

contents

Chapter 1 Introduction	1
1.1 Refrigeration Cycle	1
1.1.1 What is refrigeration?.....	1
1.1.2 What is a cycle?	1
1.1.3 Vapor compression refrigeration cycle	1
1.2 Role of Compressors	2
1.3 History of Compressors (Early Period)	2
1.4 Classification of Compressors	3
Chapter 2 Basic Theory	6
2.1 Compression Theory	6
2.1.1 Reversed Carnot cycle	6
2.1.2 P-h diagram	6
2.1.3 Adiabatic compression	9
2.1.4 Equation of energy	12
2.1.5 Leakage	12
2.2 Dynamic-mechanical Analysis.....	16
2.2.1 Motion of linkage	17
2.2.2 Equation of energy and mechanical efficiency	18
2.2.3 Excitation force and vibration of a compressor body	18
2.3 Lubrication Theory	19
2.3.1 Basic Reynolds equation	19
2.3.2 Modified Reynolds equation based on average flow model	19
2.3.3 Contact theory	20
2.3.4 Journal bearing	21
2.3.5 Thrust bearing	24
2.3.6 Rolling bearing	26
2.4 Compressor Efficiency.....	27
2.5 Refrigerants	29
2.5.1 History of refrigerant	29
2.5.2 Characteristics required of a refrigerant.....	29
2.5.3 Types of refrigerant	30
2.5.4 Designation of refrigerants.....	31
2.5.5 Comparison of commonly used refrigerants	31
2.5.6 Applications of various refrigerants	32
2.5.7 Safety of refrigerant	32
2.5.8 Safety measures	33
Chapter 3 Reciprocating Compressors	35
3.1 History of Reciprocating Compressors	35
3.2 Operating Principle and Characteristics	35
3.2.1 Compression action	35

3.2.2 Theoretical stroke volume	37
3.3 Structure of Compressors	38
3.3.1 Motion conversion mechanism	38
3.3.2 Suspension mechanisms	38
3.3.3 Lubrication systems	39
3.3.4 Valve system	40
3.3.5 Piston ring	41
3.3.6 Discharge muffler	42
3.3.7 Shaft seal mechanism	42
3.3.8 Capacity control mechanism	44
3.4 Analysis of Kinematics	45
3.4.1 Kinematic analysis	45
3.4.2 Equation of energy and mechanical efficiency	47
3.4.3 Excitation force and vibration of compressor body	47
3.5 Application and Performance	49
3.6 Other Mechanisms of Reciprocating Compressors	50
3.6.1 Ball-joint mechanism	50
3.6.2 Two-cylinder mechanism	50
3.6.3 Two-stage compression	50
3.6.4 Linear motor-driven mechanism	51
Chapter 4 Rotary Compressors	52
4.1 History of Rotary Compressors	52
4.2 Operating Principle and Characteristics	53
4.2.1 Compression action	53
4.2.2 Theoretical volume	54
4.3 Structure and Design of Compressor Components	54
4.3.1 Basic structure	54
4.3.2 Crankshaft	55
4.3.3 Bearings	56
4.3.4 Rolling piston	56
4.3.5 Vane	57
4.3.6 Cylinder	57
4.3.7 Discharge valve	57
4.4 Dynamic-mechanical Analysis	58
4.4.1 Mechanism and movements	58
4.4.2 Constraint forces and equations of motion	59
4.4.3 Equation of energy and mechanical efficiency	61
4.4.4 Mechanical excitation forces and vibration of a compressor body	62
4.5 Applications and Performance	62
4.5.1 High-temperature application rotary compressors	62
4.5.2 Low-temperature application rotary compressors	66
4.5.3 Medium-temperature application rotary compressors	67
4.6 Other Types of Rotary Compressor Mechanisms	67
4.6.1 Two-cylinder type	67

4.6.2 Swing compressors	68
4.6.3 Liquid injection	70
4.6.4 Capacity control	70
4.6.5 Two-stage compressors	73
4.6.6 Two-stage compressors with an intermediate pressure casing	74
4.7 Lubrication and Oil Separation	74
4.7.1 Lubrication system for vertical rotary compressors	74
4.7.2 Lubrication system for horizontal rotary compressors	76
4.7.3 Oil separation in rotary compressors	76
4.8 Noise and Vibration of Rotary Compressors	77
4.8.1 Excitation forces and vibration reduction	77
4.8.2 Vibration reduction through torque control	78
4.8.3 Noise of rotary compressors	79
4.9 Rotary Compressor Production Technology	81
4.9.1 High-precision machining	81
4.9.2 High-precision assembly	82
Chapter 5 Scroll Compressors	85
5.1 History of Scroll Compressors	85
5.2 Operating Principle and Characteristics	85
5.2.1 Operating principle	85
5.2.2 Scroll wrap geometry	86
5.2.3 New scroll wrap	88
5.3 Structure and Design of Compressor Components	89
5.3.1 Compression mechanisms	89
5.3.2 Forces and moments working on the drive mechanism	90
5.3.3 Sealing mechanisms	91
5.3.4 Structures of scroll compressor	92
5.4 Kinematic Analysis	93
5.4.1 Working forces and equations of motion	93
5.4.2 Equation of energy and mechanical efficiency	95
5.5 Other Scroll Compressor Mechanisms	96
5.5.1 Capacity control	96
5.5.2 Injection	96
5.6 Uses and Features	96
5.7 Production Technology of Scroll Compressors	98
5.7.1 Scroll machining	98
5.7.2 Geometric accuracy control	99
5.8 Selection Criteria of Scroll Compressor	99
Chapter 6 Twin Screw Compressors	101
6.1 History of Twin Screw Compressors	101
6.2 Working Principle and Basic Structure	102
6.2.1 Working principle	102
6.2.2 Basic structure	103

6.2.3 Oil-free type and oil-injected type	104
6.2.4 Semi-hermetic type and open type	105
6.3 Rotor Profiles	106
6.3.1 Basics and history of rotor profiles	106
6.3.2 Rotor profile modification	107
6.3.3 Number of lobes	108
6.3.4 Wrap angle	109
6.3.5 L/Dm and center distance	109
6.3.6 Sealing line and internal leakage passage	110
6.3.7 Displacement volume	111
6.4 Structure and Design of Compressor Components	111
6.4.1 Screw rotors	111
6.4.2 Rotor casing	112
6.4.3 Inlet housing	112
6.4.4 Outlet housing	112
6.4.5 Suction port	112
6.4.6 Discharge port	112
6.4.7 Other ports	113
6.4.8 Bearings	113
6.4.9 Shaft seals	115
6.4.10 Oil supply systems	117
6.4.11 Capacity control mechanisms	119
6.4.12 Balance piston	122
6.5 Dynamic-mechanical Analysis	122
6.5.1 Motion of the mechanism, constraint forces and motion equations	122
6.5.2 Equation of energy and mechanical efficiency	124
6.5.3 Mechanical excitation force and vibration of compressor body	124
6.5.4 Lateral and torsional critical speeds	125
6.6 Operating Characteristics and Applications	126
6.6.1 Performance characteristics	126
6.6.2 Capacity and pressure range	130
6.6.3 Single-stage compression and multiple-stage compression	131
6.6.4 Main applications	131
6.7 Noise and Vibration	133
6.7.1 Vibration characteristics	133
6.7.2 Noise characteristics	135
6.8 Production Technologies	136
6.8.1 Screw rotor machining techniques	136
6.8.2 Screw rotor machining accuracy control	139
 Chapter 7 Single Screw Compressors	 142
7.1 History of Single Screw Compressors	142
7.2 Basic Mechanism and Operating Principle	142
7.2.1 Compression mechanism	142
7.2.2 Operating principle	143

7.2.3 Basic structure of single screw compressors	143
7.2.4 Semi-hermetic type and open type	145
7.3 Structure and Design of Compressor Components	145
7.3.1 Shaft	145
7.3.2 Screw rotor	145
7.3.3 Gate rotor	145
7.3.4 Discharge port	146
7.3.5 Bearing	146
7.3.6 Shaft sealing feature	146
7.3.7 Casing	146
7.3.8 Capacity control mechanisms	146
7.3.9 Oil separator	148
7.4 Rotor Tooth Profile	148
7.4.1 Rotor tooth profile	148
7.4.2 Number of rotor teeth	148
7.4.3 Theoretical volume of single screw compressors	149
7.4.4 New gate rotor tooth profile	149
7.5 Performance and Noise	151
7.5.1 Efficiency characteristics	151
7.5.2 Noise characteristics	151
7.6 Other Mechanisms with Single Screw Compressors	152
7.6.1 Cooling system by oil injection	152
7.6.2 Cooling system by liquid refrigerant injection	152
7.6.3 Economizer cycle	152
Chapter 8 Automotive Air Conditioning Compressors	154
8.1 History of Automotive Air Conditioning Compressors	154
8.2 Automotive Air Conditioning Systems	155
8.2.1 Characteristics of automotive air conditioning systems	155
8.2.2 Types of automotive air conditioning compressors	157
8.2.3 Power transmission mechanism	157
8.3 Axial Compressors	158
8.3.1 Wobble plate compressors	158
8.3.2 Swash plate compressors	162
8.3.3 Variable capacity compressors	165
8.3.4 Noise and vibration of axial compressors	174
8.4 Scroll Compressors	175
8.4.1 History of scroll compressors	175
8.4.2 Structure and characteristics of scroll compressors for automotive air conditioners	176
8.4.3 Thrust bearing structure	178
8.4.4 Capacity control mechanism	179
8.4.5 Torque fluctuation and belt life	179
8.5 Rotary Vane Compressors	180
8.5.1 Operating principle	180
8.5.2 Theoretical volume	181

8.5.3 Basic structure	182
8.5.4 Dynamic-mechanical analysis	184
Chapter 9 Refrigeration Oil	190
9.1 Types of Refrigeration Oil	190
9.1.1 MO refrigeration oil	190
9.1.2 AB refrigeration oil	191
9.1.3 PAG refrigeration oil	191
9.1.4 PVE refrigeration oil	191
9.1.5 POE refrigeration oil	192
9.2 Interaction with Refrigerant	192
9.2.1 Miscibility	193
9.2.2 Solution properties	194
9.2.3 Electrical insulation	195
9.2.4 Lubricity	197
9.2.5 Stability	199
9.2.6 Compatibility with organic materials	201
9.3 Refrigeration Oil Selection Method and Considerations for Use	201
9.3.1 Refrigeration oil selection method	201
9.3.2 Considerations for use of refrigeration oil	202
Chapter 10 Motors and Inverters	205
10.1 Motor Structure and Performance	205
10.1.1 Motor classifications by drive power waveform	206
10.1.2 Motor structure and components	208
10.1.3 Motor component fabrication	210
10.1.4 Alternative stator fabrication method	213
10.2 Motor Design	213
10.2.1 Operating principle of induction motors	213
10.2.2 Operating principle of permanent-magnet synchronous motors	214
10.2.3 Motor design specifications (specification requirements, output-torque relationship)	215
10.3 Motor Materials and Evaluation Methods	217
10.3.1 Magnet wires	218
10.3.2 Varnish	219
10.3.3 Insulating papers (films)	221
10.3.4 Silicon steel sheets	222
10.3.5 Permanent magnets	224
10.4 Inverter Structure and Control	226
10.4.1 Inverter classifications and characteristics	226
10.4.2 Inverter structure and components	227
10.4.3 Principle of voltage-based inverters	231
10.4.4 Principle of motor control	232
10.5 Electrical Characteristic Measurements (with Inverter Control)	235
10.5.1 Types of loss and measurement methods	235
10.5.2 Types of noises and measurement methods	236

10.6 Standards and Regulations	237
10.6.1 Power supply voltages, standards and regulations in major countries	237
Chapter 11 Testing	241
11.1 Performance Tests	241
11.1.1 Main measurement items	241
11.1.2 Test methods	242
11.2 Noise Tests	244
11.2.1 Measurement conditions and equipment	245
11.2.2 Measurement methods	246
11.3 Vibration Tests	246
11.3.1 Measurement conditions and equipment	246
11.3.2 Measurement method	247
11.4 Reliability Tests	248
11.4.1 Types of reliability tests	248
11.4.2 Reliability test implementation	249
11.4.3 Reliability data analysis	249
11.4.4 Reliability evaluation	249
11.5 Pressure Tests	249
11.5.1 Pressure resistance test	249
11.5.2 Strength test	250
11.5.3 Airtightness test	250
11.6 Other Tests	250
Chapter 12 Measurement Technologies	251
12.1 Measurements of Basic Physical Quantities	251
12.1.1 Temperature measurement	251
12.1.2 Thermocouples and resistance thermometer sensors	252
12.1.3 Pressure measurements	253
12.1.4 Flow rate measurements	255
12.2 Applied Measurements	258
Chapter 13 About This Book	262