Contents

Preface xiii
Acknowledgments xvii

Chapter 1. Introduction 1

1.1 Why Mechanical Drive Steam Turbines Are Applied 1
1.2 Overview of Steam Turbine Fundamentals 2
1.2.1 Steam turbine staging can vary 5
1.2.2 Modern impulse design 5
1.2.3 Single-valve vs. multivalve construction 5
1.2.4 Steam balance considerations 9
1.3 Overview of Steam Turbine Types and Controls 9
1.3.1 Straight noncondensing 14
1.3.2 Automatic extraction noncondensing 15
1.3.3 Automatic extraction condensing 15
1.3.4 Basic steam control considerations 18
1.3.5 Automatic extraction condensing controls 21
1.3.6 Geared and direct-drive types 21
1.3.7 Modular design concepts 23

Chapter 2. Turbine Casing and Major Stationary Components 29

2.1 Casing Design 29
2.2 Steam Admission Sections 33
2.3 Steam Turbine Diaphragms and Labyrinth Packing 36

Chapter 3. Bearings for Mechanical Drive Turbines 51

3.1 Journal Bearings for Industrial Turbomachinery 51
3.1.1 Fixed-geometry journal bearing stability 52
3.1.2 Tilting-pad journal bearings 56
3.1.3 Advanced tilting-pad journal bearings 61
3.1.4 Lubrication-starved tilting-pad bearings 65
3.2 Key Design Parameters 68
3.3 Thrust Bearings for Turbomachinery 69
3.4 Active Magnetic Bearings 75

Chapter 4. Rotors for Impulse Turbines 81

4.1 Long-Term Operating Experience 81
4.2 Pitch Diameter and Speed 82
4.3 Steam Temperature 83
4.4 Built-Up Construction 84
4.5 Solid Construction 89
4.6 Shaft Ends 90
4.7 Turbine Rotor Balance Methods 91
4.7.1 At-speed rotor balancing 92
4.8 Balance Tolerance 94

Chapter 5. Rotors for Reaction Turbines 95

5.1 Solid Rotors 95
5.2 Materials for Solid Rotors 99
5.3 Welded Rotor Design 100
5.4 Welded Rotor Materials 105

Chapter 6. Turbine Blade Design Overview 109

6.1 Blade Materials 111
6.2 Blade Root Attachments 111
6.3 Types of Airfoils and Blading Capabilities 113
6.4 Guide Blades for Reaction Turbines 114
6.5 Low-Pressure Final Stage Blading 120

Chapter 7. Turbine Auxiliaries 125

7.1 Lube Systems 125
7.2 Barring or Turning Gears 128
7.3 Trip-Throttle or Main Stop Valves 129
7.4 Overspeed Trip Devices 132
7.5 Gland Seal Systems 135
7.6 Lube Oil Purifiers 135

Chapter 8. Governors and Control Systems 137

8.1 General 137
8.2 Governor System Terminology 140
8.2.1 Speed regulation 140
8.2.2 Speed variation 141
8.2.3 Dead band 141
8.2.4 Stability 141
8.2.5 Speed rise 141
8.3 NEMA Classifications 143
8.4 Valves 144
8.4.1 Single-valve turbines 144
8.4.2 Multivalve turbines 145
8.5 PG Governors 145
8.6 Electronic Governors 148
8.7 Governor Systems 150
8.7.1 General 150
8.7.2 Extraction control 150

Chapter 9. Couplings and Coupling Considerations 157

9.1 Power Transmission 157
9.2 Shaft Alignment 160
9.3 Maintenance 162
9.4 Influence on the Critical Speeds 162
9.5 Differential Expansions 162
9.6 Axial Thrusts 163
9.7 Limits of Application 163

Chapter 10. Rotor Dynamics Technology 165

10.1 Rotor Model 165
10.2 Dynamic Stiffness 166
10.3 Effects of Damping on Critical Speed Prediction 169
10.4 Bearing-Related Developments 170
10.5 Refinements 172
10.6 Bearing Support Considerations 173
10.7 Foundations 174
10.8 Impedance 174
10.9 Partial Arc Forces 178
10.10 Design Procedure 179
10.11 Rotor Response 180
10.12 Instability Mechanisms 180
10.13 Subsynchronous Vibration 180
10.14 Service Examples 183
10.15 Labyrinth and Cover Seal Forces 185
10.16 Rotor Stability Criteria 187
10.17 Experimental Verification 187

Chapter 11. Campbell, Goodman, and SAFE Diagrams for Steam Turbine Blades 189

11.1 Goodman Diagram 189
11.2 Goodman-Soderberg Diagram 190
11.3 Campbell Diagram 191
11.3.1 Exciting frequencies 195
11.4 SAFE Diagram—Evaluation Tool for Packeted Bladed Disk Assembly 197
11.4.1 Definition of resonance 198
11.4.2 Mode shape 198
11.4.3 Fluctuating forces 200
11.5 SAFE Diagram for Bladed Disk Assembly 203
11.6 Mode Shapes of a Packeted Bladed Disk 209
11.7 Interference Diagram Beyond *N*/2 Limit 211
11.8 Explaining Published Data by the Use of Dresser-Rand's SAFE Diagram 214
11.9 Summary 217

Chapter 12. Reaction vs. Impulse Type Steam Turbines 219

12.1 Introduction 219
12.2 Impulse and Reaction Turbines Compared 220

12.3 Efficiency 220
12.4 Design 223
12.4.1 Rotor 223
12.4.2 Blading 224
12.5 Erosion 230
12.6 Axial Thrust 232
12.7 Maintenance 233
12.8 Design Features of Modern Reaction Turbines 233
12.9 Deposit Formation and Turbine Water Washing 235

Chapter 13. Transmission Elements for High-Speed Turbomachinery 243

13.1 Spur Gear Units 243
13.2 Epicyclic Gears 245
13.3 Clutches 246
13.4 Hydroviscous Drives 253
13.5 Hydrodynamic Converters and Geared Variable-Speed Turbo Couplings 257
13.5.1 Function of the multistage variable-speed drive 261
13.5.2 Design and operating details 261
13.5.3 Working oil and lube oil circuits 264
13.5.4 Lubricating system 264
13.5.5 Lubricant oil containment on gear and variable-speed units 265

Chapter 14. Shortcut Graphical Methods of Turbine Selection 267

14.1 Mollier Chart Instructions 267
14.2 Estimating Steam Rates 271
14.3 Quick Reference Information to Estimate Steam Rates of Multivalve, Multistage Steam Turbines 303

Chapter 15. Elliott Shortcut Selection Method for Multivalve, Multistage Steam Turbines 309

15.1 Approximate Steam Rates 309
15.2 Stage Performance Determination 313
15.3 Extraction Turbine Performance 320

Chapter 16. Rerates, Upgrades, and Modifications 329

16.1 Performance and Efficiency Upgrade 331
16.1.1 Brush seals and labyrinth seals 332
16.1.2 Wavy face dry seals 336
16.1.3 Buckets 348
16.2 Reliability Upgrade 352
16.2.1 Electronic controls 352
16.2.2 Monitoring systems 356
16.3 Life Extension 356
16.4 Modification and Reapplication 358
16.4.1 Casing 359
16.4.2 Flange sizing 360
16.4.3 Nozzle ring capacity 362
16.4.4 Steam path analysis 362

16.4.5 Rotor blade loading 363
16.4.6 Thrust bearing loading 363
16.4.7 Governor valve capacity 364
16.4.8 Rotor 364
16.4.9 Shaft end reliability assessment 364
16.4.10 Speed range changes 366
16.4.11 Auxiliary equipment review 366
16.4.12 Oil mist lubrication for general-purpose steam turbines 367
16.4.13 Problem solving 376
16.5 Summary 376

Appendix A. Glossary 377
Appendix B. Units of Measurement 385
Bibliography and List of Contributors 399

Index 407