



## CONTENTS

Chapter 1 INTRODUCTION . . . . .	1
Chapter 2 BASIC PRINCIPLES . . . . .	6
2.1 Quantities and units . . . . .	6
2.2 Basic laws . . . . .	7
2.3 Magnetic circuit . . . . .	8
2.4 Poles and surface charges . . . . .	10
2.5 Stray flux and demagnetizing factor . . . . .	11
2.6 Magnetic materials . . . . .	12
2.7 Parts of an electromagnet . . . . .	14
Chapter 3 FIELDS OF SURFACE CHARGES AND DIPOLE DISTRIBUTIONS . . . . .	15
3.1 Field of surface charges . . . . .	15
3.2 Dipolar fields . . . . .	19
3.3 Optimum magnetization . . . . .	21
Chapter 4 COIL FIELDS . . . . .	23
4.1 Introduction . . . . .	23
4.2 Current distributions . . . . .	23
4.3 Field and power dissipation . . . . .	26
4.4 G-factor for homogeneous coils . . . . .	28
4.5 Homogeneous coils with slits . . . . .	30
4.6 Optimum shape of homogeneous coil . . . . .	32
4.7 Optimum axial current distribution . . . . .	34
4.8 Radial current distributions . . . . .	38
4.9 Other current distributions . . . . .	39
4.10 Long solenoids . . . . .	39
Chapter 5 FLUX DENSITY AND AMPERE-TURNS . . . . .	43
5.1 Approximations . . . . .	44
5.2 Stray flux and flux density . . . . .	48
5.3 Low and medium fields . . . . .	49
5.4 Example . . . . .	54
5.5 High field magnets . . . . .	56
5.6 Example . . . . .	60
5.7 Influence of magnetizing coil . . . . .	62

<b>Chapter 6 CORE, YOKE AND COIL DIMENSIONS . . . . .</b>	<b>66</b>
6.1 Coil parameters . . . . .	67
6.2 Yoke considerations . . . . .	70
6.3 Volume of the magnet . . . . .	71
<b>Chapter 7 DESIGN PROCEDURE FOR ELECTROMAGNETS . . . . .</b>	<b>76</b>
<b>Chapter 8 COOLING . . . . .</b>	<b>83</b>
8.1 Heat conduction in coils . . . . .	83
8.2 Thermal conductivity . . . . .	84
8.3 Space factor . . . . .	87
8.4 Heat flow in coils . . . . .	89
8.5 Axial temperature distribution . . . . .	89
8.6 Radial heat-flow . . . . .	92
8.7 Calculation of coil temperature . . . . .	96
8.8 Average coil temperature . . . . .	99
8.9 Final remarks . . . . .	100
8.10 Heat transfer . . . . .	101
8.11 Velocity . . . . .	103
8.12 Transferred power . . . . .	105
8.13 Heat transfer to free convecting air . . . . .	108
<b>Chapter 9 CONSTRUCTIONAL DETAILS . . . . .</b>	<b>109</b>
9.1 Coil design . . . . .	109
9.2 Tube-wound coils . . . . .	109
9.3 Tape-wound coils . . . . .	110
9.4 Coil winding . . . . .	111
9.5 Cooling disk . . . . .	113
9.6 Wire-wound coils . . . . .	115
9.7 Mounting . . . . .	116
9.8 Core and yoke construction . . . . .	118
<b>Chapter 10 EXAMPLES . . . . .</b>	<b>121</b>
10.1 General procedure . . . . .	122
10.2 Magnets with wire-wound coils . . . . .	123
10.2.1 Simple laboratory magnet of low power . . . . .	123
10.2.2 Wire-wound magnet for Hall-effect measurements .	127
10.3 Magnets with tape-wound coils . . . . .	129
10.3.1 Two high-field magnets . . . . .	129
10.3.2 Rotating magnet . . . . .	131

Chapter 11 COMPARISON OF MAGNETS . . . . .	133
11.1 De Klerk's criterion . . . . .	134
11.2 Montgomery's comparison . . . . .	138
Chapter 12 POWER SUPPLIES . . . . .	140
12.1 Power sources . . . . .	141
12.1.1 Batteries . . . . .	141
12.1.2 Motor-generator sets . . . . .	141
12.1.3 Silicon rectifiers . . . . .	143
12.1.4 Silicon-controlled rectifiers (thyristors) and thyratrons	144
12.2 Current stabilization . . . . .	148
12.2.1 Regulator elements . . . . .	149
12.2.2 Reference voltage . . . . .	150
12.2.3 Measuring resistor . . . . .	152
12.3 Low-stability regulators . . . . .	153
12.3.1 Light-spot regulator . . . . .	153
12.3.2 Electronic-mechanical regulator . . . . .	154
12.3.3 Feedback amplifier . . . . .	156
12.3.4 Current stabilization with thyristors . . . . .	156
12.4 Stability and accuracy of regulators . . . . .	158
12.4.1 Stability criteria . . . . .	160
12.5 More accurate regulators . . . . .	163
12.6 High-stability current regulation . . . . .	165
12.6.1 Field stabilizers . . . . .	168
12.7 Protection . . . . .	168
12.8 Reversal switch. . . . .	169
Chapter 13 FIELD HOMOGENEITY . . . . .	171
13.1 Calculation of field distribution . . . . .	172
13.2 Pole field and coil field . . . . .	173
13.3 Calculation of pole field . . . . .	173
13.3.1 Cylindrical poles . . . . .	173
13.3.2 Tapered poles . . . . .	175
13.3.3 Numerical example . . . . .	178
13.4 Coil fields . . . . .	178
13.5 Comparison with experimental results . . . . .	182
13.6 Methods of correcting magnetic fields . . . . .	183
13.7 Correction rims (shims) . . . . .	184
13.8 Current shims . . . . .	186
13.8.1 Linear gradient shims . . . . .	187

13.8.2 Circular current shims . . . . .	189
13.9 Special pole-caps . . . . .	192
<b>Chapter 14 PULSED FIELDS . . . . .</b>	<b>194</b>
14.1 Limitations . . . . .	195
14.2 Energy storage . . . . .	196
14.3 Inductive energy storage . . . . .	196
14.4 Capacitive storage . . . . .	198
14.5 Current and dissipation . . . . .	200
14.6 Coil dimensions and field . . . . .	201
14.7 Heating of the coil . . . . .	206
<b>Chapter 15 PERMANENT MAGNETS . . . . .</b>	<b>209</b>
15.1 Principle of operation . . . . .	209
15.2 General design considerations . . . . .	211
15.3 Stray flux . . . . .	211
15.4 Core shape . . . . .	213
15.5 Approximative calculation of a permanent magnet with cylindrical core . . . . .	215
15.6 Construction . . . . .	218
15.7 Magnetization . . . . .	218
<b>Chapter 16 MEASUREMENT OF MAGNETIC FIELDS . . . . .</b>	<b>220</b>
16.1 Ballistic field measurement . . . . .	220
16.1.1 Ballistic galvanometer . . . . .	221
16.1.2 Electro-mechanical flux measurement . . . . .	228
16.1.3 Electronic integration . . . . .	229
16.1.4 Rotating coil fluxmeters . . . . .	231
16.2 Hall-effect measurements . . . . .	232
16.3 Magnetoresistance effect . . . . .	233
16.4 Proton magnetic resonance . . . . .	233
<b>Chapter 17 BIBLIOGRAPHY . . . . .</b>	<b>237</b>
<b>Index . . . . .</b>	<b>249</b>