## CONTENTS

	Preface	ix
Chapter 1	Fundamentals of nonlinear control theory	1
1.1	Introductory remarks	1
1.2	Elements of the theory of nonlinear oscillations	
1.3	•	2 10
1.4	•	
1.5	•	12 13
1.6	Conclusions	19
Chapter 2	Nonlinearities in control systems	23
2.1	Idealizations	23
2.2	Some typical nonlinearities	25
2.3	Presence of nonlinearities in various links of control	
	systems	29
2.4	Methods of investigation; structural schemes	34
2.5		
2.6	Nonlinear elements; reduction of nonlinearities	
2.7	Concluding remarks	40
Chapter 3	Linearization	43
3.1	Introductory remarks	43
3.2	Equivalent linearization of the Krylov-Bogoliubov	
	theory	46
3.3		49
3.4	Linearization according to Aiserman	53
3.5	Harmonic linearization	56

	CONTENTS	xviii
3.6	Fundamentals of the method of harmonic linearization	64
3.7	Self-excitation in terms of the Hurwitz criteria	66
3.8	Stability in linearized problems	69
3.9	Example	70
3.1	Asymmetrical oscillations	72
3.1	1 Concluding remarks	74
Chapter 4	Stability in the sense of Liapounov	77
4.1	Introductory remarks; definition of stability	77
4.2	Liapounov's second method	81
	Eulerian derivative, or derivative along the trajectory	83
	Liapounov's theorems	84
	Determination of the V functions	86
4.6	Additional stability theorems	87
	Differential equations of control systems	89
	Formulation of the problem	91
	Liapounov's operator A	93
	Absolute stability on the basis of Liapounov's second	-
	method	95
4.11	Lur'e's transformation; the S procedure	96
4.12	Application of the S procedure	98
4.13	The theory of V. M. Popov; generalities	101
4.14	Absolute stability	103
4.15	Frequency characteristics	104
4.16	Analysis of linear problems	106
4.17	Analysis of nonlinear problems	107
	Popov's theorem	108
4.19	Example	114
hapter 5	Stability of nonlinear control systems	117
5.1	Introductory remarks	117
5.2	Formulation of the problem	118
5.3	Equations of controlled systems	122
5.4	<u>*</u>	123
5.5	The canonical form of differential equations in control	
	theory	124
5.6	Some applications to control problems	126
5.7	Astatic control	130
5.8	Stability of control systems	131
5.9	Modifications Lur'e's theorem	135
5.10	Simplified criteria of stability	136
	- · · · · · · · · · · · · · · · · · · ·	

	CONTENTS	xix
Chapter 6	Relay systems (general theory)	143
6.1	Introductory remarks	143
6.2	Different modes of relay actions	144
6.3	Linear parts of control systems	146
6.4	Control systems with relays	149
6.5	Equations of relay elements	151
6.6	Equations of relay systems	154
6.7	Transient processes in relay systems	155
6.8	Stability of relay systems	159
6.9	Criteria for stability of equilibrium	164
6.10	Self-excited oscillations in systems with relays	166
6.11	Conditions for existence of self-excited oscillations	170
6.12	Characteristics of relay systems	172
6.13	Later developments	173
6.14	Tsypkin's theory regarding stability in the large	176
6.15	Criteria for stability "in the large" for relay control	170
6.16	systems	178
0.10	Concluding remarks	181
Chapter 7	Method of harmonic linearization	183
7.1	Introductory remarks	183
7.2	Additional considerations regarding stability	186
7.3	Damping function	192
7.4	Comparison between the method of linearization and	
	the small-parameter method	193
7.5	Linearization of some typical nonlinearities	196
7.6	Control of motor by a relay	201
7.7	Follow-up system of the third order	205
7.8	Asymmetrical oscillations	211
7.9	Static and stationary errors	215
	Forced oscillations	217
7.11	Concluding remarks	221
Chapter 8	Piecewise linear methods	225
8.1	Introductory remarks	225
	Filter hypothesis; autoresonance	228
8.3	Method of exact solutions; preliminary remarks	232
8.4	The general form of operational equations	234
	Generalized derivatives	236
8.6	Equation of periods	237
	Exact solutions (Aiserman)	239
8.8	Determination of periodic states in relay control systems	241

	CONTENTS	XX	
8.9	Periodic solutions of piecewise linear systems	243	
8.10	Reduction to the coordinate axes	245	
8.11	Formation of equations of periods	248	
8.12	Computational work	252	
8.13	Calculation of the Fourier series	254	
8.14	Concluding remarks	255	
8.15	Remark	256	
Chapter 9	Point transformation method	259	
9.1	Introductory remarks	259	
9.2	Point-transformation theory	262	
9.3	•		
9.4			
9.5	Applications of the piecewise linear method to control		
	problems	271	
9.6	Topology of relay systems	274	
9.7	Conclusions	278	
Chapter 10	Functional transformers and analogs	282	
10.1	Introductory remarks	282	
10.2	Recent developments		
10.3	Photoelectric functional transformers		
10.4	Use of diodes for functional transformations		
10.5	Multiplying schemes		
10.6	Realization of diode schemes	292	
10.7	Continuous functional transformers	296	
10.8	Classification of schemes of integrating analogs	302	
10.9	More advanced problems	308	
10.10	Concluding remarks	316	
	Appendix The New Mexico tests	319	
	Index	325	