

Contents

I	Stability of Control Systems with the Unique Equilibrium	1
1	Classical Theory of Absolute Stability	3
1.1	Feedback Control Equation and its Transfer Function	3
1.2	Controllability. Observability. Kalman Duality Principle	4
1.3	The Transfer Function of Controllable and Observable Linear Block	12
1.4	Stable Linear Blocks	14
1.4.1	Hermite–Michailov Criterion	17
1.5	Stabilizability of Linear Block	18
1.6	Stability of Linear Feedback System. Nyquist Criterion	20
1.7	Lyapunov Stability. Direct Lyapunov Method	22
1.8	Absolute Stability of Control Systems	28
1.9	The Employment of Lyapunov Functions for Investigation of Absolute Stability	30
1.10	Yakubovich–Kalman Frequency-Domain Theorem	32
1.11	Theorem about Strict Frequency-Domain Inequality	41
1.12	Lyapunov Matrix Inequalities. Necessary and Sufficient Conditions of Solvability	43
1.13	Circle Criterion	46
1.14	Popov Criterion	48
1.14.1	Geometrical Interpretation of Popov Criterion	51
1.15	Aizerman Conjecture. Kalman Conjecture	54
2	Absolute Stability of Control Systems Described by Integral Volterra Equations	59
1.16	Alternative Mathematical Description of Feedback Control System	59
1.17	A Priori Integral Estimates Method. General Stability Theorem	61
1.18	The Case of Stationary Nonlinear Function. Popov Criterion	81
1.19	The Case of Differentiable Nonlinearity	96
1.20	Critical Cases	101
1.20.1	The Case of a Couple of Pure Imaginary Poles	101
1.20.2	The Case of a Zero Pole and a Couple of Pure Imaginary Poles	107
1.20.3	The Case of Two Zero Poles	107

1.20.4 The Case of One Zero Pole	108
--	-----

II Asymptotic Behavior of Systems with Multiple Equilibria **111**

3 Control Systems Described with Ordinary Differential Equations	113
A Basic Definitions. Dichotomy. Systems with Finite Equilibria	113
2.1 Global Asymptotic Properties of Differential System	113
2.2 Frequency-Domain Criterion of Dichotomy	118
2.3 Global Behavior of Chua's Circuits	125
B Systems with Denumerable Equilibria	133
2.4 Pendulum-Like Feedback Systems	133
2.5 Dichotomy of Pendulum-Like Systems. Gradient-Like Behavior of Pendulum-Like Systems with Nonlinearities Having Zero Mean-Value . .	141
2.6 Extension of the Circle Criterion. Invariant Cones	143
2.7 Extension of the Method of Invariant Cones	157
2.7.1 Systems with One Nonlinearity and a Bounded Forcing Term .	157
2.7.2 Systems with Vector-Valued Nonlinearities	159
2.8 Bakaev Stability	161
2.9 The Method of Periodic Lyapunov Functions. The Bakaev–Guzh Technique	165
2.10 The Bakaev–Guzh Technique in the Case of Differentiable Nonlinearities	169
C Non-Local Reduction Method	177
2.11 Lyapunov-Type Stability Theorems	178
2.12 Second-Order Pendulum-Like Equations	185
2.13 Application of Non-Local Reduction Idea to Pendulum-Like Systems .	201
2.14 Stability Investigation of Phase-Locked Loops by Non-Local Reduction Method	208
2.15 Non-Local Reduction Method for Non-Autonomous Pendulum-Like Systems	214
2.16 Non-Local Reduction of Higher Dimensional Systems to Autonomous Systems of the Second Order	224
2.17 Localization of Attractors	241
2.18 Sharpening of Circle Criterion by Means of Non-Local Reduction Method	249
4 Systems Described by Volterra Integro-Differential Equations	259
2.19 Volterra Integro-Differential Equations with Periodic Nonlinear Functions. General Properties of Solutions	259
2.20 Preliminary Results of the Method of A Priori Integral Estimates for Integro-Differential Equations	264
2.21 Bakaev–Guzh Technique	272
2.22 Non-local Reduction Method	278

2.23	Sharpening of Circle Criterion for Integro-Differential Equations . . .	292
------	---	-----

III Circular Solutions and Cycles 307

5	Existence of Circular Solutions and Cycles for Systems Described with Ordinary Differential Equations	309
3.1	Periodic Solutions of a Control System with a Nonlinearity from the Hurwitzian Sector	309
3.2	Periodic Solutions of Dissipative Systems	332
3.3	Pendulum-Like Systems with a Single Sign-Constant Nonlinearity . .	346
3.4	Existence of Circular Solutions and Cycles of the Second Kind of Pendulum-Like Systems	348
3.5	Circular Solutions and Cycles of the Second Kind in Concrete Systems	358
3.6	Estimation of the Period of a Cycle of the Second Kind	368
3.7	Cycles of the First Kind in the Pendulum-Like Systems	381
6	Necessary Conditions of Gradient-Like Behavior for the Systems Described by Integro-Differential Equations	397
3.8	Frequency-Domain Criterion of Existence of Circular Solutions for an Integro-Differential Equation with a Periodic Nonlinearity	397
3.9	Estimation of the Period of Periodic Solutions of the Second Kind . .	404

IV Existence of Homoclinic Orbits 415

7	Homoclinic Orbits in Pendulum-Like Systems	417
4.1	Homoclinic Orbits. Preliminary Consideration	417
4.2	Homoclinic Orbits of Pendulum-Like Systems with One Nonlinearity .	420
4.3	Dynamics of Synchronous Machines	430

V Dimension of Attractors 437

8	Frequency-Domain Estimates of Hausdorff Dimension of Attractors	439
5.1	Preliminary Considerations	439
5.2	Topological Dimension	442
5.3	Hausdorff Measure and Hausdorff Dimension	445
5.4	Differentiable Mappings: Upper Estimates of Hausdorff Dimension of Compacts	453
5.5	Differential Equations: Upper Estimates of Hausdorff Dimension of Attractors	457
5.6	Frequency-domain Estimates of Hausdorff Dimension of Attractors . .	466

Bibliography**477****Index****497**