

Contents

| | |
|--|------|
| Abbreviations and Symbols | XIII |
| Introduction | 1 |
| 1 Some Elementary Principles of Mechanics | 4 |
| 1.1 Newtons Law | 4 |
| 1.2 Moment of Inertia | 6 |
| 1.3 Effect of Gearing | 7 |
| 1.4 Power and Energy | 9 |
| 1.5 Experimental Determination of Inertia | 10 |
| 2 Dynamics of a Mechanical Drive | 12 |
| 2.1 Equations Describing the Motion of Drive with Lumped Inertia | 12 |
| 2.2 Steady State Characteristics of Different Types of Motors and Loads | 15 |
| 2.3 Stable and Unstable Operating Points | 18 |
| 3 Integration of the Simplified Equation of Motion | 21 |
| 3.1 Solution of the Linearized Equation | 21 |
| 3.1.1 Start of a Motor with Shunt-type Characteristic at no-load | 22 |
| 3.1.2 Starting the Motor with a Load Torque Proportional to Speed | 23 |
| 3.1.3 Loading Transient of the Motor Running at no-load Speed | 24 |
| 3.1.4 Starting of a DC Motor by Sequentially Shorting Starting Resistors | 26 |
| 3.2 Analytical Solution of Nonlinear Differential Equation | 28 |
| 3.3 Numerical and Graphical Integration | 29 |
| 4 Thermal Effects in Electrical Machines | 33 |
| 4.1 Power Losses and Temperature Restrictions | 33 |
| 4.2 Heating of a Homogeneous Body | 34 |

| | | |
|-----------|---|------------|
| 4.3 | Different Modes of Operation | 37 |
| 4.3.1 | Continuous Duty | 37 |
| 4.3.2 | Short Time Intermittent Duty | 38 |
| 4.3.3 | Periodic Intermittent Duty | 39 |
| 5 | Separately Excited DC Machine | 41 |
| 5.1 | Introduction | 41 |
| 5.2 | Differential Equations and Block Diagram | 43 |
| 5.3 | Steady State Characteristics with Armature and Field Control | 45 |
| 5.3.1 | Armature Control | 46 |
| 5.3.2 | Field Control | 47 |
| 5.3.3 | Combined Armature and Field Control | 50 |
| 5.4 | Dynamic Behaviour of DC Motor at Constant Flux | 52 |
| 6 | DC Motor with Series Field Winding | 57 |
| 6.1 | Block Diagram of Series Motor | 58 |
| 6.2 | Steady State Characteristics | 60 |
| 7 | Control of a Separately Excited DC Machine | 65 |
| 7.1 | Introduction | 65 |
| 7.2 | Cascade Control of DC Motor in the Armature Control Range | 67 |
| 7.3 | Cascade Control of DC Motor in the Field-weakening Region | 76 |
| 7.4 | Supplying a Separately Excited DC Motor from a Rotating Generator | 81 |
| 8 | The Static Converter Used as a Power Actuator | 84 |
| 8.1 | Electronic Switching Devices | 84 |
| 8.2 | Line-commutated Converter in the Single-phase Bridge Connection | 88 |
| 8.3 | Line-commutated Converter in Three-phase Bridge Connection | 102 |
| 8.4 | Line-commutated Converters with Reduced Reactive Power | 111 |
| 8.5 | Closed Loop Control with Converter Used as Actuator | 114 |
| 9 | Control of Converter-supplied DC Drives | 120 |
| 9.1 | DC Drive with Line-commutated Converter | 120 |
| 9.2 | DC Drives with Converters Employing Forced Commutation | 131 |
| 10 | Symmetrical Three-phase AC Induction Machine | 142 |
| 10.1 | Mathematical Model of the Symmetrical Induction Motor for Dynamic Conditions | 142 |
| 10.2 | Operation in Steady-state with Sinusoidal Symmetrical Three-phase Supply Voltages | 152 |

| | |
|--|------------|
| 10.2.1 Stator Current, Current Locus | 152 |
| 10.2.2 Steady State Torque, Efficiency | 157 |
| 10.2.3 Comparison with Practical Motor Designs | 161 |
| 10.2.4 Starting of the Induction Motor | 162 |
| 10.3 Generalized Operation of the Induction Motor with Impressed Stator Voltages of any Waveform | 165 |
| 10.4 Steady-state Operation of Symmetrical Induction Motor Supplied with Sinusoidal but Unsymmetrical Line Voltages . . . | 175 |
| 10.4.1 Symmetrical Components | 175 |
| 10.4.2 Single-phase Induction Motor | 179 |
| 10.4.3 Single-phase Electric Brake for AC Crane-drives | 182 |
| 10.4.4 Unsymmetrical Starting Scheme for Induction Motor . . . | 183 |
| 11 Power Supplies for Variable Speed AC Drives | 187 |
| 11.1 Pulse-width Modulated (PWM) Transistor Inverter Operating at High Switching Frequency | 188 |
| 11.2 Pulse-width Modulated Thyristor Converter with Constant Direct Voltage Supply (Voltage Source Inverter) | 191 |
| 11.3 Thyristor Converter with Impressed Direct Current Supply (Current Source Inverter) | 197 |
| 11.4 AC/AC Converter without DC Link (Cycloconverter) | 200 |
| 12 Control of Induction Motor Drives | 204 |
| 12.1 Speed Control of Induction Motor with Impressed Sinusoidal Stator Currents and Open Loop Flux Control | 205 |
| 12.2 Control of Induction Motor in Field Coordinates Assuming Impressed Stator Currents | 214 |
| 12.2.1 Principle of Field Orientation | 214 |
| 12.2.2 Acquisition of Flux Signals | 222 |
| 12.2.3 Effects of Residual Lag of the Current Control Loops . . . | 224 |
| 12.2.4 Digital Signal Processing | 227 |
| 12.2.5 Experimental Results | 229 |
| 12.3 Control in Field Coordinates of an Induction Motor Fed by a Voltage Source Inverter | 230 |
| 12.4 Control in Field Coordinates of an Induction Motor Fed by a Current Source Inverter | 237 |
| 13 Induction Motor Drive with Restricted Speed Range | 244 |
| 13.1 Doubly Fed Induction Machine with Constant Stator Frequency and Field Orientated Rotor Current Control | 244 |
| 13.2 Wound Rotor Induction Motor with Slip-power Recovery . . . | 254 |

| | |
|---|-----|
| 14 Variable Frequency Synchronous Motor Drives | 260 |
| 14.1 Control of Synchronous Motors with Permanent Magnet Excitation | 261 |
| 14.2 Control of Synchronous Motors with Field Winding and Variable Frequency Stator Supply by Cycloconverter | 270 |
| 14.3 Synchronous Motor with Direct Current Link and Natural Commutation of the Machine-side Converter | 277 |
| 15 Some Applications of Controlled Electrical Drives | 286 |
| 15.1 Speed Control Systems | 286 |
| 15.2 Linear Position Control | 295 |
| 15.3 Linear Position Control with Moving Target | 305 |
| 15.4 Time Optimal Position Control with Fixed Target | 311 |
| 15.5 Time Optimal Position Control with Moving Target | 318 |
| References | 323 |
| Subject Index | 343 |