

Electrical Machinery Fundamentals (4th)

Stephen J. Chapman

侯中權教授

Chung-Chuan Hou

中華大學電機系

清華大學電機博士

Contents

1. 電機機械原理簡介 Introduction to Machinery Principles
 2. 變壓器 Transformers
 3. 電力電子簡介 Introduction to Power Electronics
 4. 交流電機基本觀念 AC Machinery Fundamentals
 5. 同步發電機 Synchronous Generators
 6. 同步電動機 Synchronous Motors
 7. 感應電動機 Induction Motors
 8. 直流電機原理 DC Machinery Fundamentals
 9. 直流電動機與發電機 DC Motors and Generators
 10. 單相及特殊用途的電動機 Single-Phase and Special-Purpose Motors
- Appendix A 三相電路 Three-Phase Circuits
- Appendix B 線圈節距與分佈繞組 Coil Pitch and Distributed Windings
- Appendix C 同步電機的凸極理論 Salient-Pole Theory of Synchronous Machines
- Appendix D 單位變換因素及常數表 Tables of Constants and Conversion Factors
- Index

1. 電機機械原理簡介 Introduction to Machinery Principles

1.1 電機機械、變壓器與日常生活 Electrical Machines, Transformers, and Daily Life

1.2 單位與符號說明 A Note on Units and Notation

Notation

1.3 旋轉運動、牛頓定理與功率關係 Rotational Motion, Newton's Law, and Power Relationships

Angular Position θ / Angular Velocity ω / Angular Acceleration α / Torque τ /
Newton's Law of Rotation / Work W Power P

1.4 磁場 The Magnetic Field

Production of a Magnetic Field / Magnetic Circuits / Magnetic Behavior of
Ferromagnetic Materials / Energy Losses in a Ferromagnetic Core

1.5 法拉第定律:從一時變磁場感應電壓 Faraday's Law — Induced Voltage from a
Time-Changing Magnetic Field

1.6 導線感應力的產生 Production of Induced Force on a Wire

1.7 磁場中運動導體的感應電壓 Induced Voltage on a Conductor Moving in a
Magnetic Field

1.8 一個簡單例子:線性直流機 The Linear DC Machine — A Simple Example

Starting the Linear DC Machine / The Linear DC Machine as a Motor / The Linear
DC machine as a Generator/Starting Problems with the Linear Machine

1.9 交流電路之實功、虛功與視在功率 Real, Reactive, and Apparent Power in AC Circuits

Alternative Forms of the Power Equations / Complex Power / The Relationships
between impedance Angles, Current Angle, and Power / The Power Triangle

1.10 總結 Summary (Questions, Problems, References)

2. 變壓器 Transformers

2.1 變壓器對日常生活的重要性 Why Transformers Are Important to Modern Life

2.2 變壓器的型式及結構 Type and Construction of Transformers

2.3 理想變壓器 The Ideal Transformer

Power in an Ideal Transformer / Impedance Transformation through a Transformer / Analysis of Circuits Containing Ideal Transformers

2.4 實際單相變壓器的操作理論 Theory of Operation of Real Single-Phase Transformers

The Voltage Ratio across a Transformer / The Magnetization Current in a Real Transformer / The Current Ratio on a Transformer and the Dot Convention

2.5 變壓器的等效電路 The Equivalent Circuit of a Transformer

The Exact Equivalent Circuit of a Real Transformer / Approximate Equivalent Circuits of a Transformer / Determining the Values of Components in the Transformer Model

2.6 標么系統 The Pure-Unit System of Measurements

2.7 變壓器的電壓調整率及效率 Transformer Voltage Regulation and Efficiency

The Transformer Phasor Diagram / Transformer Efficiency

2.8 變壓器的分接頭及電壓調整率 Transformer Taps Voltage Regulation

2.9 自耦變壓器 The Autotransformer

Voltage and Current Relationships in an Autotransformer / The Apparent Power Rating Advantage of Autotransformers / The Internal Impedance of an Autotransformer

2.10 三相變壓器 Three-Phase Transformers

Three-Phase Transformer Connections / The Per-Unit System for Three-Phase Transformers

2.11 以兩單相變壓器作三相電壓轉換 Three-Phase Transformation Using Two Transformers

The Open- Δ (or V-V) Connection / The Open-Wye-Open-Delta Connection / The Scott-T Connection / The Three-Phase T Connection

2.12 變壓器的額定及一些相關問題 Transformer Ratings and Related Problems

The Voltage and Frequency Ratings of a Transformer / The apparent Power Ratings of a Transformer / The Problem of Current Inrush / The Transformer Nameplate

2.13 儀器變壓器 Instrument Transformers

2.14 總結 Summary (Questions, Problems, References)

3.電力電子簡介 Introduction to Power Electronics

3.1電力電子元件 Power Electronic Components

The Diode / The Two-Wire Thyristor or PNP Diode / The Three-Wire Thyristor or SCR / The Gate Turnoff Thyristor / The DIAC / The TRIAC / The Power Transistor / The Insulated-Gate Bipolar Transistor / Power and Speed Comparison of Power Electronic Components

3.2基本整流電路 Basic Rectifier Circuits

The Half-Wave Rectifier / The Full-Wave Rectifier / The Three-Phase Half-Wave Rectifier / The Three-Phase Full-Wave Rectifier / Filtering Rectifier Output

3.3脈波電路 Pulse Circuits

A Relaxation Oscillator using a PNP Diode / Pulse Synchronization

3.4交流相位控制的電壓調整 Voltage Variation by AC Phase Control

AC Phase Control for a DC Load Driven from an AC Source / AC Phase Angle Control for a AC Load / The Effect of Inductive Loads on Phase Angle Control

3.5直流到直流功率控制:截波器 DC-to-DC Power Control—Choppers

Forced Commutation in Chopper Circuits / Series-Capacitor Commutation Circuits / Parallel-Capacitor Commutation Circuits

3.6變頻器 Inverters

The Rectifier / External Commutation Inverters / Self-Commutation Inverters / A Single-Phase Current Source Inverter / A Three-Phase Current Source Inverter / A Three-Phase Voltage Source Inverter / Pulse-Width Modulation Inverters

3.7頻率轉換器 Cycloconverters

Basic Concepts / Noncirculating Current Cycloconverters / Circulating Current Cycloconverters

3.8諧波問題 Harmonic Problems

3.9總結 Summary (Questions, Problems, References)

4. 交流電機基本觀念 AC Machinery Fundamentals

4.1 置於均勻磁場內之單一匝線圈 A Simple Loop in a Uniform Magnetic Field

The Voltage Induced in a Simple Rotating Loop

The Torque Induced in a Current-Carrying Loop

4.2 旋轉磁場 The Rotating Magnetic Field

Proof of the Rotating Magnetic Field Concept / The Relationship between Electrical Frequency and the Speed of Magnetic Field Rotation / Reversing the Direction of Magnetic Field Rotation

4.3 交流電機內的磁力和磁通分佈 Magnetomotive Force and Flux Distribution on AC Machines

4.4 交流電機的感應電壓 Induced Voltage in AC Machines

The Induced Voltage in a Coil on a Two-Pole Stator / The Induced Voltage in a Three-Phase Set of Coils / The RMS Voltage in a Three-Phase Stator

4.5 交流電機的感應轉矩 Induced Torque in an AC Machine

4.6 交流電機的繞組絕緣 Winding Insulation in an AC Machine

4.7 交流電機的功率潮流與損失 AC Machine Power Flows and Losses

The Losses in AC Machines / The Power-Flow Diagram

4.8 電壓調整率與速度調整率 Voltage Regulation and Speed Regulation

4.9 總結 Summary (Questions, Problems, References)

5. 同步發電機 Synchronous Generators

- 5.1 同步發電機之結構 Synchronous Generator Construction
- 5.2 同步發電機的轉速 The Speed of Rotation of a Synchronous Generator
- 5.3 同步發電機內部所產生的電壓 The Internal Generated Voltage of a Synchronous Generator
- 5.4 同步發電機之等效電路 The Equivalent Circuit of a Synchronous Generator
- 5.5 同步發電機之相量圖 The Phasor Diagram of a Synchronous Generator
- 5.6 同步發電機之功率及轉矩 Power and Torque in Synchronous Generators
- 5.7 同步發電機模型之參數量測 Measuring Synchronous Generator Model Parameters
The Short-Circuit Ratio
- 5.8 單獨運轉之同步發電機 The Synchronous Generator Operating Alone
The Effect of Load Changes on Synchronous Generator Operating Alone / Example Problems
- 5.9 交流發電機之並聯運轉 Parallel Operation of AC Generators
The Conditions Required for Paralleling / The General Procedure for Paralleling Generators /
Frequency-Power and Voltage-Reactive Power Characteristics of a Synchronous Generator /
Operation of Generators in Parallel with Large Power Systems / Operation of Generators in
Parallel with Other Generators of the Same Size
- 5.10 同步發電機暫態 Synchronous Generator Transients
Transient Stability of Synchronous Generators / Short-circuit Transients in Synchronous
Generators
- 5.11 同步發電機額定 Synchronous Generator Ratings
The Voltage, Speed, and Frequency Ratings / Apparent Power and Power-Factor Ratings /
Synchronous Generator Capability Curves / Short-Time Operation and Service Factor
- 5.12 總結 Summary (Questions, Problems, References)

6. 同步電動機 Synchronous Motors

6.1 電動機運轉之基本原理 Basic Principles of Motor Operation

The Equivalent Circuits of a Synchronous Motor / The Synchronous Motor from a Magnetic Field Perspective

6.2 穩態同步電動機運轉 Steady-State Synchronous Motor Operation

The Synchronous Motor Torque-Speed Characteristic Curve / The effect of Load Changes on a Synchronous Motor / The Effect of Field Changes on a Synchronous Motor / The Synchronous Motor and Power-Factor Correction / The Synchronous Capacitor or Synchronous Condenser

6.3 起動同步電動機 Starting Synchronous Motors

Motor Starting by Reduced Electrical frequency / Motor Starting with an External Prime Mover / Motor Starting by Using Amortisseur Windings / The Effect of Amortisseur Windings on Motor Stability

6.4 同步發電機和同步電動機結 Synchronous Generators and Synchronous Motors

6.5 同步電動機額定 Synchronous Motors Ratings

6.6 總結 Summary (Questions, Problems, References)

7.感應電動機 Induction Motors

7.1感應電動機的構造 Induction Motor Construction

7.2感應電動機的基本觀念 Basic Induction Motor Concepts

[The Development of Induced Torque in an Induction Motor / The Concept of Rotor Slip / The Electrical Frequency on the Rotor](#)

7.3感應電動機的等效電路 The Equivalent Circuit of an Induction Motor

[The transformer Model of an Induction Motor / The Rotor Circuit Model / The Final Equivalent Circuit](#)

7.4感應電動機的功率與轉矩 Power and Torque in Induction Motors

[Losses and the Power-Flow Diagram / Power and Torque in an Induction Motor / Separating the Rotor Copper Losses and the Power Converted in an Induction Motor's Equivalent Circuit](#)

7.5感應電動機的轉矩速度特性 Induction Motor Torque-Speed Characteristics

[Induced Torque from a Physical Standpoint / the Derivation of the Induction Motor Induced Torque Equation / Comments on the Induction Motor Torque-Speed Curve / Maximum \(Pullout\) Torque in an Induction Motor](#)

7.6感應電動機轉矩速度特性曲線的變化 Variations in Induction Motor Torque-Speed Characteristics

[Control of Motor Characteristics by Cage Rotor Design / Deep-Bar and Double-Cage Rotor Designs / Induction Motor Design Classes](#)

7.7感應電動機的設計趨勢 Trends in Induction Motor Design

7.8感應電動機的啟動 Starting Induction Motors [Induction Motor Starting Circuits](#)

7.9感應電動機的速度控制 Speed Control of Induction Motors

[Induction Motor Speed Control by Pole Changing / Speed Control by Changing the Line Frequency / Speed Control by Changing the Line Voltage / Speed Control by Changing the Rotor Resistance](#)

7.10固態感應電動機驅動器 Solid-State Induction Motor Drives

[Frequency \(Speed\) Adjustment / A Choice of Voltage and Frequency Patterns / Independently Adjustable Acceleration and Deceleration Ramps / Motor Protection](#)

7.11決定電路模型的參數 Determining Circuit Model Parameters

[The No-Load Test / The DC Test for Stator Resistance / The Locked-Rotor Test](#)

7.12感應發電機 The Induction Generator

[The Induction Generator Operating Alone / Induction Generator Applications](#)

7.13感應電動機的額定 Induction Motor Ratings

7.14總結 Summary (Questions, Problems, References)

8. 直流電機原理 DC Machinery Fundamentals

- 8.1 曲線極面間之簡單旋轉迴圈 A Simple Rotating Loop between Curved Pole Faces
The Voltage Induced in a Rotating Loop / Getting DC Voltage out of the Rotating Loop / The Induced Torque in The Rotating Loop
- 8.2 簡單之四迴圈直流電機之換向 Commutation in a Simple Four-Loop DC Machine
- 8.3 實際直流電機之換向和電樞構造 Commutation and Armature Construction in Real DC Machines
The Rotor Coils / Connections to the Commutator Segments / The lap Winding / The Wave Winding / The Frog-Leg Winding
- 8.4 實際電機之換向問題 Problems with Commutation in Real Machines
Armature Reaction / $L \, di/dt$ Voltages / Solutions to the Problems with Commutation
- 8.5 實際電機之內生電壓及感應轉矩方程式 The Internal Generated Voltage and Induced Torque Equations of Real DC Machines
- 8.6 直流電機之構造 The Construction of DC Machines
Pole and Frame Construction / rotor or Armature Construction / Commutator and Brushes / Winding Insulation
- 8.7 直流電機之電力潮流及損失 Power Flow and Losses DC Machine
The Losses in DC Machines / The Power-Flow Diagram
- 8.8 總結 Summary (Questions, Problems, References)

9. 直流電動機與發電機 DC Motors and Generators

- 9.1 直流電動機簡介 Introduction to DC Motors
- 9.2 直流電動機的等效電路 The Equivalent Circuit of a DC Motor
- 9.3 直流機的磁化曲線 The Magnetization Curve of a DC Motor
- 9.4 外激和分激式直流電動機 Separately Excited and Shunt DC Motors
 - The Terminal Characteristic of a Shunt DC Motor / Nonlinear Analysis of a Shunt DC Motor / Speed Control of Shunt DC Motors / The Effect of an Open Field Circuit
- 9.5 永磁式直流電動機 The Permanent-Magnet DC Motor
- 9.6 直流串激電動機 The Series DC Motor
 - Induced Torque in a Series DC Motor / The Terminal Characteristic of a Series DC Motor / Speed Control of Series DC Motors
- 9.7 複激式直流電動機 The Compounded DC Motor
 - The Torque-Speed Characteristic of a Cumulatively Compounded DC Motor / The Torque-Speed Characteristic of a Differentially Compounded DC Motor / The Nonlinear Analysis of Compounded DC Motors / Speed Control in the Cumulatively Compounded DC Motor
- 9.8 直流電動機起動器 DC Motor Starters DC Motor Problems on Starting / DC Motor Starting Circuits
- 9.9 華德-里翁納德系統和固態速度控制器 The Ward-Leonard System and Solid-State Speed Controllers
 - Protection Circuit Section / Start/Stop Circuit Section / High-Power Electronics Section / Low-Power Electronics Section
- 9.10 直流電動機效率之計算 DC Motor Efficiency Calculations
- 9.11 直流發電機簡介 Introduction to DC Generators
- 9.12 他激式發電機 The Separately Excited Generator
 - The Terminal Characteristic of a Separately Excited DC Generator / Control of Terminal Voltage / Nonlinear Analysis of a Separately Excited DC Generator
- 9.13 分激式直流發電機 The Shunt DC Generator
 - Voltage Buildup in a Shunt Generator / The Terminal Characteristic of a Shunt DC Generator / Voltage Control for a Shunt DC Generator / The Analysis of Shunt DC Generators
- 9.14 串激式直流發電機 The Series DC Generator The Terminal Characteristic of a Series DC Generator
- 9.15 積複激式直流發電機 The Cumulatively Compounded DC Generator
 - The Terminal Characteristic of a Cumulatively Compounded DC Generator / Voltage Control of Cumulatively Compounded DC Generators / Analysis of Cumulatively Compounded DC Generators
- 9.16 差複激式直流發電機 The Differentially Compounded DC Generator
 - The Terminal Characteristic of a Differentially Compounded DC Generator / Voltage Control of Differentially Compounded DC Generators / Graphical Analysis of a Differentially Compounded DC Generator
- 9.17 總結 Summary (Questions, Problems, References)

10. 單相及特殊用途的電動機 Single-Phase and Special-Purpose Motors

10.1 萬用電動機 The Universal Motor

[Applications of Universal Motors / Speed Control of Universal Motors](#)

10.2 單相感應電動機之簡介 Introduction to Single-Phase Induction Motors

[The Double-Revolving-Field Theory of Single-Phase Induction Motors / The Cross-Field Theory of Single-Phase Induction Motors](#)

10.3 單相感應電動機的啟動 Starting Single-Phase Induction Motors

[Split-Phase Windings / Capacitor-Start Motors / Permanent Split-Capacitor and Capacitor-Start, Capacitor-Run Motors / Shaded-Pole Motors / Comparison of Single-Phase Induction Motors](#)

10.4 單相感應電動機之速度控制 Speed Control of Single-Phase Induction Motors

10.5 總單相感應電動機之電路模型 The Circuit Model of a Single-Phase Induction Motor

[Circuit Analysis with the Single-Phase Induction Motor Equivalent Circuit](#)

10.6 其它形式的電動機 Other Types of Motors

[Reluctance Motors / Hysteresis Motors / Stepper Motors / Brushless DC Motors](#)

10.7 總結 Summary (Questions, Problems, References)

Appendix A 三相電路 Three-Phase Circuits

A.1 三相電壓及電流的產生 Generation of Three-Phase Voltages and Currents

A.2 三相電路中之電壓及電流 Voltages and Currents in a Three-Phase Circuit

Voltages and Currents in the Wye (Y) Connection / Voltages and Currents in the Delta (Δ) Connection

A.3 三相電路中的功率關係 Power Relationships in Three-Phase Circuits

Three-Phase Power Equations Involving Phase Quantities / Three-Phase Power Equations Involving Line Quantities

A.4 平衡三相系統的分析 Analysis of Balanced Three-Phase Systems

A.5 單線圖 One-Line Diagrams

A.6 使用功率三角形 Using the Power Triangle (Questions, Problems, References)

Appendix B 線圈節距與分佈繞組 Coil Pitch and Distributed Windings

B.1 交流電機線圈節距之效應 The Effect of Coil Pitch on AC Machines

The Pitch of a Coil / The Induced Voltage of a Fractional-Pitch Coil / Harmonic Problems and Fractional-Pitch Windings

B.2 交流電機之分佈繞組 Distributed Windings in AC Machines

The Breadth or Distribution Factor / The Generated Voltage Including Distribution Effects / Tooth or Slot Harmonics

B.3 總結 Summary (Questions, Problems, References)

Appendix C 同步電機的凸極理論 Salient-Pole Theory of Synchronous Machines

C.1 Development of the Equivalent Circuit of a Salient-Pole Synchronous Generator

C.2 Torque and Power Equations of Salient-Pole Machine (Problems)

Appendix D 單位變換因素及常數表 Tables of Constants and Conversion Factors