

INDEX

- Absorber. *See* Vibration absorber
- Accelerance, 260
- Acceleration, 78. *See also* Dynamics
 - base, 98
 - gyroscopic, 354
 - harmonic excitation, due to, 211
 - measurement of, 261
 - response, 161
 - vector, 357, 361
- Accelerometer, 261
- Amplitude response, 201
 - bandwidth, 253
 - base excitation, 227
 - cutoff frequencies, 252
 - damping-dominated region, 218
 - filter characteristics, 251
 - mass-dominated region, 219
 - quality factor, 253
 - rotating unbalanced mass, 222
 - stiffness-dominated region, 218
 - structural damping, 279
 - summary, 230
- Aperiodic motion, 286, 508, 515, 523, 524
- Axial force. *See* Beams
- Bars, vibration of. *See* State-space formulation
- Base excitation, 97, 227
 - two degree-of-freedom system, 536
- Beams
 - axial force, 552, 616
 - boundary conditions, 555, 560, 568, 583
 - characteristic equation, 574, 575, 576
 - elastic foundation, 553, 616
 - forced oscillations, 622
 - frequency-response function, 631
 - governing equation, 547, 559, 567
 - in-span attachments, with, 599
 - kinetic energy, 551
 - Lagrange's equation, 557
 - Lagrangian, 554
 - mode shapes, 577, 579, 583
 - natural frequencies, 583
 - natural frequencies, solution for, 570
 - orthogonality of mode shapes, 580
 - potential energy, 550
 - rigid body mode, 587
 - single degree-of-freedom system,
 - in-span, 554
 - tapered, 617
- Chaotic behavior, 286, 508, 515
- Coefficient of restitution, 167
- Collision
 - particle damper, 516
 - vehicle bumper, 168
 - viscoelastic bodies, 172
- Convolution integral, 298, 463, 627
- Coulomb (dry friction) damping, 52, 273
- Coulomb damping, 184
- Critical damping, 92
- Curve fitting, 28, 33, 92, 163, 249, 250
- Damped natural frequency, 150, 154, 155, 245, 298, 319, 415, 463, 465, 627
- Damping. *See* Dissipation elements; Energy dissipation
- Damping coefficient, 44
- Damping factor
 - logarithmic decrement, from, 173
 - rotating system, 92
 - system parameters, effects of, 93
 - translating and rotating system, 108
 - translating system, 92
- Damping matrix, 357, 358, 413, 415, 416
- Degrees of freedom. *See* Dynamics
- Displacement
 - base excitation, due to, 226
 - beam, arbitrary excitation of, 627
 - forced harmonic, damped, 201
 - forced harmonic, undamped, 214
 - free response, 150
 - multiple degree-of-freedom system, arbitrary excitation of, 464

- Displacement (*cont.*)
 multiple degree-of-freedom system,
 harmonic excitation of, 478
 transient excitation, due to, 298
 unbalanced mass, due to, 222
- Dissipation elements, 12, 44
 combined with spring, 50
 Coulomb (dry friction), 52
 energy dissipation, 49
 fluid (velocity-squared) damping, 52
 squeeze film air damping, 53
 structural (hysteretic) damping, 53
 viscous fluid, 44, 54
- Dynamics, 647–60
- Eigenfunctions, 571
- Eigenvalues, 181, 379, 381, 396, 412, 571, 580
- Eigenvector, 379
- Energy dissipation, 165, 271
 comparisons of different types, 276
 Coulomb (dry friction), 273
 equivalent viscous damping, 270
 fluid (velocity-squared), 274
 structural, 275
 viscous, 271
- Equivalent viscous damping, 270
 Coulomb, 274
 fluid (velocity squared), 275
 structural, 276
- Fluid (velocity-squared) damping, 52,
 184, 276
- Force on fixed surface, 81, 164
 impulse, from, 302
 rotating unbalanced mass, 224
- Force-balance method, 77, 346
- Forced harmonic excitation, 200
 Maxwell model, 233
 N harmonic components (Fourier series), 241
 nonlinear springs, with, 282
 resonance, 215
 steady state, 201, 210
 transient part, 201
 two harmonic components, with, 238
 undamped, 214
- Fourier series, 241
 periodic pulse train, 243
- Fourier transform, 304
- Free response of multiple degree-of-freedom
 systems, 378
 characteristic equation, 379, 385
 modal matrix, 380, 384
 mode shapes, 378, 380
 natural frequencies, 378
 rigid-body mode, 390
- Free response of single degree-of-freedom
 system, 150
 critically damped system, 151
 Kelvin–Voigt model, 157
 Maxwell model, 176
 overdamped system, 151
 undamped system, 151
 underdamped system, 150
- Frequency-response function, 248, 255
 alternate forms, 260
 Fourier transform, relation to, 258
 two degree-of-freedom system, 473, 475, 485
- Fundamental frequency, 241
- Generalized coordinates, 102, 346, 347,
 434, 489
- Generalized force, 102, 428
- Governing equation of single degree-of-freedom
 system
 added mass of fluid, 100
 base excitation, 97
 Coulomb damping, 96
 fluid (velocity-squared) damping, 97
 force balance method, from, 78
 moment balance method, from, 83
 nonlinear damping, 184
 nonlinear spring, with, 182
 piecewise linear springs, with, 182
 structural damping, 97
 unbalanced rotating mass, 99
- Governing equations multiple degree-of-freedom
 systems, 346
 base excitation, 536
 bounce and pitch, systems with, 351
 equilibrium position, 352
 force balance methods, from, 346
 Lagrange's equations, using, 359
 matrix form, 347, 356
 moment balance methods, from, 347
 N degree-of-freedom system, 356
- Gyroscopic force, 421
- Harmonic excitation. *See* Forced harmonic
 excitation
- Hysteresis loop, 276
- Impact. *See* Transient excitation
- Impact testing, 338
- Impulse response, 301

- Inertia
 - elements, 12
 - force, 78
 - mass moment of, 16
 - rotary, 84
 - varying, 17
- Inertia matrix, 347, 357, 358, 415
- Initial conditions, 157, 465
- Initial value problem, 148
- Input-output relationship, 198, 304
- Isolation. *See* Vibration isolation
- Kelvin–Voigt model, 50
- Kinetic energy, 13, 102, 165, 359, 425, 551, 554. *See also* Dynamics
- Lagrange’s equations for multiple
 - degree-of-freedom systems, 102
 - bell and clapper, 369
 - bounce and pitch, 364
 - generalized coordinates, 102
 - generalized force, 102
 - hand-arm vibrations, 373
 - kinetic energy, 102
 - Lavrov’s device, 371
 - pendulum absorber, 366
 - potential energy, 102
 - Rayleigh dissipation function, 102
 - translating mass and oscillating disc, 363
 - translating mass with pendulum, 393
 - translating mass with system of single
 - degree-of-freedom systems, 400
 - translating two degree-of-freedom system, 362
- Lagrange’s equations for single
 - degree-of-freedom system, 103
 - car seat, 115
 - centrifugal governor, 127
 - crankshaft, 124
 - disc segment, 111
 - disc with extended mass, 117
 - inverted pendulum, 108
 - MEMS device, 119
 - pretensioned spring, 114
 - rotating system, 128
 - slider mechanism, 122
 - translation and rotation, 106
- Laplace transform. *See also* Laplace transform pairs
 - base excitation, solution to, 329
 - beam equation, solution to, 571
 - beam, forced vibrations of, 626
 - frequency-response function, relation to, 257
 - initial value problem, solution to, 149
 - stability, determination of, 179
 - transfer function, 255
 - transient excitation, solution to, 298, 316
- Laplace transform pairs, 661–7
- Linear momentum, 301
 - principle of, 14
- Linear systems, 211, 271, 356, 363, 508
 - reciprocity property, 633
- Linearization, 83, 352, 376, 507
- Logarithmic decrement, 163
- Maxwell model, 50, 233
 - reduction to Kelvin–Voigt model, 235
- Mechanical impedance, 261
- Mobility, 260
- Modal analysis, experimental, 28, 261
- Modal matrix, 380, 402, 408, 461
- Mode shapes. *See* Multiple degree-of-freedom systems
- Model construction, 55
 - aircraft wing, 57
 - axial fan, 59
 - civil structure, 56
 - crane, 58
 - drop forge, 59
 - human body, 62
 - loudspeaker, 56
 - machine tool cutting process, 64
 - MEMS accelerometer, 60
 - motorcycle, 59
 - ski, 63
- Moment-balance method, 77, 347
- Moving base. *See* Base excitation
- Multiple degree-of-freedom systems
 - arbitrary forcing, response to, 472
 - characteristics of damped systems, 411
 - conservation of energy, 421
 - damping factor, constant, 416
 - frequency-response function, 473, 475, 485
 - generalized coordinates, 461
 - harmonic forcing, 475
 - initial conditions, response to, 463, 465
 - linear independence of modes, 410
 - modal coordinates, 463
 - modal damping, 463
 - modal damping factor, 414
 - modal mass, 408
 - modal matrix, 380, 402, 415, 461
 - modal stiffness, 408

- Multiple degree-of-freedom systems (*cont.*)
 - mode shapes, orthogonality of, 402
 - mode shapes, table of, 402
 - natural frequencies, table of, 402
 - node points, 397
 - normal mode solution, 461
 - orthonormal mode, 409
 - proportional damping, 413, 462
 - rotating shafts, 424
 - stability, 434
 - structural damping, 483
- Natural frequency of single degree-of-freedom systems
 - disc segment, 113
 - MEMS device, 121
 - pendulum system, 110
 - rotating system, 88, 119, 129
 - static deflection, from, 88
 - translating and rotating system, 108
 - translating system, 87
 - translating system with pretensioned spring, 115, 117
- Nonlinear damping, 184
- Nonlinear stiffness, 32
 - cubic, 282
 - cubic, 32, 33
 - cubic, 283
 - cubic hardening, 182
 - due to geometry, 34
 - gear backlash, 286
 - piecewise linear, 182
 - quadratic, 82
- Normal modes, 380
 - orthonormal, 409
- Orthogonal function, 580, 624, 626
- Orthogonality
 - eigenvectors, 407, 415
 - modes, 402, 466, 580
- Overdamped system, 92, 151
- Overshoot. *See* Transient excitation
- Parallel axis theorem, 13
- Parameter estimation, 250
- Pendulums, 41
 - absorber, 366, 511
 - inverted, 108
 - inverted, instability of, 180
- Period of free oscillation
 - damped, 161
 - undamped, 88
- Phase response, 201
 - base excitation, 227
 - rotating unbalanced mass, 222
 - structural damping, 279
 - summary, 230
- Phase-plane plot, 165
- Potential energy
 - beam, 550
 - compressed gas, 40
 - fluid element, 38
 - nonlinear stiffness element, 32
 - pendulums, 41
 - spring, 19
- Principal coordinates, 463
- Quality factor, 253
 - power dissipated, and, 272
- Rayleigh dissipation function, 102
- Rigid body mode, 389, 587
- Rise time. *See* Transient excitation
- Root locus diagram, 179
- Rotating shafts. *See* Multiple degree-of-freedom systems
- Settling time. *See* Transient excitation
- Shafts, vibration of. *See* State-space formulation
- Single degree-of-freedom systems
 - beam, attached to, 559
 - damping factor, 92
 - forced harmonic excitation, 200, 238
 - forced harmonic undamped, 214
 - free response, 150
 - governing equation added mass of fluid, 101
 - governing equation rotation, 84
 - governing equation translation, 80
 - natural frequency, 87
 - transient excitation, response to, 298
 - vibration isolation of, 263
- Springs
 - equivalent spring constant, 29
 - equivalent torsional spring constant, 22
 - equivalent translation spring constant, 21, 28, 30, 31
 - in parallel, 21, 23
 - in series, 21
 - nonlinear, 182
 - potential energy, 20, 22
 - structural elements, 25
 - torsion, 20
 - translation, 20

- Squeeze film air damping, 53
- Stability
 - asymptotic, 180
 - multiple degree-of-freedom system, 434
 - pendulum, inverted, 180
 - root locus diagram, 179
 - single degree-of-freedom, 178
- State-space formulation, 689–95
- Static displacement, 79
 - unbalanced rotating mass, 100
- Static equilibrium position, 79, 82, 86
- Steady state response, 201, 209, 217, 238, 520, 522
- Step force
 - single degree-of-freedom system, 312
 - two degree-of-freedom system, 472
- Step force, response to
 - single degree-of-freedom system, 310
 - two degree-of-freedom system, 472
- Stiffness
 - complex-valued, 281
- stiffness elements, 31
- Stiffness elements, 12, 18
 - nonlinear, 32
 - nonlinear from geometry, 34, 36
- Stiffness matrix, 348, 357, 358, 415
- Strings, vibration of. *See* State-space formulation
- System identification, 28
- Transfer function, 255
 - frequency-response function, relation to, 255
- Transient excitation, 297
 - convolution integral, using, 298
 - impulse, 300
 - impulse testing, 304
 - Laplace transform, using, 298
 - moving base, 329
 - multiple degree-of-freedom systems, 464
 - nonlinear spring, with, 331
 - overshoot, percentage, 312
 - rectangular pulse, 316
 - rise time, 312
 - settling time, 313
 - spectral content, significance of, 334
 - step input, 310
 - waveforms, other, 320
- Transmissibility ratio, 265
 - Maxwell model, of, 266
 - single degree-of-freedom system, 265
 - two degree-of-freedom system, 531
- Unbalanced rotating mass, 99, 221, 224
- Underdamped system, 92
- Unstable. *See* Stability
- Velocity, 274
 - harmonic excitation, due to, 211, 218, 219
 - particle damper, 518
 - transient response, 157
- Vibration absorber, 489
 - bar-slider system, 508
 - centrifugal pendulum, 504
 - damped, 492
 - optimal values, 497, 498
 - particle impact damper, 515
 - pendulum, 511
 - table of, 525
 - undamped, 489
- Vibration isolation, 263, 531
 - base excitation, 264
 - mass excitation, 264
- Vibrations
 - brief history of, 6
 - definition of, 1
 - design for, 65
 - subset of dynamics, 5
 - unwanted, 1
- Viscous damping, 44, 101, 103, 271, 348, 359, 622
- Whirling, 433
- Work, 15
- Work-energy theorem, 15