

SOUMITRO BANERJEE

Dynamics

FOR ENGINEERS

 WILEY

Contents

Preface	xi
I Obtaining differential equations for physical systems	1
1 Introduction to System Elements	3
1.1 Introduction	3
1.1.1 The inertial element	3
1.1.2 The compliant element	5
1.1.3 The resistive element	6
1.1.4 The voltage source and externally impressed force	7
1.1.5 The current source and externally impressed sources of flow	8
1.2 Chapter Summary	9
Further Reading	10
2 Obtaining Differential Equations for Mechanical Systems by the Newtonian Method	11
2.1 The Configuration Space	12
2.2 Constraints	13
2.3 Differential Equations from Newton's Laws	15
2.4 Practical Difficulties with the Newtonian Formalism	16
2.5 Chapter Summary	17
Further Reading	18
Problems	18
3 Differential Equations of Electrical Circuits from Kirchoff's Laws	21
3.1 Kirchoff's Laws about Current and Voltage	21
3.2 The Mesh Current and Node Voltage Methods	23
3.3 Using Graph Theory to Obtain the Minimal Set of Equations	28
3.3.1 Kirchoff's laws relating to loops and cutsets	29

3.3.2	Tree and co-tree	30
3.3.3	The independent KCL and KVL equations	31
3.3.4	The choice of the state variables	31
3.3.5	Derivation of differential equations	32
3.4	Chapter Summary	41
	Further Reading	42
	Problems	42
4	The Lagrangian Formalism	45
4.1	Elements of the Lagrangian Approach	46
4.1.1	Motivation	46
4.1.2	The concept of admissible motions	46
4.1.3	The generalized coordinates	48
4.1.4	Dynamical equations in terms of energies	50
4.2	Obtaining Dynamical Equations by Lagrangian Method	53
4.3	The Principle of Least Action	62
4.4	Lagrangian Method Applied to Electrical Circuits	67
4.5	Systems with External Forces or Electromotive Forces	68
4.6	Systems with Resistance or Friction	70
4.7	Accounting for Current Sources	74
4.8	Modelling Mutual Inductances	75
4.9	A General Methodology for Electrical Networks	77
4.10	Modelling Coulomb Friction	78
4.11	Chapter Summary	80
	Further Reading	80
	Problems	81
5	Obtaining First-order Equations	85
5.1	First-order Equations from the Lagrangian Method	85
5.2	The Hamiltonian Formalism	88
5.3	Chapter Summary	100
	Problems	101
6	Unified Modelling of Systems Through the Language of Bond Graphs	105
6.1	Introduction	105
6.2	The Basic Concept	106
6.3	One-port Elements	106
6.4	The Junctions	108
6.5	Junctions in Mechanical Systems	110
6.6	Numbering of Bonds	112
6.7	Reference Power Directions	112

6.8	Two-port Elements	116
6.9	The Concept of Causality	118
6.10	Differential Causality	121
6.11	Obtaining Differential Equations from Bond Graphs	123
6.12	Alternative Methods of Creating System Bond Graphs	128
6.12.1	Electrical systems	129
6.12.2	Mechanical systems	130
6.13	Algebraic Loops	132
6.14	Fields	134
6.15	Activation	138
6.16	Equations for Systems with Differential Causality	141
6.17	Bond Graph Software	142
6.18	Chapter Summary	144
	Further Reading	145
	Problems	145
II	Solving differential equations and understanding dynamics	151
7	Numerical Solution of Differential Equations	153
7.1	The Basic Method and the Techniques of Approximation	153
7.1.1	The Euler method	154
7.1.2	The trapezoidal rule	155
7.1.3	The fourth-order Runge-Kutta formula	156
7.2	Methods to Balance Accuracy and Computation Time	158
7.3	Chapter Summary	159
	Further Reading	159
	Problems	160
8	Dynamics in the State Space	161
8.1	The State Space	162
8.2	Vector Field	163
8.3	Local Linearization Around Equilibrium Points	163
8.4	Chapter Summary	166
	Problems	166
9	Solutions for a System of First-order Linear Differential Equations	169
9.1	Solution of a First-order Linear Differential Equation	170
9.2	Solution of a System of Two First-order Linear Differential Equations	171
9.3	Eigenvalues and Eigenvectors	172

9.4	Using Eigenvalues and Eigenvectors for Solving Differential Equations	173
9.4.1	Eigenvalues real and distinct	174
9.4.2	Eigenvalues complex conjugate	177
9.4.3	Eigenvalues purely imaginary	180
9.4.4	Eigenvalues real and equal	184
9.5	Solution of a Single Second-order Differential Equation	186
9.6	Systems with Higher Dimensions	189
9.7	Chapter Summary	194
	Further Reading	195
	Problems	195
10	Linear Systems with External Input	197
10.1	Constant External Input	197
10.1.1	Constant voltage applied to an RL circuit	197
10.1.2	The concept of time constant	199
10.1.3	Constant voltage applied to an RC circuit	201
10.1.4	Constant voltage applied to an RLC circuit	202
10.2	When the Forcing Function is a Square Wave	203
10.3	Sinusoidal Forcing Function	204
10.3.1	First-order systems excited by sinusoidal source	204
10.3.2	Second-order system excited by sinusoidal source	210
10.4	Other Forms of Excitation Function	213
10.5	Chapter Summary	215
	Further Reading	215
	Problems	215
11	Dynamics of Nonlinear Systems	219
11.1	All Systems of Practical Interest are Nonlinear	219
11.2	Vector Fields for Nonlinear Systems	220
11.3	Attractors in Nonlinear Systems	227
11.4	Limit Cycle	228
11.5	Different Types of Periodic Orbits in a Nonlinear System	229
11.6	Chaos	231
11.7	Quasiperiodicity	234
11.8	Stability of Limit Cycles	236
11.9	Chapter Summary	236
	Further Reading	237
	Problems	237

12 Discrete-time Dynamical Systems	241
12.1 The Poincaré Section	241
12.2 Obtaining a Discrete-time Model	245
12.3 Dynamics of Discrete-time Systems	248
12.4 One-dimensional Maps	248
12.5 Bifurcations	255
12.6 Saddle-node Bifurcation	256
12.7 Period-doubling Bifurcation	258
12.8 Periodic Windows	260
12.9 Two-dimensional Maps	261
12.10 Bifurcations in 2-D Discrete-time Systems	264
12.11 Global Dynamics of Discrete-time Systems	269
12.12 Chapter Summary	272
Further Reading	273
Problems	273
 Index	 277