
Table of Contents

Table of Contents	vii
List of Figures	xiii
List of Tables	xxvii
Acknowledgements	xxix
Preface	xxxi
Introduction	1
Glossary	7
1. Basic Concepts of Phased Array Ultrasonic Technology	13
1.1 Principles	13
1.2 Delay Laws, or Focal Laws	17
1.3 R/D Tech Main Components for Tomoscan FOCUS Phased Array Instrument	19
1.3.1 Tomoscan FOCUS™	19
1.3.2 Phased Array Components for OmniScan	21
1.3.3 Complete Phased Array System	21
2. Main Formulas and Ultrasonic Reference Data	29
2.1 Physics of Ultrasonics—Definitions	29
2.2 Some Common Velocities and Wavelengths	30
2.3 Sound Pressure Formulas	33
2.4 An Example of Temperature Effects	42
2.5 Circular Transducers	42
2.6 Beam Divergence	48
2.7 Rectangular Probes	50
2.8 Focused Sounds Fields	53

2.9	Time-Frequency Response	58
2.10	Probe Classification Based on <i>BW</i> (Damping)	60
2.11	Ultrasonic Beam Interaction with Test Piece / Reflectors	64
2.12	Attenuation	68
2.13	Defect Sizing Using Diffraction and Mode-Conversion Techniques	70
2.13.1	TOFD (Time-of-Flight Diffraction)	70
2.13.2	RATT	80
2.13.3	AATT	81
2.13.4	Mode-converted Techniques	84
2.13.5	Pitch-Catch and Tandem Techniques	88
2.13.6	Satellite Pulses	89
2.14	Testing Round Parts	90
2.15	Measuring the Lengths of Small Defects	92
2.16	Reliability of Ultrasonic Inspection	94
3.	Probes and Ultrasonic Field Formula	97
3.1	Piezo-composite Materials	97
3.1.1	Matching Layer and Cable Requirements	98
3.1.2	Backing Material	98
3.2	Piezo-Composites	99
3.3	Types of Phased Array Probes for Industrial Applications	103
3.4	Linear Array	108
3.4.1	Active Aperture	108
3.4.2	Effective Active Aperture	109
3.4.3	Minimum Active Aperture	110
3.4.4	Passive Aperture	110
3.4.5	Element Gap	111
3.4.6	Element Width	111
3.4.7	Maximum Element Size	111
3.4.8	Elementary Pitch	111
3.4.9	Sweep Range	112
3.4.10	Steering Focus Power	112
3.4.11	Gain Compensation	112
3.4.12	Beam Length	113
3.4.13	Beam Width	114
3.4.14	Focal Depth	115
3.4.15	Depth of Field	116
3.4.16	Focal Range	116
3.4.17	Near-surface Resolution	117
3.4.18	Far-surface Resolution	117
3.4.19	Lateral and Axial Resolution	117
3.4.20	Angular Resolution	118
3.4.21	Main Lobe	118
3.4.22	Side Lobes	118
3.4.23	Grating Lobes	118

3.4.24	Beam Apodization	119
3.4.25	Grating Lobe Amplitude	119
3.5	Dynamic Depth Focusing	121
3.5.1	DDF Beam Divergence	122
3.5.2	DDF Advantages	123
3.6	Probe on the Wedge	123
3.6.1	Wedge Delay	123
3.6.2	Index Point Length	124
3.6.3	Index Point Migration	125
3.7	Beam Deflection on the Wedge	126
3.7.1	Azimuthal Deflection	126
3.7.2	Lateral Deflection	126
3.7.3	Skew Deflection	126
3.7.4	Active Axis	127
3.7.5	Passive Axis	127
3.8	2D Matrix Phased Array Probes	128
3.9	Focal Law Calculator	130
3.10	Other Array Features	134
3.10.1	Sensitivity	134
3.10.2	Impedance	134
3.10.3	Cross-talk	134
3.11	PASS	135
3.12	Probe Design	136
3.12.1	Physics Guidelines	137
3.12.2	Practical Guidelines	139
3.13	Probe Identification	140
3.14	Probe Characterization and Periodic Checking	141
3.14.1	Probe Characterization	141
3.14.2	Tolerances	142
4.	Scanning Patterns and Views	147
4.1	Scanning Patterns	147
4.1.1	Bidirectional	148
4.1.2	Unidirectional	148
4.1.3	Linear Scan	149
4.1.4	Angular	150
4.1.5	Helical	150
4.1.6	Spiral	151
4.1.7	Beam Directions	151
4.1.8	Other Scanning Patterns	152
4.1.9	Free Running Scanning	154
4.2	Ultrasonic Views (Scans)	155
4.2.1	A-Scan	157
4.2.2	B-Scan	159
4.2.3	C-Scan	160

4.2.4	D-Scan	160
4.2.5	S-Scan	161
4.2.6	Polar Views	162
4.2.7	Strip Charts	163
4.2.8	Multiple Views	164
4.2.9	Top, Side, and End Views and Layouts	165
4.2.10	TOFD (Time-of-Flight Diffraction)	166
4.2.11	Combined TOFD and Pulse-Echo (PE)	169
4.2.12	Combined Strip Charts	169
4.2.13	R/D Tech Cube Views	170
5.	Applications	173
5.1	R/D Tech Instruments	174
5.2	Ultrasonic Setup Details	178
5.2.1	Pulse Width	179
5.2.2	Band-Pass Filters	180
5.2.3	Smoothing	180
5.2.4	Digitizing Frequency	181
5.2.5	Averaging	182
5.2.6	Compression	182
5.2.7	Repetition Rate (PRF, or Pulse Repetition Frequency)	183
5.2.8	Acquisition Rate	183
5.2.9	12-Bit versus 8-Bit	184
5.2.10	Setup File	184
5.2.11	Data File Size	185
5.2.12	Ray Tracing	186
5.2.13	On-Site Equipment Checking	187
5.2.14	Active Element Integrity Checking	188
5.3	Aerospace	189
5.3.1	Inspection of Titanium Billets	189
5.3.2	Inspection of Friction Stir Welds	192
5.3.3	Inspection of Fastener Holes	196
5.3.4	Inspection of Landing Gear Using Manual Phased Arrays	199
5.3.5	Corrosion Mapping of Aircraft Fuselage	200
5.4	Energy	201
5.4.1	Dissimilar Welds Inspection of BWR Core Shroud	201
5.4.2	High-Speed Inspection of Stainless Steel and Carbon Steel Pipe Welds	204
5.4.3	Inspection of PWR Main Coolant Wrought Stainless Steel Piping Weld Specimen Using Phased Arrays	207
5.4.4	Reactor Vessel Nozzle-to-Shell Weld	208
5.4.5	CANDU® Feeder Tube Cracking	210
5.4.6	Detection of Stress Corrosion Cracking in Welded Rotor or Single Block Rotor	211

5.4.7	Detection of SCC in Disc Keyway and Anti-Rotation Key in Low-Pressure Turbine Rotor	212
5.4.8	Boresonic Inspection: Detect and Size SCC in the Rotor Body ...	213
5.4.9	Detection and Sizing of SCC in Low-Pressure Turbine Components	215
5.4.10	Detection and Sizing of SCC in Disc Rim-Blade Attachment (GE Style)	217
5.4.11	Detection and Sizing of Fatigue Cracks in Blade Hooks—Axial Entry Parson/Siemens-style	218
5.5	Pressure Vessel Construction Inspection	220
5.5.1	Inspection Codes for Pressure Vessels	220
5.5.2	PV-100: Linear Scanning Using TOFD and PE	223
5.5.3	PV-200: Versatile Phased Array and TOFD System	225
5.5.4	PV-300: Premium Inspection System Using Ultrasonics, Phased Arrays, and Eddy Current Arrays	227
5.5.5	Typical Pressure Vessel Mechanics	229
5.6	Pipeline Phased Arrays	233
5.6.1	Standard Pipeline Zone Discrimination	233
5.6.2	Seamless Pipe Girth Welds	239
5.6.3	Risers and Tendons	240
5.6.4	Small Diameter Piping	241
5.7	Other Applications	243
5.7.1	In-service Inspection of Pipe for Stress Corrosion Cracking	243
5.7.2	Seam Weld Inspections of Coiled Tubing for Offshore Petrochemical Applications	244
5.7.3	T-weld Inspection of Bridge Members	246
5.8	Mills and Manufacturing	247
5.8.1	ERW (Electrical Resistance Welded) Pipes Using Phased Arrays	247
5.8.2	Volumetric Phased Array Inspection of Bars	250
5.8.3	Phased Array Inspection of Whole Body Pipe (In-line)	253
5.8.4	Phased Array Inspection of Copper Canister Weld for Nuclear Waste Fuel	257
5.8.5	Phased Array Inspection of Heavy Forgings	259
5.9	Railroad Transportation	260
5.9.1	Axle (with or without Wheel)	260
5.9.2	Rail Inspection	261
5.9.3	Wheel Inspection	262
6.	Conclusions and Recommendations	267
6.1	Advantages of Phased Arrays	267
6.2	General Phased Array Solutions to Inspection Problems	267
6.3	Implementing Phased Array Technology	270

Appendix: Technical Support 273
References 279
Index 287