CONTENTS

Foreword xi

Preface xv

List of Symbols xxi

Chapter 1 Optimization 1

1.1 Special characteristics of lens design as an optimization problem 2
1.2 The nature of the merit function 2
1.2.1 The Strehl ratio 2
1.2.2 MTF optimization 2
1.2.3 General comments 3
1.2.4 Comparison with the optical thin-film design problem 3
1.2.5 Nonlinearity of the aberrations 4
1.2.6 Changes needed to reduce high-order aberrations 5
1.2.7 A method of visualizing the problem of optimization in lens design 5
1.3 Theory of damped least squares (Levenberg-Marquardt) 6
1.4 Some details of damped least squares as used in lens design 8
1.4.1 Paraxial (first-order) properties 8
1.4.2 Seidel and Buchdahl coefficients 9
1.4.3 Transverse ray or wavefront aberrations 9
1.4.4 Aberration balancing and choice of weighting factors 9
1.4.5 Damping 11
1.4.6 Control of physical constraints 12
1.4.7 Control of glass boundary conditions 20
1.4.8 Solves 23
1.4.9 Lagrange multipliers 25
1.5 Some reasons for the success of the DLS method 25
1.6 Experiments with optimization programs 26
1.6.1 Effect of changing the damping factor 26
1.6.2 Effect of scaling the parameter changes 27
1.7 An optimization example 29
References 34

Chapter 2 Buchdahl Aberrations 37

2.1 Third-order coefficients 37
2.2 Fifth-order coefficients 38
2.3 Comparison with H.H. Hopkins notation 39
2.4 Examples 39
2.4.1 Double Gauss 39
2.4.2 Shafer lens with zero third- and fifth-order aberrations 45
References 49

Chapter 3 Synthesis of New Lens Designs 51

3.1 Choice of a starting point 51
3.1.1 Modification of an existing design 51
3.1.2 Purchase of a competing lens 52
3.1.3 Analytic solutions 52
3.1.4 Nonanalytic synthesis of new design forms 52
3.2 Examples 53
3.2.1 A unit magnification telecentric doublet pair 53
3.2.2 A simple zoom lens 59
3.3 The use of catalog components 67
3.3.1 Singlets 68
3.3.2 Doublets and triplets 68
3.3.3 Meniscus singlets 69
3.3.4 Field flatteners 70
3.3.5 Cemented triplets 71
References 72

Chapter 4 Lenses for 35-mm Cameras 73

4.1 The triplet 74
4.2 The tessar 75
4.3 The double-Gauss (planar-type) 78
4.4 The Sonnar 82
4.5 Wide-angle lenses for rangefinder cameras (Zeiss Biogon) 84
4.6 Wide-angle lens for rangefinder camera (Schneider Super-Angulon) 86
4.7 Wide-angle lenses for SLR cameras 89
4.8 Telephoto lens 91
4.9 Long-focus telephoto lens 93
4.10 Lens for compact point-and-shoot camera 95
4.11 Single lens for disposable cameras 97
References 99

Chapter 5 Secondary Spectrum and Apochromats 101

5.1 Apochromatic doublets 101
5.2 Apochromatic triplets 104
5.3 Petzval lenses 105
5.4 Double-Gauss lenses 106
5.5 Telephoto lenses 108
5.6 Zoom lenses 108
5.7 Microscope objectives 108
5.8 Secondary spectrum correction with normal glasses 108
5.8.1 Liquids 108
5.8.2 Diffractive optics 109
5.8.3 McCarthy-Wynne principle 109
5.8.4 Schupmann principle 112
5.9 Transverse secondary spectrum 115
References 115

Chapter 6 Lenses for Laser Applications 117

6.1 Gaussian beams 117
6.2 Laser beam expanders 118
6.2.1 Two-lens beam expanders 118
6.2.2 Three-lens beam expanders 122
6.3 F-Theta lenses 124
6.4 Lenses for optical disks 126
6.5 Laser diode collimators 129
References 130

Chapter 7 Microscope Objectives 133

7.1 Classical microscope objectives 133
7.2 Flat-field microscope objectives 135
7.3 Oil-immersion objectives 141
References 144

Chapter 8 Microlithographic Projection Optics 145

8.1 Unit-magnification zero-power monocentric systems 145
8.1.1 Dyson 1× relay 146
8.1.2 Offner 1× relay 148
8.2 Wynne-Dyson 1× relay 149
8.3 Wynne-Offner 1× relay 152
8.4 Reduction lenses 153
8.5 Catadioptric reduction systems 163
8.6 Catoptric reduction systems 167
References 170

Chapter 9 Zoom Lenses 173

9.1 General principles 173
9.1.1 Control of chromatic aberration 173
9.1.2 Field curvature 173
9.1.3 Minimization of movements 174
9.2 Two-component zooms 174
9.2.1 Minus-plus plastic disposable zoom 174
9.2.2 Plus-minus plastic disposable zoom 175
9.2.3 A typical minus-plus zoom 177
9.2.4 A typical plus-minus zoom 178
9.3 Three-component zooms 179
9.4 Four-component zooms 181
9.5 Zoom relays 188
9.6 Zoom telescopes 189
9.7 Zoom modules 190
References 190

Chapter 10 Decentered and Asymmetric Systems 193

10.1 General properties of decentered systems 193
10.2 Coordinate systems 194
10.3 Interpretation of results 196
10.4 New-axis surface 197
10.5 Toroids 197
10.6 Offset surfaces (or off-axis surfaces) 198
10.7 Convention for mirrors 198
10.8 Kutter system 199
10.9 Single parabolic mirror 202
10.9.1 Alpha rotations 204
10.9.2 Beta rotations 205
10.9.3 Alpha and beta rotations 206
10.10 Scanning systems 207
10.11 The "active" side of a surface 209
10.12 X-ray telescopes 210
10.12.1 WOLTER2 example 210
10.12.2 WOLTER1 example 211

Chapter 11 Design for Manufacturability 215

11.1 Tolerancing 215
11.2 Simplicity of design 216
11.3 Air spaces 217
11.4 Glass components 218
11.5 Glass choice 220
11.6 Mirror surfaces 220

11.7 Redesign for actual "melt" data 220
11.8 Use of existing tools and test plates 221
11.9 Selective assembly and adjustment after assembly 221
11.10 General points 221
References 222

Index 223