
Contents

Preface	xi
Book Structure and Content	xvii
Chapter 1. The Control Loop: Characterization and Behavior in Open Loop and Closed Loop	1
1.1. Introduction.	1
1.2. Definition and terminology	2
1.3. The plant	2
1.3.1. Definition	2
1.3.2. From a modeling difficulty to a pragmatic approach to disturbances	3
1.4. Functional representation of the control loop	5
1.4.1. Block diagram and corresponding transfers	5
1.4.2. Regarding the gap detector	6
1.5. Open-loop transmittance	9
1.5.1. Definition	9
1.5.2. General expression	9
1.5.3. Regarding the input impedance of the open loop	10
1.5.4. Open-loop Nichols locus: elementary form and characteristic quantities	12
1.5.5. Left-hand criterion in the Nichols plane	14
1.6. Closed-loop transmittances	19
1.6.1. Transmittance in tracking	20
1.6.2. Transmittance in regulation	21
1.6.3. A tracking-regulation dilemma?	22

1.7. Input sensitivity	23
1.7.1. Input sensitivity in tracking	24
1.7.2. Input sensitivity in regulation	24
1.7.3. Input sensitivity in tracking and regulation	25
1.8. Behavior and frequency performances in tracking and regulation	34
1.8.1. Frequency and time behavior	35
1.8.2. Frequency performances	37
1.8.3. Regarding the effect of the increase in frequency ω_u	38
1.9. Dynamics in tracking and regulation	40
1.10. Charts in tracking and regulation	42
1.10.1. Chart in tracking: Nichols chart	42
1.10.2. Chart in regulation: dual of the Nichols chart	45
1.10.3. Passage from the Nichols chart to its dual	48
1.10.4. A little background	49
Chapter 2. The Control Loop: Stability and Stability Degree, Precision, Dynamic Performances and Controller Synthesis	51
2.1. Introduction	51
2.2. Stability	52
2.2.1. Definition	52
2.2.2. Fundamental stability condition	52
2.2.3. Stability algebraic criteria	53
2.2.4. Stability graphic criteria	54
2.3. Stability margins	58
2.3.1. Gain margin	59
2.3.2. Phase margin	59
2.4. Stability degree	69
2.4.1. Time domain	69
2.4.2. Frequency domain	70
2.4.3. Comparison with pole-placement control: an observation confirmed by section 2.4.2	71
2.5. Precision	73
2.5.1. Definition	73
2.5.2. Precision in tracking and regulation	74
2.5.3. Precision in steady state	74
2.6. Stability degree–precision dilemma	77
2.6.1. Definition	77
2.6.2. Highlighting the dilemma in the Nichols plane	77
2.6.3. Compromise between stability degree and precision, and optimum adjustment	78
2.6.4. Improving the compromise between stability degree and precision	78

2.6.5. Bringing the dilemma into question	79
2.7. Dynamics	80
2.8. Time dynamic performances.	80
2.9. Frequency dynamic performances	81
2.10. Determination of dynamics.	81
2.10.1. Overshoot.	81
2.10.2. Damping	82
2.10.3. Rapidity.	82
2.11. Study consideration for the controller synthesis	83
2.12. Controller phase at frequency ω_u	84
2.13. Type of controller	85
2.13.1. Phase-lead correction.	85
2.13.2. Phase-lag correction	87
2.13.3. An additional correction to obtain a PID regulator	89
2.14. Example of a practical task: detailed study of the single phase-lead controller	90
Chapter 3. An Overview of Linearizing Approaches	95
3.1. Introduction.	95
3.2. Linearization by immersion	96
3.2.1. Principle	96
3.2.2. Application	97
3.3. Linearization by high gain	102
3.3.1. Principle	102
3.3.2. Application	103
3.3.3. Conclusion and comments	104
3.4. Linearization by disturbance rejection	105
3.4.1. Principle	105
3.4.2. Application	105
3.4.3. Conclusion and comments	107
3.5. Linearization of the plant around a nominal trajectory: tangent linearized	107
3.5.1. Principle	107
3.5.2. Application	110
3.6. Additional discussion provided by Brigitte d'Andréa-Novel.	116
Chapter 4. High-Gain, Feedforward, Internal-Model, Quadratic-Criterion and Predictive Controls: From Principle to Control Loop	119
4.1. Introduction.	119
4.2. High-gain control	122
4.2.1. Principle	122

4.2.2. From high-gain control to control loop	123
4.2.3. Input sensitivity	125
4.3. Feedforward control.	127
4.3.1. Principle	127
4.3.2. From feedforward to reference filtering of the elementary control loop	129
4.3.3. Tracking and regulation	130
4.4. Internal-model control	131
4.4.1. Principle	131
4.4.2. From internal-model control to control loop	133
4.4.3. Robustifying strategies.	135
4.4.4. From internal model to high-gain control.	139
4.5. Quadratic-criterion control.	141
4.5.1. On control law synthesis.	141
4.5.2. A property of linear systems that is decisive in this area.	141
4.5.3. Study plant.	142
4.5.4. Control objective and strategy	144
4.5.5. Regulator synthesis through minimization of a quadratic criterion	145
4.5.6. From quadratic-criterion control to control loop.	149
4.6. Predictive control	153
4.6.1. Principle	153
4.6.2. From CGPC to LQ then LQG control.	155
4.6.3. LQ and quadratic-criterion control.	157
4.6.4. Study plant.	159
4.6.5. Control law synthesis	159
4.6.6. From predictive control to control loop	163
4.6.7. On the phase-lead regulator stemming from the change to the control loop.	166
4.6.8. A specific scenario suitable as the basis of an exercise or a problem.	172
Chapter 5. On the Three Generations of CRONE Control	175
5.1. Introduction.	175
5.2. From the porous dyke to first- and second-generation CRONE control	177
5.2.1. First interpretation of the relaxation model: first-generation CRONE control.	178
5.2.2. Second interpretation of the relaxation model: second-generation CRONE control	181

5.3. Second-generation CRONE control and uncertainty domains	185
5.3.1. Uncertainty domains	185
5.3.2. Particular open-loop uncertainty domains	187
5.3.3. Adequacy of the second-generation CRONE control template to the particular uncertainty domains	188
5.4. Generalization of the vertical template through the third-generation CRONE control.	189
5.4.1. First level of generalization	189
5.4.2. Second level of generalization	193
5.4.3. Open-loop transfer integrating the curvilinear template	196
5.4.4. Optimization of the open-loop behavior	198
5.4.5. Structure and parametric estimation of the controller.	200
5.4.6. Application	200
5.5. An appendix on the frequency response describing the generalized template	203
Solved Problems.	205
Presentation of Problem 1: Elementary Synthesis of a PID Regulator Based on the Single Phase-Lead Controller	207
Presentation of Problem 2: Improvement of the Elementary Synthesis of a PID Regulator by Reducing Transitional Frequency Dispersion	219
Presentation of Problem 3: Synthesis of a PID Regulator Based on Three Phase-Lead Controller Structures: Comparison and Choice of the Best Structure	229
Presentation of Problem 4: Linearizing Control of a Motor Shaft: Linearization by Immersion	241
Presentation of Problem 5: Linearizing Control of a Motor Shaft: Linearization by Disturbance Rejection	255
Presentation of Problem 6: High-Gain Control: Characterization in Tracking and Regulation	265
Presentation of Problem 7: Feedforward Control: Characterization in Tracking and Regulation by a Direct Approach and by an Indirect Approach via a Reference Prefilter	275

Presentation of Problem 8: Synthesis of an Internal-Model Control Using a PID Controller of the Equivalent Elementary Control Loop	283
Presentation of Problem 9: Quadratic-Criterion Control	295
Presentation of Problem 10: Synthesis of a Constant Phase-Lead CRONE Controller: The Essential Stage in the Synthesis of the Fractional PID Whose (Integer) Integration at Low Frequency Simply Results from a Cascade Proportional–Integral	305
Presentation of Problem 11: Synthesis of a Constant Phase-Lead CRONE Controller with Successively Symmetrical and Asymmetrical Frequency Placement	319
Presentation of Problem 12: Synthesis of a Constant Phase-Lag CRONE Controller and Synthesis Parameters of the Third-Generation CRONE Control	331
Presentation of Problem 13: Synthesis of a Variable-Phase CRONE Controller for the Synthesis of a Narrow-Band (Vertical and Generalized) Template	347
Appendices	365
Appendix 1: From Regulation Function to Active Noise Control	367
Appendix 2: Closed-Loop Behavior and Dynamic Performance of Second-Generation CRONE Control	375
Appendix 3: Iso-overshoot Contours and Isodamping Contours	389
References	409
Index	413