Contents

Preface					
Acknowledgements					
G	General notation				
1	Introduction	1			
2	The vibrations of systems having one degree of freedom	10			
	2.1 Free undamped vibration	11			
	2.1.1 Translational vibration	11			
	2.1.2 Torsional vibration	15			
	2.1.3 Non-linear spring elements	18			
	2.1.4 Energy methods for analysis	19			
	2.2 Free damped vibration	28			
	2.2.1 Vibration with viscous damping	29			
	2.2.2 Vibration with Coulomb (dry friction) damping	37			
	2.2.3 Vibration with combined viscous and Coulomb damping	40			
	2.2.4 Vibration with hysteretic damping	41			
	2.2.5 Energy dissipated by damping	43			
	2.3 Forced vibration	46			
	2.3.1 Response of a viscous damped system to a simple harmonic exciting force with constant amplitude	46			
	2.3.2 Response of a viscous damped system supported on a				
	foundation subjected to harmonic vibration	55			

		2.3.2.1 Vibration isolation	56
		2.3.3 Response of a Coulomb damped system to a simple harmonic	
		exciting force with constant amplitude	69
		2.3.4 Response of a hysteretically damped system to a simple harmonic	
		exciting force with constant amplitude	70
		2.3.5 Response of a system to a suddenly applied force	71
		2.3.6 Shock excitation	72
		2.3.7 Harmonic analysis	74
		2.3.8 Random vibration	77
		2.3.8.1 Probability distribution	77
		2.3.8.2 Random processes	80
		2.3.8.3 Spectral density	84
		2.3.9 The measurement of vibration	86
3	The	vibrations of systems having more than one degree of freedom	88
		The vibration of systems with two degrees of freedom	92
		3.1.1 Free vibration of an undamped system	92
		3.1.2 Free motion	94
		3.1.3 Coordinate coupling	96
		3.1.4 Forced vibration	102
		3.1.5 The undamped dynamic vibration absorber	104
		3.1.6 System with viscous damping	113
	3.2	The vibration of systems with more than two degrees of freedom	115
		3.2.1 The matrix method	115
		3.2.1.1 Orthogonality of the principal modes of vibration	118
		3.2.2 The Lagrange equation	121
		3.2.3 Receptances	125
		3.2.4 Impedance and mobility	135
4	The	vibrations of systems with distributed mass and elasticity	141
	4.1	Wave motion	141
		4.1.1 Transverse vibration of a string	141
		4.1.2 Longitudinal vibration of a thin uniform bar	142
		4.1.3 Torsional vibration of a uniform shaft	143
		4.1.4 Solution of the wave equation	144
	4.2	Transverse vibration	147
		4.2.1 Transverse vibration of a uniform beam	147
		4.2.2 The whirling of shafts	151
		4.2.3 Rotary inertia and shear effects	152
		4.2.4 The effects of axial loading	152
		4.2.5 Transverse vibration of a beam with discrete bodies	153
		4.2.6 Receptance analysis	155
	4.3	The analysis of continuous systems by Rayleigh's energy method	159
		4.3.1 The vibration of systems with heavy springs	159
		4.3.2 Transverse vibration of a beam	160

Contents ix

		4.3.3 Wind or current excited vibration	167
	4.4	The stability of vibrating systems	169
	4.5	The finite element method	170
5	Aut	omatic control systems	172
	5.1	The simple hydraulic servo	178
		5.1.1 Open loop hydraulic servo	178
		5.1.2 Closed loop hydraulic servo	180
	5.2	Modifications to the simple hydraulic servo	185
		5.2.1 Derivative control	185
		5.2.2 Integral control	188
	5.3	The electric position servomechanism	194
		5.3.1 The basic closed loop servo	195
		5.3.2 Servo with negative output velocity feedback	203
		5.3.3 Servo with derivative of error control	207
		5.3.4 Servo with integral of error control	207
	5.4	The Laplace transformation	221
		System transfer functions	224
		Root locus	228
		5.6.1 Rules for constructing root loci	230
		5.6.2 The Routh-Hurwitz criterion	242
	5.7	Control system frequency response	255
		5.7.1 The Nyquist criterion	255
		5.7.2 Bode analysis	271
6	Pro	blems	280
	6.1	Systems having one degree of freedom	280
		Systems having more than one degree of freedom	292
	6.3	Systems with distributed mass and elasticity	309
		Control systems	311
7	Ans	swers and solutions to selected problems	328
Bibliography			419
Ir	Index		