

Contents

Preface	v
Chapter 1: Three-Dimensional Theories	1
1.1 Nonlinear Electroelasticity for Strong Fields	1
1.2 Linear Piezoelectricity for Weak Fields	7
1.3 Linear Theory for Small Fields Superposed on a Finite Bias	12
1.4 Cubic Theory for Weak Nonlinearity	19
Chapter 2: Piezoelectric Plates	22
2.1 Exact Modes in a Plate	22
2.1.1 Thickness-shear vibration of a quartz plate	22
2.1.2 Propagating waves in a plate	28
2.2 Power Series Expansion	34
2.2.1 Expansions of displacement and potential	35
2.2.2 Strains and electric fields	37
2.2.3 Constitutive relations	38
2.2.4 Equations of motion and charge	39
2.3 Zero-Order Theory for Extension	41
2.3.1 Equations for zero-order theory	41
2.3.2 Extensional and face-shear waves	47
2.3.3 Equations for ceramic plates	49
2.3.4 Radial vibration of a circular ceramic disk	54
2.4 First-Order Theory	58
2.4.1 Coupled extension, flexure and thickness-shear	58
2.4.2 Flexural and thickness-shear waves	64
2.4.3 Reduction to classical flexure	66
2.4.4 Thickness-shear approximation	69
2.4.5 Equations for ceramic plates	72
2.4.6 Shear correction factors for ceramic plates	78
2.4.7 Thickness-shear vibration of an inhomogeneous ceramic plate	82
2.4.8 A ceramic plate piezoelectric gyroscope	91

2.4.9	Equations for a quartz plate	96
2.4.10	A quartz piezoelectric resonator	102
2.4.11	Free vibration eigenvalue problem	104
2.5	Second-Order Theory	107
2.5.1	Equations for second-order theory	108
2.5.2	Extension, thickness-stretch and symmetric thickness-shear	111
2.5.3	Elimination of extension	116
2.5.4	Thickness-stretch approximation	117
Chapter 3: Laminated Plates and Plates on Substrates		122
3.1	Elastic Plates with Symmetric Piezoelectric Actuators	122
3.1.1	Equations for a partially electroded piezoelectric actuator	122
3.1.2	Equations for an elastic plate	125
3.1.3	Equations for an elastic plate with symmetric actuators	127
3.1.4	Reduction to classical flexure	130
3.1.5	Dispersion relations	131
3.2	Elastic Plates with Piezoelectric Actuators on One Side	133
3.2.1	Classical theory	133
3.2.2	Stress function formulation for static problems	138
3.2.3	A circular plate under a uniform load	140
3.2.4	A circular plate under a concentrated load	143
3.3	Laminated Piezoelectric Plates	145
3.3.1	Power series expansion	145
3.3.2	First-order theory	147
3.4	A Plate on a Substrate	150
3.4.1	A piezoelectric film on an elastic half-space	150
3.4.2	Piezoelectric surface waves guided by a thin elastic film	162
Chapter 4: Nonlinear Effects in Electroelastic Plates		168
4.1	Plates under Biasing Fields	168
4.1.1	First-order theory	168
4.1.2	Buckling of ceramic plates	172
4.2	Large Thickness-Shear Deformations	179
4.2.1	First-order theory	180
4.2.2	Thickness-shear vibration of a quartz plate	184

Chapter 5: Piezoelectric Shells	189
5.1 First-Order Theory	189
5.2 Classical Theory	196
5.3 Membrane Theory	199
5.4 Vibrations of Ceramic Shells	201
5.4.1 Radial vibration of a spherical shell	201
5.4.2 Radial vibration of a circular cylindrical shell	202
5.5 A Shell on a Non-Thin Body	204
5.5.1 A piezoelectric shell on an elastic body	204
5.5.2 An elastic shell on a piezoelectric body	210
5.5.3 An elastic shell in a viscous fluid	220
Chapter 6: Piezoelectric Beams	225
6.1 Power Series Expansion	225
6.2 Zero-Order Theory For Extension	227
6.2.1 Equations for zero-order theory	228
6.2.2 Equations for ceramic beams	231
6.2.3 Extensional vibration of a ceramic beam	234
6.3 First-Order Theory	235
6.3.1 Coupled extension, flexure and shear	236
6.3.2 Reduction to classical flexure	242
6.3.3 Thickness-shear approximation	244
6.3.4 Equations for ceramic bimorphs	249
6.3.5 A transformer — free vibration analysis	252
Chapter 7: Piezoelectric Rings	262
7.1 First-Order Theory	262
7.2 Classical Theory	266
7.3 Radial Vibration of a Ceramic Ring	268
Chapter 8: Piezoelectric Parallelepipeds	270
8.1 Power Series Expansion	270
8.2 Zero-Order Equations	273
8.3 A Piezoelectric Gyroscope	274
8.3.1 Governing equations	275
8.3.2 Free vibration	277
8.3.3 Forced vibration	280

8.4	A Transformer — Forced Vibration Analysis	283
8.4.1	Governing equations	284
8.4.2	Forced vibration analysis	287
	References	291
	Appendix 1 Notation	296
	Appendix 2 Electroelastic Material Constants	298
	Index	312