

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Why Fusion?	1
1.2	What Is Fusion?	2
1.3	What Is a Plasma?	3
1.4	Fusion Energy Production and the Lawson Criterion	6
1.5	What Is a Tokamak?	9
1.6	Feedback Control in Tokamaks	13
1.7	Electromagnetic Control	14
1.7.1	Modelling for Control	14
1.7.2	Plasma Boundary Estimation	15
1.7.3	Vertical Position Control	16
1.7.4	Plasma Radial Position and Current Control	17
1.7.5	Plasma Shape Control	18
1.7.6	Control of the Resistive Wall Modes	20
1.7.7	Other Magnetic Control Problems	20
 <b>Part I Plasma Modelling</b>		
<b>2</b>	<b>Plasma Modelling for Magnetic Control</b>	<b>23</b>
2.1	The Ideal Magnetohydrodynamics Theory	23
2.2	Magnetohydrodynamics in Axisymmetric Toroidal Geometry: the Poloidal Flux Function	25
2.3	A Plasmaless Model	28
2.4	The Plasma Equilibrium	34
2.5	A Linearized Model for Plasma Behaviour	38
<b>3</b>	<b>The Plasma Boundary and Its Identification</b>	<b>43</b>
3.1	Plasma Boundary Definition	43
3.2	The Plasma Boundary Descriptors	46
3.3	Tokamak Magnetic Diagnostics for Plasma Shape Identification	49
3.4	Plasma Shape Identification	53

3.5	An Algorithm for Plasma Shape Identification . . . . .	55
3.5.1	Choice of the Eigenfunctions for the Fourier Expansion . . . . .	55
3.5.2	Choice of the Singular Point for the Toroidal Harmonics . . . . .	57
3.5.3	Numerical Results . . . . .	60
3.6	Taking into Account the Eddy Currents . . . . .	61
<b>4</b>	<b>Modelling of the Resistive Wall Modes . . . . .</b>	<b>63</b>
4.1	Linear Stability of MHD Equilibria . . . . .	63
4.2	Resistive Wall Modes . . . . .	68
4.3	Linear Model of the Resistive Wall Modes . . . . .	71
 <b>Part II Plasma Control</b>		
<b>5</b>	<b>Plasma Magnetic Control Problem . . . . .</b>	<b>77</b>
5.1	Model for Controller Design . . . . .	78
5.2	Simulation Model. . . . .	80
5.3	Requirements for the Controller Design . . . . .	81
5.3.1	Gap Control Approach . . . . .	81
5.3.2	Isoflux Control Approach . . . . .	83
5.3.3	Typical Requirements and Constraints. . . . .	85
5.4	Plasma Vertical Stabilization Problem. . . . .	85
5.5	Control of the Currents in the Active Coils . . . . .	86
5.6	Possible Different Solutions. . . . .	88
<b>6</b>	<b>Plasma Position and Current Control at FTU . . . . .</b>	<b>91</b>
6.1	The FTU Simulation Model. . . . .	92
6.1.1	Plasma Model . . . . .	94
6.1.2	Plasma Shape Identification Block . . . . .	96
6.1.3	The Radial and Plasma Current Controllers . . . . .	96
6.1.4	The F and T Circuit Converter Models . . . . .	97
6.2	Choice of the Controller Gains. . . . .	97
<b>7</b>	<b>Plasma Vertical Stabilization . . . . .</b>	<b>101</b>
7.1	Vertical Stabilization Problem . . . . .	101
7.2	Vertical Stabilization Problem in the ITER Tokamak . . . . .	104
7.2.1	Vertical Stabilization in the ITER Tokamak Using Ex-vessel Coils. . . . .	104
7.2.2	Use of Inner Vessel Coils for Vertical Stabilization in the ITER Tokamak. . . . .	108
7.3	Vertical Stabilization Problem for the TCV Tokamak . . . . .	111
<b>8</b>	<b>Plasma Shape Control for ITER. . . . .</b>	<b>117</b>
8.1	Singular Perturbation Decomposition for the ITER Tokamak. . . . .	117

8.2	Current and Shape Controller Design . . . . .	121
8.3	Simulation Results . . . . .	124
<b>9</b>	<b>Plasma Shape Control at TCV . . . . .</b>	<b>129</b>
9.1	Description of the TCV. . . . .	129
9.1.1	Magnetic Diagnostics . . . . .	130
9.1.2	Description of the Controlled Variables. . . . .	132
9.2	Design Specifications . . . . .	133
9.2.1	Controller Robustness . . . . .	133
9.2.2	Quantization Errors in the Measurements. . . . .	134
9.3	A Solution Based on the $H_\infty$ Theory . . . . .	135
9.3.1	Choice of the Plant for the Design . . . . .	136
9.3.2	Description of the Weighting Functions. . . . .	136
9.3.3	Robust Stability . . . . .	138
9.3.4	Current and Shape Controller Synthesis. . . . .	139
9.4	Experimental Results . . . . .	139
<b>10</b>	<b>Plasma Shape Control at JET. . . . .</b>	<b>143</b>
10.1	Control Requirements and Simplified Plasma Modelling . . . . .	144
10.2	The Controller Design . . . . .	149
10.2.1	Requirements and Motivations . . . . .	149
10.2.2	Optimal Output Regulation . . . . .	150
10.2.3	Design of PI Controllers . . . . .	156
10.3	Experimental Results . . . . .	157
10.4	The Current Limit Avoidance System. . . . .	161
<b>11</b>	<b>Control of the Resistive Wall Modes for the ITER Tokamak . . . . .</b>	<b>169</b>
11.1	The RWM Control Problem for ITER. . . . .	169
11.1.1	Output Variables and Measurements for RWM Stabilization. . . . .	172
11.1.2	Input Variables and Coil Power Supply Models . . . . .	174
11.2	The Best Achievable Performance . . . . .	175
11.3	Controller Design. . . . .	177
	<b>Appendix A: Some Mathematical Background . . . . .</b>	<b>181</b>
	<b>Appendix B: Model Reduction. . . . .</b>	<b>189</b>
	<b>Appendix C: Units Used in Plasma Physics . . . . .</b>	<b>193</b>
	<b>References . . . . .</b>	<b>195</b>
	<b>Index . . . . .</b>	<b>201</b>

<http://www.springer.com/978-3-319-29888-7>

Magnetic Control of Tokamak Plasmas

Ariola, M.; Pironti, A.

2016, XV, 203 p. 78 illus., 67 illus. in color., Hardcover

ISBN: 978-3-319-29888-7