Contents

	Preface	xi
1	**Introduction to fluid power**	1
1.1.	History	1
1.2.	Advantages of fluid power systems	3
1.3.	Fluids for power transmission	4
1.4.	Aeration	8
1.5.	Cavitation	15
1.6.	High temperature systems	17
1.7.	Sources of power	17
1.8.	Accumulators and filters	19
1.9.	Pump sets	22
1.10.	Simple concepts of automatic control	23
1.11.	Feedback control systems	23
1.12.	Feedback in practice	25
1.13.	Some problems associated with fluid power control systems	26
2	**Discharge characteristics of servovalve orifices**	27
2.1.	Introduction	27
2.2.	Theoretical determination of the discharge coefficient	30
2.3.	Spool valve orifices	30
2.4.	Poppet valve orifices	34
2.5.	Flapper nozzle valves	34
2.6.	Experimental determination of discharge coefficients	35
2.7.	Reattached flow in spool valves	40
2.8.	Effects of chamber geometry	45
2.9.	Poppet valves	46
2.10.	Flapper nozzle valves	46
2.11.	Short tube orifices	49
2.12.	Gas flow through orifices	50

3 Directional control valves 55
3.1. Introduction 55
3.2. Two-way valve 55
3.3. Three-way valves 57
3.4. Four-way valves 58
3.5. Losses in two- and three-position valves—valve ratings 60
3.6. Infinite position valves—Servovalves 61
3.7. Two-way servovalves 61
3.8. Linearisation of valve characteristics 64
3.9. The three-way servovalve 66
3.10. Three-way valve, spool, hydraulic 67
3.11. Three-way valve, pneumatic 69
3.12. The flapper nozzle valve, hydraulic 71
3.13. Flapper nozzle valve, pneumatic 72
3.14. The three-way jet pipe valve 73
3.15. Four-way servovalves 74
3.16. Some comments on the use of valve characteristics 78
3.17. The electric field valve 78

4 Flow forces in valves 81
4.1. Introduction 81
4.2. Steady state flow forces in spool valves 82
4.3. Compensation of flow forces in spool valves 83
4.4. Transient flow forces in spool valves 87
4.5. Flow forces in poppet valves 90
4.6. Forces on flapper nozzle valves 94

5 System dynamics 99
5.1. Introduction 99
5.2. Basic Relationships 99
5.3. A simple system 103
5.4. Controlling elements 104
5.5. Dynamic characteristics 105
5.6. Design example 107
5.7. Fluid transmission lines 110
5.8. Distributed parameter model 111

6 Hydraulic servomechanisms 116
6.1. Introduction 116
6.2. Precision control systems in hydraulics 118
6.3. Effects of oil compressibility 119
6.4. Stability considerations 123
6.5. Determination of optimum response 124
6.6. Response characteristics 126

6.7. Effects of load disturbances 126
6.8. Cavitation in the hydraulic actuator 130
6.9. Effect on underlap on cavitation 133
6.10. Graphical analysis of the closed loop step response 134
6.11. Method of solution 138

7 Electrohydraulic servomechanisms and general aspects of analysis 145

7.1. Introduction 145
7.2. Complete system equations 146
7.3. Simple case 147
7.4. Results from analogue computer study 149
7.5. Practical considerations 153
7.6. Effect of flow forces 153
7.7. More exact simulation 157

8 The small signal response of the hydraulic servo and means of improving performance 162

8.1. Introduction 162
8.2. Characteristics of the threshold region 163
8.3. Methods of improving performance 165
8.4. Computer study of small amplitude response 168
8.5. Further methods of improving performance 172
8.6. Two-stage electrohydraulic valve 180

9 Pneumatic servomechanisms 185

9.1. Introduction 185
9.2. Pneumatic servo 186
9.3. Ram equations 188
9.4. Load sensitivity 191
9.5. Method of stabilisation 192
9.6. Stabilisation using auxiliary tanks 195
9.7. Hot gas servomotors 198

10 Some practical aspects of servo testing and design 201

10.1. Introduction 201
10.2. Position transducers 202
10.3. Recording instruments 204
10.4. System testing 205
10.5. Frequency response equipment 206
10.6. Amplitude response 208
10.7. The servo amplifier 208
10.8. Matching the torque motor to the servo amplifier 209
10.9. Natural frequency calculations in the servo actuator 211
10.10. Performance assessment 214
10.11. Choice of control valve 216

11 Control of pressure 221
11.1. Introduction 221
11.2. Applications—hydraulic 224
11.3. Applications—pneumatic 226
11.4. Response of spool valves 227
11.5. Use of flow forces 230
11.6. Dynamics of pressure control valves 232

12 Speed control 237
12.1. Pneumatic actuators 237
12.2. Dynamic analysis of meter-out speed control 245
12.3. Speed control of hydraulic motors 248
12.4. Dynamic analysis of hydraulic meter-out control 251
12.5. Hydropneumatics 253
12.6. Synchronisation 254
12.7. Speed control servos 258

13 Fluidics 260
13.1. Introduction 260
13.2. Devices without moving parts 260
13.3. Advantages and disadvantages of non-moving part devices 271
13.4. Auxiliary equipment 273

14 Boolean algebra and fluid logic 277
14.1. Introduction 277
14.2. The language of Boolean algebra 277
14.3. Some further logic gates and devices 281
14.4. Manipulation of logic expressions 283
14.5. A circuit design 286
14.6. Some special circuits 289

15 Some applications of non-moving part fluidic elements 293
15.1. Introduction 293
15.2. Gauging and positioning 294
15.3. Oscillators and their uses 296
15.4. Rate measurement 299
15.5. Control systems 300
15.6. Sequences and interlocking logic systems 303

16 Sequential circuits 306
16.1. Introduction 306
16.2. Unequal loading 307
16.3. Use of sequence valves 307
16.3. Programmers 309
16.4. Direct signal interlocks 311

16.5. Other means of eliminating locked signals 314
16.6. Use of electrics 315
16.7. A simple design technique for sequence circuits 316
16.8. The cascade system 320
16.9. The logic approach to circuit design 324

17 Discontinuously controlled and digital servos 329

17.1. Introduction 329
17.2. Digital to analogue converters 329
17.3. Pulse controls 331
17.4. Digital actuators 334
17.5. On-off controlled system 337
17.6. Oscillating control systems—pulse width modulation 337
17.7. Response improvements using digital techniques 341
17.8 Some phenomena associated with on-off controlled hydraulic servos. 344

Appendix I
Units and the SI system 351

Appendix II
Bibliography 355

Index 363