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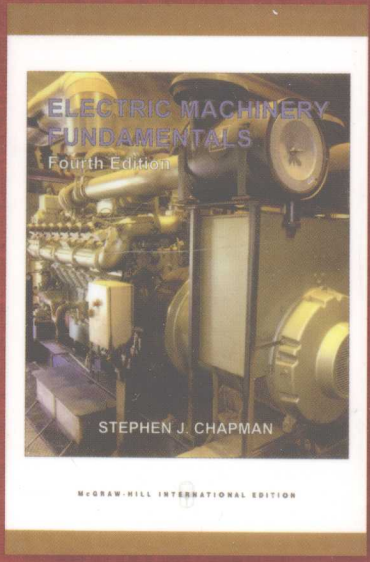

电机原理及驱动

—— 电机学基础（第4版）

Electric Machinery Fundamentals

(Fourth Edition)

Stephen J. Chapman 原著

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ABOUT THE AUTHOR

Stephen J. Chapman received a B.S. in Electrical Engineering from Louisiana State University (1975) and an M.S.E. in Electrical Engineering from the University of Central Florida (1979), and pursued further graduate studies at Rice University.

From 1975 to 1980, he served as an officer in the U.S. Navy, assigned to teach electrical engineering at the U.S. Naval Nuclear Power School in Orlando, Florida. From 1980 to 1982, he was affiliated with the University of Houston, where he ran the power systems program in the College of Technology.

From 1982 to 1988 and from 1991 to 1995, he served as a member of the technical staff of the Massachusetts Institute of Technology's Lincoln Laboratory, both at the main facility in Lexington, Massachusetts, and at the field site on Kwajalein Atoll in the Republic of the Marshall Islands. While there, he did research in radar signal processing systems. He ultimately became the leader of four large operational range instrumentation radars at the Kwajalein field site (TRADEX, ALTAIR, ALCOR, and MMW).

From 1988 to 1991, Mr. Chapman was a research engineer in Shell Development Company in Houston, Texas, where he did seismic signal processing research. He was also affiliated with the University of Houston, where he continued to teach on a part-time basis.

Mr. Chapman is currently manager of systems modeling and operational analysis for BAE SYSTEMS Australia, in Melbourne.

Mr. Chapman is a senior member of the Institute of Electrical and Electronic Engineers (and several of its component societies). He is also a member of the Association for Computing Machinery and the Institution of Engineers (Australia).

编译者序

改革开放以来，我国的经济进入了快速发展期，很快融入了世界经济发展的大潮。随着我国加入 WTO，日益国际化的经济对我国专业人员的国际化水平提出了更高的要求。较高的国际化水平的一个突出的方面是专业人员的专业英文的交流能力有待极大提高。

因为客观市场对此有迫切需求，国家教委也将双语教学列为高等学校教育质量评估中的一项重要指标。

作为本书的编译者，我在多年与英国大学的合作研究和与外国公司的合作中，深刻认识到，专业英文的直接交流会极大地帮助我们发挥自身的潜能，增加在世界舞台上的竞争能力。而另一方面，在东北大学的多年教学中和在面试研究生和博士生的口语时，我也发现目前国内学生的专业英文能力比之他们的口语能力差距较大。因此我坚信：坚持双语教学，对于提高我国专业技术人员的直接交流能力，适应我国快速的经济发展需要，必将会起到积极的推动作用。

本书是基于由 Stephen J. Chapman 编写，McGraw-Hill 出版社出版的 *Electric Machinery Fundamentals* 一书的第 4 版(2005)改编。原著凝聚了作者在美国佛罗里达海军核动力学院和休斯敦大学的多年教学经验，作者在著书时掌握的主要原则是使其尽可能地通俗易懂，便于自学，这是本书的最大特点。此外，书中的内容最大限度地跟踪最新技术的发展，因此，原著自 1985 年第 1 版出版以来，已经成为世界上的畅销教材。

随着现代电力电子技术和交流控制技术的发展，交流电机在更多的领域不断取代直流电机的应用，而原著的第 4 版也正是为了适应新技术的发展，先阐述交流部分内容，开创了以交流内容作为重点的先河，有别于一般的传统教材。

本书保留了原著第 4 版的大部分章节。其中删除了原书中的第 3 章“功率电子学”部分，因为在我国，大部分学校另设这门课程。在原著中，关于同步电机有两章，同步发电机和同步电动机(原书的第 5 章和第 6 章)，而我们在教授这门课程时，往往没有很多课时用在同步电机上，因此将原著的两章合并为一章(作为本书的第 4 章)。

为了便于读者理解，编译者增加了“词汇”和“导读”部分。在“词汇”部分，侧重点是专业词汇，给出了相对应的汉语术语。尽管穿插在书中各节列出了一些词汇，但是，为了读者查阅方便，在最后附录中，还按字母顺序列出了总的英汉对照词汇表。

为了使读者减少对中文的依赖性，编译者在“导读”部分，使用汉语注释的侧重点是理解上的难点，而不是本章节的重点；而本章节的重点内容，读者可以阅读原文中的“Summary”，还可以由教师在讲课中予以指导。

参加本书编译工作的还有边春元，李爱萍，杨东升等，在此，向他们表示谢意。

在本教材的编译过程中，得到了清华大学出版社的鼎力支持，在此，表示诚挚的感谢。

本教材可以作为高等学校电气工程和自动化专业本科学生的专业基础课双语教材，也可以作为电气工程和自动化领域工程技术人员的技术参考书。

东北大学　满永奎

2008 年 6 月

PREFACE

In the years since the first edition of *Electric Machinery Fundamentals* was published, there has been rapid advance in the development of larger and more sophisticated solid-state motor drive packages. The first edition of this book stated that dc motors were the method of choice for demanding variable-speed applications. That statement is no longer true today. Now, the system of choice for speed control applications is most often an ac induction motor with a solid-state motor drive. DC motors have been largely relegated to special-purpose applications where a dc power source is readily available, such as in automotive electrical systems.

The third edition of the book was extensively restructured to reflect these changes. The material on ac motors and generators is now covered in Chapters 4 through 7, before the material on dc machines. In addition, the dc machinery coverage was reduced compared to earlier editions. The fourth edition continues with this same basic structure.

Chapter 1 provides an introduction to basic machinery concepts, and concludes by applying those concepts to a linear dc machine, which is the simplest possible example of a machine. Chapter 2 covers transformers, and Chapter 3 is an introduction to solid-state power electronic circuits. The material in Chapter 3 is optional, but it supports ac and dc motor control discussions in Chapters 7, 9, and 10.

After Chapter 3, an instructor may choose to teach either dc or ac machinery first. Chapters 4 through 9 cover ac machinery, and Chapters 8 and 9 cover dc machinery. These chapter sequences have been made completely independent of each other, so that instructors can cover the material in the order that best suits their needs. For example, a one-semester course with a primary concentration in ac machinery might consist of parts of Chapters 1 to 7, with any remaining time devoted to dc machinery. A one-semester course with a primary concentration in dc machinery might consist of parts of Chapters 1, 3, 8, and 9, with any remain-

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编译者注：由于本书对原书章节做了一些删节与合并，因此本前言中的章节号与书中内容有一些不同。参见“编译者序”。为了便于读者更好地理解本前言内容，现将原书各章标题列出：Chapter 1 Introduction to Machinery Principles；Chapter 2 Transformers；Chapter 3 Introduction to Power Electronics；Chapter 4 AC Machinery Fundamentals；Chapter 5 Synchronous Generators；Chapter 6 Synchronous Motors；Chapter 7 Induction Motors；Chapter 8 DC Machinery Fundamentals；Chapter 9 DC Motors and Generators；Chapter 10 Single-Phase and Special-Purpose Motors。

ing time devoted to ac machinery. Chapter 10 is devoted to single-phase and special-purpose motors, such as universal motors, stepper motors, brushless dc motors, and shaded-pole motors.

The homework problems and the ends of chapters have been revised and corrected, and more than 70 percent of the problems are either new or modified since the last edition.

In recent years, there have been major changes in the methods used to teach machinery to electrical engineering and electrical technology students. Excellent analytical tools such as MATLAB have become widely available in university engineering curricula. These tools make very complex calculations simple to perform, and allow students to explore the behavior of problems interactively. This edition of *Electric Machinery Fundamentals* makes selected use of MATLAB to enhance a student's learning experience where appropriate. For example, students use MATLAB in Chapter 7 to calculate the torque–speed characteristics of induction motors and to explore the properties of double-cage induction motors.

This text does not teach MATLAB; it assumes that the student is familiar with it through previous work. Also, the book does *not* depend on a student having MATLAB. MATLAB provides an enhancement to the learning experience if it is available, but if it is not, the examples involving MATLAB can simply be skipped, and the remainder of the text still makes sense.

Supplemental materials supporting the book are available from the book's website, at www.mhhe.com/engcs/electrical/chapman. The materials available at that address include MATLAB source code, pointers to sites of interest to machinery students, a list of errata in the text, some supplemental topics that are not covered in the main text, and supplemental MATLAB tools.

This book would never have been possible without the help of dozens of people over the past 18 years. I am not able to acknowledge them all here, but I would especially like to thank Charles P. LeMone, Teruo Nakawaga, and Tadeo Mose of Toshiba International Corporation for their invaluable help with the solid-state machinery control material in Chapter 3. I would also like to thank Jeffrey Kostecki, Jim Wright, and others at Marathon Electric Company for supplying measured data from some of the real generators that the company builds. Their material has enhanced this revision.

Finally, I would like to thank my wife Rosa and our children Avi, David, Rachel, Aaron, Sarah, Naomi, Shira, and Devorah for their forbearance during the revision process. I couldn't imagine a better incentive to write!

Stephen J. Chapman
Melbourne, Victoria, Australia

BRIEF CONTENTS

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CHAPTER 1

INTRODUCTION TO MACHINERY PRINCIPLES

1.1 ELECTRICAL MACHINES, TRANSFORMERS, AND DAILY LIFE

An **electrical machine** is a device that can convert either mechanical energy to electrical energy or electrical energy to mechanical energy. When such a device is used to convert mechanical energy to electrical energy, it is called a *generator.* When it converts electrical energy to mechanical energy, it is called a *motor.* Since any given electrical machine can convert power in either direction, any machine can be used as either a generator or a motor. Almost all practical motors and generators convert energy from one form to another through the action of a magnetic field, and only machines using magnetic fields to perform such conversions are considered in this book.

The *transformer* is an electrical device that is closely related to electrical machines. It converts ac electrical energy at one voltage level to ac electrical energy at another voltage level. Since transformers operate on the same principles as generators and motors, depending on the action of a magnetic field to accomplish the change in voltage level, they are usually studied together with generators and motors.

These three types of electric devices are ubiquitous in modern daily life. Electric motors in the home run refrigerators, freezers, vacuum cleaners, blenders, air conditioners, fans, and many similar appliances. In the workplace, motors provide the motive power for almost all tools. Of course, generators are necessary to supply the power used by all these motors.

Why are electric motors and generators so common? The answer is very