Contents

1 Undesired Effects of Input Saturation 1
- 1.1 Introductory Remarks 1
- 1.2 Controller Windup 3
- 1.3 Plant Windup in Stable Systems 6
- 1.4 Plant Windup in Unstable Systems 12
- 1.5 Problem of Directionality in MIMO Systems 16
- 1.6 Short Outline of the Approaches to Preventing the Undesired Effects of Input Saturation 18

2 Prevention of Controller Windup 21
- 2.1 Introductory Remarks 21
- 2.2 Some Measures to Prevent Controller Windup for PI and PID Compensators 23
- 2.3 Prevention of Controller Windup for Observer-based Controllers 27
  - 2.3.1 Time Domain Approach 27
  - 2.3.2 Frequency Domain Approach 34
- 2.4 Realization of General Compensators in the Observer Structure 40
- 2.5 Prevention of Controller Windup in the Presence of Signal Models for Disturbance Rejection 43
  - 2.5.1 Disturbance Observers – Johnson's Approach 43
  - 2.5.2 Observer-based Controllers Containing Disturbance Models – Davison's Approach 50

3 Prevention of Plant Windup in Stable Systems 59
- 3.1 Introductory Remarks 59
- 3.2 Criteria for the Prevention of Plant Windup 61
- 3.3 Additional Dynamic Element for the Prevention of Plant Windup 65
  - 3.3.1 Additional Dynamic Element in the Frequency Domain 65
  - 3.3.2 Additional Dynamic Element in the Time Domain 77

4 Further Methods for the Prevention of Windup 81
4.1 Introductory Remarks 81
4.2 Relations Between the Observer Technique and Other Methods for the Prevention of Controller Windup 83
4.3 The Approach of Schneider and Teel and Kapoor to the Prevention of Windup 88
4.4 Bühler's Cascaded Control Scheme 92

5 Prevention of Plant Windup in Stable and Unstable Single Input Systems 103
5.1 Introductory Remarks 103
5.2 A New Scheme for the Prevention of Windup 105
5.3 Reference Shaping Filter for Unstable Systems 108
5.4 Reference Shaping Filter for Stable Systems 123
5.5 Incorporating State-plus-disturbance Observers 136
5.6 Application of the New Scheme to General Controllers 151

6 Prevention of Windup in Multivariable Systems 159
6.1 Introductory Remarks 159
6.2 Multivariable Systems with Input Saturation 162
6.3 Prevention of Controller Windup in Multivariable Systems 166
6.4 Prevention of Plant Windup in Stable Multivariable Systems 167
6.5 Problem of Directionality 174
6.6 Systematic Solution of the Directionality Problem 181

7 Additional Rate Constraints 197
7.1 Introductory Remarks 197
7.2 Application to the Case of Stable Systems 200
7.3 Application to the Case of Unstable Systems 206
7.4 An Alternative Solution for Stable Systems 212

8 Bumpless Transfer 217
8.1 Introductory Remarks 217
8.2 Bumpless Transfer in Observer-based Controllers 219
8.3 Bumpless Transfer in the Scheme of Schneider and Teel and Kapoor 220
8.4 Bumpless Transfer Between Two Controllers that Give Rise to Plant Windup 221
8.5 Bumpless Transfer in Conjunction with the Reference Shaping Filter 222

9 Résumé and Concluding Discussions 229
9.1 Introductory Remarks 229
9.2 Controller Windup 231
9.3 Plant Windup in Stable Systems 232

9.4 Plant Windup in Unstable Systems 234
9.5 Other Methods for the Prevention of Windup 236
9.6 Multivariable Systems with Input Saturation 237
9.7 Additional Aspects 238

A Design of Observer-based Controllers 239
A.1 Introductory Remarks 239
A.2 State Feedback in the Time and in the Frequency Domains ... 241
A.3 State Observation in the Time Domain 244
A.4 Observer-based Control in the Time and in the Frequency Domains 246
A.5 Incorporation of Disturbance Models 265
A.5.1 Johnson's Disturbance Observer in the Time and in the Frequency Domains 266
A.5.2 Davison's Disturbance Model in the Time and in the Frequency Domains 281
A.6 Time Domain Design of Observer-based Controllers with Disturbance Models for MIMO Systems 299

References 307

Index 311