
Contents

From the Series Editor	xix
Preface	xxi
Preface to First Edition	xxiii
Author	xxv
Chapter 1 Waves and Beams	1
1.1 The Wave Equation	1
1.2 Plane Waves	2
1.3 Spherical Waves	2
1.4 Cylindrical Waves	2
1.5 Waves as Information Carriers	3
1.5.1 Amplitude/Intensity-Based Sensors	4
1.5.2 Sensors Based on Phase Measurement	4
1.5.3 Sensors Based on Polarization	5
1.5.4 Sensors Based on Frequency Measurement	5
1.5.5 Sensors Based on Change of Direction	5
1.6 The Laser Beam	5
1.7 The Gaussian Beam	6
1.8 <i>ABCD</i> Matrix Applied to Gaussian Beams	8
1.8.1 Propagation in Free Space	9
1.8.2 Propagation through a Thin Lens	10
1.8.3 Mode Matching	12
1.9 Nondiffracting Beams—Bessel Beams	12
1.10 Singular Beams	13
Bibliography	17
Additional Reading	17
Chapter 2 Optical Interference	19
2.1 Introduction	19
2.2 Generation of Coherent Waves	20
2.2.1 Interference by Division of Wavefront	20
2.2.2 Interference by Division of Amplitude	20
2.3 Interference between Two Plane Monochromatic Waves ...	21
2.3.1 Young's Double-Slit Experiment	22
2.3.2 Michelson Interferometer	24
2.4 Multiple-Beam Interference	25

2.4.1	Multiple-Beam Interference: Division of Wavefront	25
2.4.2	Multiple-Beam Interference: Division of Amplitude	27
	2.4.2.1 Interference Pattern in Transmission	27
	2.4.2.2 Interference Pattern in Reflection	29
2.5	Interferometry	29
2.5.1	Dual-Wavelength Interferometry	30
2.5.2	White Light Interferometry	31
2.5.3	Heterodyne Interferometry	31
2.5.4	Shear Interferometry	32
2.5.5	Polarization Interferometers	33
2.5.6	Interference Microscopy	34
2.5.7	Doppler Interferometry	36
2.5.8	Fiber-Optic Interferometers	37
2.5.9	Phase-Conjugation Interferometers	38
	Bibliography	39
	Additional Reading	40
Chapter 3	Diffraction	43
3.1	Fresnel Diffraction	43
3.2	Fraunhofer Diffraction	44
3.3	Action of a Lens	45
3.4	Image Formation and Fourier Transformation by a Lens ...	45
	3.4.1 Image Formation	47
	3.4.2 Fourier Transformation	47
3.5	Optical Filtering	49
3.6	Optical Components in Optical Metrology	50
	3.6.1 Reflective Optical Components	50
	3.6.2 Refractive Optical Components	50
	3.6.3 Diffractive Optical Components	52
	3.6.3.1 Sinusoidal Grating	55
	3.6.4 Phase Grating	56
	3.6.5 Diffraction Efficiency	57
3.7	Resolving Power of Optical Systems	57
	Bibliography	58
Chapter 4	Phase-Evaluation Methods	59
4.1	Interference Equation	59
4.2	Fringe Skeletonization	60
4.3	Temporal Heterodyning	61
4.4	Phase-Sampling Evaluation: Quasi-Heterodyning	62
4.5	Phase-Shifting Method	63
4.6	Phase-Shifting with Unknown but Constant Phase-Step	63
4.7	Spatial Phase-Shifting	66

4.8	Methods of Phase-Shifting	68
	4.8.1 PZT-Mounted Mirror	68
	4.8.2 Tilt of Glass Plate	69
	4.8.3 Rotation of Polarization Component	70
	4.8.4 Motion of a Diffraction Grating	72
	4.8.5 Use of a CGH Written on a Spatial Light Modulator	72
	4.8.6 Special Methods	72
4.9	Fourier Transform Method	72
4.10	Spatial Heterodyning	73
	Bibliography	75
	Additional Reading	75
Chapter 5	Detectors and Recording Materials	79
5.1	Detector Characteristics	79
5.2	Detectors	80
	5.2.1 Photoconductors	80
	5.2.2 Photodiodes	81
	5.2.3 Photomultiplier Tube	84
5.3	Image Detectors	84
	5.3.1 Time-Delay and Integration Mode of Operation	89
5.4	Recording Materials	89
	5.4.1 Photographic Films and Plates	90
	5.4.2 Dichromated Gelatin	94
	5.4.3 Photoresists	95
	5.4.4 Photopolymers	95
	5.4.5 Thermoplastics	96
	5.4.6 Photochromics	96
	5.4.7 Ferroelectric Crystals	97
	Bibliography	98
	Additional Reading	98
Chapter 6	Holographic Interferometry	101
6.1	Introduction	101
6.2	Hologram Recording	102
6.3	Reconstruction	103
6.4	Choice of Angle of Reference Wave	104
6.5	Choice of Reference Wave Intensity	105
6.6	Types of Holograms	105
6.7	Diffraction Efficiency	105
6.8	Experimental Arrangement	105
	6.8.1 Lasers	106
	6.8.2 Beam-Splitters	107
	6.8.3 Beam-Expanders	107
	6.8.4 Object-Illumination Beam	107

6.8.5	Reference Beam	107
6.8.6	Angle between Object and Reference Beams	108
6.9	Holographic Recording Materials	108
6.10	Holographic Interferometry	108
6.10.1	Real-Time HI	108
6.10.2	Double-Exposure HI	109
6.10.3	Time-Average HI	110
6.10.4	Real-Time, Time-Average HI	115
6.11	Fringe Formation and Measurement of Displacement Vector	115
6.12	Loading of the Object	116
6.13	Measurement of Very Small Vibration Amplitudes	117
6.14	Measurement of Large Vibration Amplitudes	117
6.14.1	Frequency Modulation of Reference Wave	117
6.14.2	Phase Modulation of Reference Beam	119
6.15	Stroboscopic Illumination/Stroboscopic HI	120
6.16	Special Techniques in Holographic Interferometry	121
6.16.1	Two-Reference-Beam HI	121
6.16.2	Sandwich HI	123
6.16.3	Reflection HI	125
6.17	Extending the Sensitivity of HI	127
6.17.1	Heterodyne HI	127
6.18	Holographic Contouring/Shape Measurement	129
6.18.1	Dual-Wavelength Method	129
6.18.2	Dual-Refractive Index Method	131
6.18.3	Dual-Illumination Method	132
6.19	Holographic Photoelasticity	132
6.20	Digital Holography	132
6.20.1	Recording	132
6.20.2	Reconstruction	133
6.21	Digital Holographic Interferometry	135
	Bibliography	136
	Additional Reading	137
Chapter 7	Speckle Metrology	149
7.1	The Speckle Phenomenon	149
7.2	Average Speckle Size	149
7.2.1	Objective Speckle Pattern	150
7.2.2	Subjective Speckle Pattern	150
7.3	Superposition of Speckle Patterns	151
7.4	Speckle Pattern and Object Surface Characteristics	152
7.5	Speckle Pattern and Surface Motion	152
7.5.1	Linear Motion in the Plane of the Surface	152
7.5.2	Out-of-Plane Displacement	152
7.5.3	Tilt of the Object	153
7.6	Speckle Photography	155

7.7	Methods of Evaluation	158
7.7.1	Pointwise Filtering	158
7.7.2	Wholefield Filtering	160
7.7.3	Fourier Filtering: Measurement of Out-of-Plane Displacement	161
7.8	Speckle Photography with Vibrating Objects: In-Plane Vibration	161
7.9	Sensitivity of Speckle Photography	162
7.10	Particle Image Velocimetry	162
7.11	White-Light Speckle Photography	162
7.12	Shear Speckle Photography	163
7.13	Speckle Interferometry	164
7.14	Correlation Coefficient in Speckle Interferometry	167
7.15	Out-of-Plane Speckle Interferometer	168
7.16	In-Plane Measurement: Duffy's Method	169
7.17	Filtering	171
7.17.1	Fringe Formation	171
7.18	Out-of-Plane Displacement Measurement	173
7.19	Simultaneous Measurement of Out-of-Plane and In-Plane Displacement Components	174
7.20	Other Possibilities for Aperturing the Lens	175
7.21	Duffy's Arrangement: Enhanced Sensitivity	176
7.22	Speckle Interferometry—Shape Measurement/Contouring	177
7.23	Speckle Shear Interferometry	177
7.23.1	The Meaning of Shear	177
7.24	Methods of Shearing	178
7.25	Theory of Speckle Shear Interferometry	180
7.26	Fringe Formation	181
7.26.1	The Michelson Interferometer	181
7.26.2	The Apertured Lens Arrangement	182
7.27	Shear Interferometry without Influence of the In-Plane Component	183
7.28	Electronic Speckle Pattern Interferometry	183
7.28.1	Out-of-Plane Displacement Measurement	184
7.28.2	In-Plane Displacement Measurement	185
7.28.3	Vibration Analysis	185
7.28.4	Measurement on Small Objects	186
7.28.5	Shear ESPI Measurement	187
7.29	Contouring in ESPI	187
7.29.1	Change of Direction of Illumination	188
7.29.2	Change of Wavelength	189
7.29.3	Change of Medium Surrounding the Object	189
7.29.4	Tilt of the Object	189
7.30	Special Techniques	189
7.30.1	Use of Retro-Reflective Paint	189

7.31	Spatial Phase-Shifting	190
	Bibliography	191
	Additional Reading	191
Chapter 8	Photoelasticity	201
8.1	Superposition of Two-Plane Polarized Waves	201
8.2	Linear Polarization	202
8.3	Circular Polarization	203
8.4	Production of Polarized Light	203
	8.4.1 Reflection	204
	8.4.2 Refraction	204
	8.4.3 Double Refraction	204
	8.4.3.1 Phase Plates	205
	8.4.3.2 Quarter-Wave Plate	206
	8.4.3.3 Half-Wave Plate	206
	8.4.3.4 Compensators	206
	8.4.4 Dichroism	207
	8.4.5 Scattering	207
8.5	Malus's Law	207
8.6	The Stress-Optic Law	207
8.7	The Strain-Optic Law	209
8.8	Methods of Analysis	210
	8.8.1 Plane Polariscope	210
	8.8.2 Circular Polariscope	212
8.9	Evaluation Procedure	216
8.10	Measurement of Fractional Fringe Order	217
	8.10.1 Tardy's Method	217
8.11	Phase-Shifting	220
	8.11.1 Isoclinics Computation	220
	8.11.2 Computation of Isochromatics	221
8.12	Birefringent Coating Method: Reflection Polariscope	222
8.13	Holophotoelasticity	223
	8.13.1 Single-Exposure Holophotoelasticity	224
	8.13.2 Double-Exposure Holophotoelasticity	225
8.14	Three-Dimensional Photoelasticity	229
	8.14.1 The Frozen-Stress Method	229
	8.14.2 Scattered-Light Photoelasticity	230
8.15	Examination of the Stressed Model in Scattered Light	230
	8.15.1 Unpolarized Incident Light	230
	8.15.2 Linearly Polarized Incident Beam	232
	Bibliography	233
	Additional Reading	234
Chapter 9	The Moiré Phenomenon	239
9.1	Introduction	239

9.2	The Moiré Fringe Pattern between Two Linear Gratings	239
	9.2.1 $a \neq b$ but $\theta = 0$	241
	9.2.2 $a = b$ but $\theta \neq 0$	241
9.3	The Moiré Fringe Pattern between a Linear Grating and a Circular Grating	242
9.4	Moiré between Sinusoidal Gratings	243
9.5	Moiré between Reference and Deformed Gratings	245
9.6	Moiré Pattern with Deformed Sinusoidal Grating	246
	9.6.1 Multiplicative Moiré Pattern	247
	9.6.2 Additive Moiré Pattern	247
9.7	Contrast Improvement of the Additive Moiré Pattern	248
9.8	Moiré Phenomenon for Measurement	248
9.9	Measurement of In-Plane Displacement	248
	9.9.1 Reference and Measurement Gratings of Equal Pitch and Aligned Parallel to Each Other	248
	9.9.2 Two-Dimensional In-Plane Displacement Measurement	249
	9.9.3 High-Sensitivity In-Plane Displacement Measurement	251
9.10	Measurement of Out-of-Plane Component and Contouring	253
	9.10.1 The Shadow Moiré Method	254
	9.10.1.1 Parallel Illumination and Parallel Observation	254
	9.10.1.2 Spherical-Wave Illumination and Camera at Finite Distance	255
	9.10.2 Automatic Shape Determination	257
	9.10.3 Projection Moiré	257
	9.10.4 Light-Line Projection with TDI Mode of Operation of CCD Camera	260
	9.10.5 Coherent Projection Method	262
	9.10.5.1 Interference between Two Collimated Beams	262
	9.10.5.2 Interference between Two Spherical Waves	263
	9.10.6 Measurement of Vibration Amplitudes	264
	9.10.7 Reflection Moiré Method	265
9.11	Slope Determination for Dynamic Events	267
9.12	Curvature Determination for Dynamic Events	268
9.13	Surface Topography with Reflection Moiré Method	269
9.14	Talbot Phenomenon	271
	9.14.1 Talbot Effect in Collimated Illumination	272
	9.14.2 Cut-Off Distance	273
	9.14.3 Talbot Effect in Noncollimated Illumination	273

9.14.4	Talbot Effect for Measurement.....	274
9.14.4.1	Temperature Measurement	274
9.14.4.2	Measurement of the Focal Length of a Lens and the Long Radius of Curvature of a Surface.....	275
	Bibliography	275
	Additional Reading	275
Index		283