed Tomography, 382
  - 9.22.1 Scan Procedure, 382
  - 9.22.2 Applications of Industrial Computed Tomography, 383
  - 9.22.3 CT System Components, 384
- 9.23 Automatic Defect Recognition, 387
  - 9.23.1 Imaging Improvements, 387
  - 9.23.2 LDA Design and Operation, 389
  - 9.23.3 ADR Techniques, 389
  - 9.23.4 Neural Network Artificial Intelligence (AI), 390
  - 9.23.5 Rule Base Using Specific Algorithms, 392
    - 9.23.5.1 Operating Sequence, 392
  - 9.23.6 ADR Advances of a PC Platform Over Proprietary Hardware, 392
  - 9.23.7 ADR Techniques, 392
  - 9.23.8 SADR, 392
  - 9.23.9 Conclusions, 393
- 9.24 The Digitome® Process, 393

- 9.24.1 Examination Concept, 394
- 9.24.2 Digital Flat Panel Detector, 395
- 9.24.3 Image Acquisition, 396
- 9.24.4 Flaw Location and Measurement, 396
- 9.24.5 Other Applications, 396
- 9.25 Manufacturing Processes and Discontinuities, 397
- 9.26 Other Isotope Applications, 397
  - 9.26.1 Electron Capture Detection, 397
  - 9.26.2 Moisture Gauging, 397
  - 9.26.3 Bone Density, 400
  - 9.26.4 Gamma and Beta Thickness Gauging, 401
  - 9.26.5 Gamma and Beta Backscatter Thickness Gauging, 401
  - 9.26.6 Gamma Level Gauging, 402
  - 9.26.7 Gamma Density Measurement, 402
  - 9.26.8 Point Level Switch, 404
    - 9.26.8.1 Features and Benefits, 405
  - 9.26.9 Oil Well Logging, 405

## 10 Thermal/Infrared Testing Method

407

- 10.1 Basic Modes of Heat Transfer, 407
- 10.2 The Nature of Heat Flow, 408
  - 10.2.1 Exothermic and Endothermic Reactions, 408
    - 10.2.1.1 Exothermic Reactions, 408
    - 10.2.1.2 Endothermic Reactions, 409
- 10.3 Temperature Measurement, 409
- 10.4 Common Temperature Measurements, 410
  - 10.4.1 Melting Point Indicators, 410
- 10.5 Color Change Thermometry, 411
  - 10.5.1 Irreversible Color Change Indicators, 411
  - 10.5.2 Thermochromic Liquid Crystal Indicators, 413
  - 10.5.3 Liquid in Glass Thermometers, 415
- 10.6 Temperature Sensors with External Readouts, 416
  - 10.6.1 Thermocouple Sensors, 416
  - 10.6.2 Special Thermocouple Products, 418
  - 10.6.3 Resistance Temperature Devices (RTDs), 418
    - 10.6.3.1 RTD Sensing Elements and Typical Temperature Ranges, 418
  - 10.6.4 Resistance Temperature Elements (RTEs), 420
- 10.7 Infrared Imaging Energy, 420
- 10.8 Heat and Light Concepts, 421
- 10.9 Pyrometers, 422
  - 10.9.1 Error Correction, 422
  - 10.9.2 Principles of Operation, 423
    - 10.9.2.1 Narrow-Band Optical Pyrometers, 423
    - 10.9.2.2 Broad-Band Optical Pyrometers, 424

- 10.9.3 Design and Operations of Optical Pyrometers, 426
- 10.9.4 Applications for Broad-Band Optical Pyrometers, 427
- 10.9.5 Installation of Optical Pyrometers, 427
- 10.10 Infrared Imaging Systems, 427
  - 10.10.1 Blackbody Calibration Sources, 427
- 10.11 Spatial Resolution Concepts, 428
  - 10.11.1 FOV, IFOV, MIFOV, and GIFOV, 428
  - 10.11.2 Angular Resolving Power, 428
  - 10.11.3 Error Potential in Radiant Measurements, 429
- 10.12 Infrared Testing Method, 429
  - 10.12.1 Preventive and Predictive Maintenance Programs, 429
  - 10.12.2 Electrical PdM Applications, 429
  - 10.12.3 Mechanical PdM Applications, 430
- 10.13 High-Performance Thermal Imager for Predictive Maintenance, 430
  - 10.13.1 Predictive Maintenance Program, 431
  - 10.13.2 Specifications, 432
    - 10.13.2.1 Thermal, 432
    - 10.13.2.2 Controls, 433
    - 10.13.2.3 Optional Features, 433
    - 10.13.2.4 Other, 433
- 10.14 High-Performance Radiometric IR System, 433
  - 10.14.1 Introduction, 433
  - 10.14.2 Applications, 434
  - 10.14.3 Theory of Operation, 434
  - 10.14.4 Operating Technique, 436
  - 10.14.5 Typical Specifications, 438
- 10.15 Mikron Instrument Company, Inc., 439
- 10.16 Mikron 7200V Thermal Imager and Visible Light Camera, 440
  - 10.16.1 General Features, 440
  - 10.16.2 Technical Data, 440
    - 10.16.2.1 Performance, 440
    - 10.16.2.2 Presentation, 441
    - 10.16.2.3 Measurement, 441
    - 10.16.2.4 Interface, 442
- 10.17 High-Speed IR Line Cameras, 442
  - 10.17.1 General Information—MikroLine Series 2128, 442
  - 10.17.2 High-Speed Temperature Measurement of Tires, 442
    - 10.17.2.1 Camera Specifications, 443
- 10.18 Other Thermal Testing Methods, 444
  - 10.18.1 Fourier Transform Infrared Spectrometer, 444
    - 10.18.1.1 DLATGS Pyroelectric Detectors, 447
    - 10.18.1.2 FTIR Evaluation of Hard Disk Fluoresin Coating, 447
    - 10.18.1.3 Measurement of Film Thickness on a Silicon Wafer, 448

- 10.18.2 Advanced Mercury Analyzer, 448
  - 10.18.2.1 Introduction, 448
  - 10.18.2.2 Theory of Operation, 449
  - 10.18.2.3 Software, 450
- 10.18.3 Identification of Materials, 450
  - 10.18.3.1 Thermoelectric Alloy Sorting, 450
  - 10.18.3.2 Applications, 453
- 10.18.4 Advantages and Disadvantages, 454
  - 10.18.4.1 Advantages, 454
  - 10.18.4.2 Disadvantages, 456

## 11 Ultrasonic Testing

457

- 11.1 Introduction, 457
- 11.2 Definition of Acoustic Parameters of a Transducer, 458
- 11.3 Noncontacting Ultrasonic Testing, 458
  - 11.3.1 NCU Transducers, 460
  - 11.3.2 Instant Picture Analysis System, 463
  - 11.3.3 Limitations, 465
  - 11.3.4 Bioterrorism, 466
- 11.4 Ultrasonic Pulsers/Receivers, 466
- 11.5 Multilayer Ultrasonic Thickness Gauge, 470
- 11.6 Conventional Ultrasound, 471
  - 11.6.1 Flaw Detection, 473
  - 11.6.2 Frequency, 474
  - 11.6.3 Ultrasonic Wave Propagation, 476
  - 11.6.4 Acoustic Impedance, 477
  - 11.6.5 Reflection and Refraction, 478
  - 11.6.6 Diffraction, Dispersion, and Attenuation, 481
  - 11.6.7 Fresnel and Fraunhofer Fields, 482
  - 11.6.8 Generation of Ultrasonic Waves, 483
  - 11.6.9 Search Unit Construction, 484
  - 11.6.10 Test Methods, 489
- 11.7 Ultrasonic Testing Equipment, 498
  - 11.7.1 Equipment Operation, 507
  - 11.7.2 Flaw Transducers, 509
    - 11.7.2.1 Instrument Features, 509
    - 11.7.2.2 Ultrasonic Specifications, 510
    - 11.7.2.3 Physical Description and Power Supply, 510
  - 11.7.3 Testing Procedures, 512
    - 11.7.3.1 Variables Affecting Results, 517
- 11.8 Time-of-Flight Diffraction (TOFD), 519

**12 Vibration Analysis Method****521**

- 12.1 Introduction, 521
- 12.2 Principles/Theory, 522
  - 12.2.1 Modes of Vibration, 522
  - 12.2.2 Resonance, 523
  - 12.2.3 Degrees of Freedom, 524
- 12.3 Sources of Vibration, 524
- 12.4 Noise Analysis, 525
- 12.5 Stress Analysis, 525
- 12.6 Modal Analysis, 526
- 12.7 Vibration Analysis/Troubleshooting, 527
  - 12.7.1 Rotating Equipment Analysis, 527
  - 12.7.2 Order Analysis, 527
- 12.8 Transfer Functions, 528
- 12.9 Predictive Maintenance, 528
- 12.10 Failure Analysis, 529
- 12.11 Impact Testing and Frequency Response, 529
- 12.12 Pass and Fail Testing, 530
- 12.13 Correction Methods, 530
  - 12.13.1 Alignment and Balance, 530
  - 12.13.2 Beat Frequency, 530
  - 12.13.3 Vibration Damping, 532
  - 12.13.4 Dynamic Absorber/Increasing Mass, 534
  - 12.13.5 Looseness/Nonlinear Mechanical Systems, 536
  - 12.13.6 Isolation Treatments, 536
  - 12.13.7 Speed Change, 540
  - 12.13.8 Stiffening, 540
- 12.14 Machine Diagnosis, 541
- 12.15 Sensors, 543
  - 12.15.1 Strain Gauges, 543
  - 12.15.2 Accelerometers, 544
  - 12.15.3 Velocity Sensors, 545
  - 12.15.4 Displacement Sensors, 545
- 12.16 Rolling Element Bearing Failures, 547
- 12.17 Bearing Vibration/Noise, 548
- 12.18 Blowers and Fans, 550
- 12.19 Vibrotest 60 Version 4, 550
- 12.20 Signal Conditioning, 555
  - 12.20.1 Acoustic Filters, 555
- 12.21 Equipment Response to Environmental Factors, 555
  - 12.21.1 Temperature/Humidity, 555
- 12.22 Data Presentation, 555
  - 12.22.1 Acceleration, Velocity, and Displacement, 555
  - 12.22.2 Fast Fourier Transform (FFT)/Time Waveform, 556

- 12.22.3 Cepstrum Analysis, 557
- 12.22.4 Nyquist Frequency/Plot, 557
- 12.22.5 Orbit, Lissajous, X-Y, and Hysteresis Plots, 559
- 12.23 Online Monitoring, 560
  - 12.23.1 Trend Analysis, 560
- 12.24 Portable Noise and Vibration Analysis System, 560
  - 12.24.1 Typical Applications, 562
  - 12.24.2 System Requirements, 562
- 12.25 Laser Methods, 562
  - 12.25.1 Theory of Operation, 563
  - 12.25.2 Applications, 565
  - 12.25.3 Specifications, 566
- 12.26 TEC's Aviation Products, 567
  - 12.26.1 Analyzer Plus Model 1700, 567
    - 12.26.1.1 Flexible System, 568
    - 12.26.1.2 User Friendly, 568
    - 12.26.1.3 Expandability, 568
    - 12.26.1.4 Quality Commitment, 568
    - 12.26.1.5 Engine Fan Balancing Application, 569
    - 12.26.1.6 Technical Specifications, 569
  - 12.26.2 ProBalancer Analyzer 2020, 570
    - 12.26.2.1 Software Features, 571
    - 12.26.2.2 Technical Specifications, 572
  - 12.26.3 Viper 4040, 572
    - 12.26.3.1 Automated Track and Balancing, 572
    - 12.26.3.2 Vibration Analysis, 574
    - 12.26.3.3 Acoustic Analysis, 574
    - 12.26.3.4 Technical Specifications, 574

## **13 Visual and Optical Testing**

575

- 13.1 Fundamentals, 575
- 13.2 Principles and Theory of Visual Testing, 576
- 13.3 Selection of Correct Visual Technique, 576
- 13.4 Equipment, 578
  - 13.4.1 Borescopes, 578
  - 13.4.2 Jet Engine Inspection, 581
  - 13.4.3 Nuclear Applications, 582
  - 13.4.4 Other Applications, 584
- 13.5 Fiberscopes and Videoscopes, 584
  - 13.5.1 Applications, 585
- 13.6 SnakeEye™ Diagnostic Tool, 587
- 13.7 Industrial Videoscopes, 589
  - 13.7.1 Equipment and Features, 589
  - 13.7.2 Instrument Setup, 590



- 13.7.3 3D Viewing, 592
- 13.7.4 Applications, 592
- 13.7.5 Working Tools, 592
- 13.8 Projection Microscopes, 593
  - 13.8.1 Leica FS4000 Forensic Comparison Microscope, 596
- 13.9 The Long-Distance Microscope, 600
  - 13.9.1 New Developments, 600
  - 13.9.2 Model K-2 Long-Distance Microscope, 601
    - 13.9.2.1 Numerical Aperture (NA), 604
    - 13.9.2.2 Care and Cleaning, 605
  - 13.9.3 InfiniVar CFM-2 Video Inspection Microscope, 605
  - 13.9.4 Accordion™ Machine Vision, 607
  - 13.9.5 InFocus Microscope Enhancement System, 607
    - 13.9.5.1 Spherical Aberrations, 607
    - 13.9.5.2 InFocus Corrections, 608
    - 13.9.5.3 Applications, 608
- 13.10 InfiniMax™ Long-Distance Microscope, 611
- 13.11 Remote Visual Inspection, 611
  - 13.11.1 Industries—Applications, 614
  - 13.11.2 Camera Head Options, 616
  - 13.11.3 Camera Pan and Tilt Features, 617
  - 13.11.4 Hand-Held Controller, 618
  - 13.11.5 Camera Control Unit, 619
  - 13.11.6 Hand-Held Controller Details, 620
  - 13.11.7 Applications, 622
- 13.12 Robotic Crawler Units, 623
  - 13.12.1 Control Unit, 623
  - 13.12.2 Cable Reels, 623
  - 13.12.3 Crawler and Camera Options, 624
  - 13.12.4 Applications, 624
- 13.13 Pipe and Vessel Inspections/Metal Joining Processes, 626
- 13.14 Ocean Optics Photometers, 629
  - 13.14.1 Optical Resolution, 630
  - 13.14.2 System Sensitivity, 633
  - 13.14.3 Specifications, 634
  - 13.14.4 Applications, 636

## **14 Overview of Recommended Practice No. SNT-TC-1A, 2001 Edition**

639

- 14.1 Purpose, 639
  - 14.1.1 Personnel Qualification and Certification in Nondestructive Testing 639
- 14.2 NDT Levels of Qualification, 640

14.3	Recommended NDT Level III Education, Training, and Experience, 640	
14.4	Written Practice, 641	
14.5	Charts, 641	
14.6	Recommended Training Courses, 641	
14.6.1	Acoustic Emissions Testing Method, 641	
14.6.2	Electromagnetic Testing Method, 643	
14.6.3	Laser Testing Methods—Holography/Shearography, 644	
14.6.4	Laser Testing Methods—Profilometry, 646	
14.6.5	Leak Testing Methods, 646	
14.6.6	Liquid Penetrant Testing Methods, 648	
14.6.7	Magnetic Particle Testing Method, 648	
14.6.8	Neutron Radiographic Testing Method, 649	
14.6.9	Radiographic Testing Method, 651	
14.6.10	Thermal/Infrared Testing Method, 653	
14.6.11	Ultrasonic Testing Method, 654	
14.6.12	Vibration Analysis Method, 655	
14.6.13	Visual Testing Method, 656	
14.6.14	Appendix, 657	
	14.6.14.1 Example Questions, 657	
	14.6.14.2 Answers to Example Questions, 658	
14.6.15	A Dynamic Document, 658	
14.6.16	Special Disclaimer, 659	
<b>Appendix 1: Bibliography of Credits</b>		<b>661</b>
<b>Appendix 2: Company Contributors</b>		<b>667</b>
<b>Index</b>		<b>671</b>