Contents

1	Introduction					
	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			
Par	t I P	lasma Modelling				
2	Plasn	na Modelling for Magnetic Control	23			
	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			
3	The Plasma Boundary and Its Identification					
	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
4	Mod	elling of the Resistive Wall Modes	63
	4.1	Linear Stability of MHD Equilibria	63
	4.2	Resistive Wall Modes	68
	4.3	Linear Model of the Resistive Wall Modes	71

Part II Plasma Control

5	Plasn	na Magnetic Control Problem
	5.1	Model for Controller Design 78
	5.2	Simulation Model
	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
	5.4	Plasma Vertical Stabilization Problem
	5.5	Control of the Currents in the Active Coils
	5.6	Possible Different Solutions
6	Plasn	na Position and Current Control at FTU
	6.1	The FTU Simulation Model. 92
		6.1.1 Plasma Model 94
		6.1.2 Plasma Shape Identification Block
		6.1.3 The Radial and Plasma Current Controllers
		6.1.4 The F and T Circuit Converter Models 97
	6.2	Choice of the Controller Gains
7	Plasn	na Vertical Stabilization 101
	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
	7.3	Vertical Stabilization Problem for the TCV Tokamak 111
8	Plasn	na Shape Control for ITER 117
	8.1	Singular Perturbation Decomposition for the ITER
		Tokamak 117

	8.2 8.3	Current and Shape Controller Design	121 124	
9	Plasn 9.1	na Shape Control at TCV	129 129 130 132	
	9.2	Design Specifications9.2.1Controller Robustness9.2.2Quantization Errors in the Measurements	133 133 134	
	9.3	A Solution Based on the H_{∞} Theory9.3.1Choice of the Plant for the Design9.3.2Description of the Weighting Functions.9.3.3Robust Stability	135 136 136 138	
	9.4	9.3.4 Current and Shape Controller Synthesis Experimental Results	139 139	
10	Plasm 10.1 10.2	na Shape Control at JET. Control Requirements and Simplified Plasma Modelling The Controller Design 10.2.1 Requirements and Motivations 10.2.2 Optimal Output Regulation 10.2.3 Design of PI Controllers	143 144 149 149 150 156	
	10.3 10.4	Experimental Results	157 161	
11	11.1	rol of the Resistive Wall Modes for the ITER Tokamak The RWM Control Problem for ITER. 11.1.1 Output Variables and Measurements for RWM Stabilization. 11.1.2 Input Variables and Coil Power Supply Models	169 169 172 174	
	11.2 11.3	The Best Achievable Performance	175 177	
Арј	pendix	A: Some Mathematical Background	181	
Ap	pendix	B: Model Reduction	189	
Appendix C: Units Used in Plasma Physics				
References				
Index				