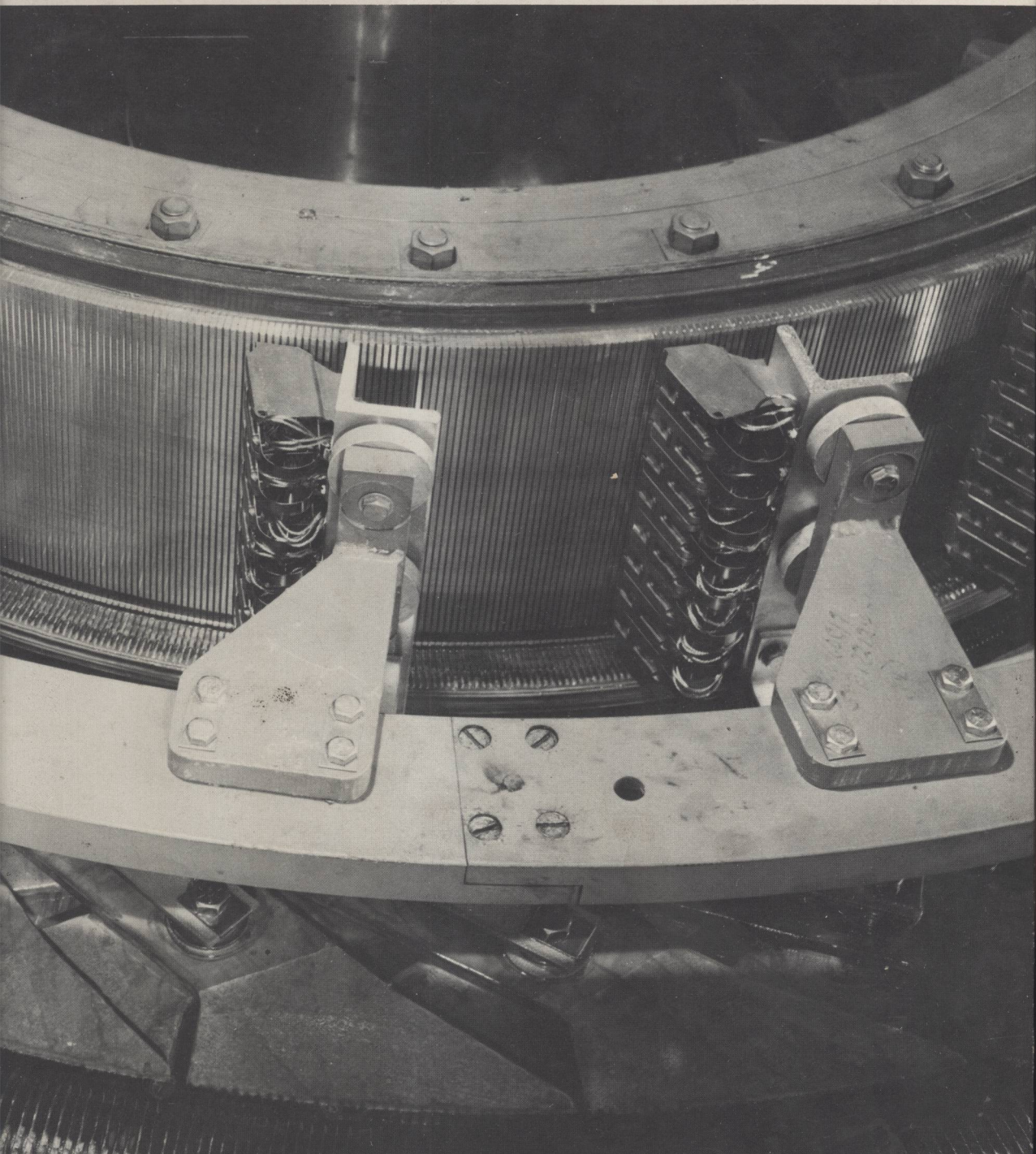


**ROSENBLATT  
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DIRECT AND  
ALTERNATING CURRENT  
MACHINERY

**2ND EDITION**



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# Direct and Alternating Current Machinery

2nd Edition

Jack Rosenblatt and M. Harold Friedman

New York City Technical College  
City University of New York



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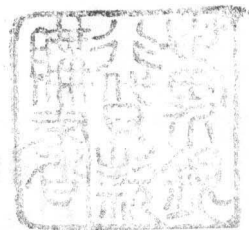
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# Direct and Alternating Current Machinery

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# PREFACE

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When the authors prepared the earlier edition of this book, it was to help the student meet the needs of industry. For approximately 18 years this text has been effectively providing the student with technical knowledge. However, the introduction of computers, programmable controllers, solid-state devices, and energy-saving devices, and the reintroduction of the metric system, have pointed out the need for a new edition.

The new edition retains all of the desirable features that made the earlier one so popular. A chapter explaining the metric system has been added as well as another one discussing solid-state and magnetic motor controllers. The chapter on single-phase motors has been expanded. Problems and illustrative examples are now given using SI units to allow the instructor to select problems using English Units or SI units, or a combination of both. Photographs and questions were added to improve comprehension and self evaluation. Computer programs are presented to illustrate the applicability of the computer to repetitive computations. There is also an introduction to the programmable controller so that the student can understand how the standard ladder diagram can be used to program the controller. This new edition continues to stress fundamentals and provides the background upon which further technical advances depend.

Upon reviewing the preface of the earlier edition, the authors have concluded that with few exceptions the needs that existed then still hold true. Hence the major portion of the original preface is restated to present the logic, intent and need for writing the text.

The fields of automatic control and automation have brought an increasing demand for energy-conversion devices. Industrial plants are continually seeking means to improve production methods and control the quality of their products and services. To satisfy these needs, techniques involving sequential and logic circuits, servomechanisms, static switching, data processing, and electronics to control motors and generators have been rapidly developed and improved. In dealing with control circuits, it is necessary to understand the theory of operation of the device to be controlled. Motors, gen-

erators, and transformers are integral parts of many control systems, and it is essential that today's engineer and technician be familiar with this equipment.

This book was written for the electrical technology student attending a two-year college, the nonelectrical engineering student attending a four-year college, and those enrolled in industrial training programs. Characteristics and basic theory are stressed rather than design, and so a knowledge of calculus is not required.

The authors have had extensive teaching experience in both collegiate and industrial training programs. Based upon this experience, one feature of the text is the arrangement of the subject matter to afford a great degree of flexibility in classroom presentation. It is therefore suitable for a one-year course for the specialist, or a shorter course as required by a particular curriculum.

Another feature is the use of line drawings so that referenced materials can be clearly and specifically illustrated. In many cases where phasor diagrams are illustrated, in addition to showing the completed phasor diagram with all component phasors, several phasor diagrams are presented which illustrate each step in the logical development of the final diagram.

Use of correct technical terminology is stressed throughout. Special consideration, however, is given to simplicity of language in the development of the theory. This should enable the student to make effective use of the text. There are some long mathematical manipulations, but close examination will show that the mathematics is limited to trigonometry and algebra.

There are many problems at the ends of the chapters, as well as many illustrative examples interwoven with the theory. Alternative methods of solution are often provided to enable the student to work in the manner best suited to him or her. Despite this, the emphasis is qualitative rather than quantitative, since the problems and examples are designed to illustrate the application of theory in analyzing and understanding machine performance.

Basic controllers are described for both direct- and alternating-current motors, but the field of control engineering and control technology has become so enlarged and specialized in recent years that it requires a course or even a curriculum of its own. However, the descriptions of these basic controllers provide a foundation for the study of more complex control systems.

Many texts have already been written on electrical machinery, but one more is presented here for a very specific reason. There is a gap between books written for the high school student and those for the college student majoring in electrical engineering. It is hoped that this book will materially assist in filling that gap.

The authors would like to acknowledge the enthusiastic assistance of many longtime users of the first edition in making this improved second edition possible, especially Salvatore J. Levanti of Queensborough Community College (N.Y.), Charles N. Koehler of Stark Technical College (Ohio), and Alphonso F. Bowers of New Mexico State University.

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# CHAPTER 1

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## System of Units

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### GENERAL 1.1

The need for electrical machinery is constantly changing. In some fields the demand has increased, in some it has decreased, and in others it has shifted from one type to another. However, in general, the requirements of industry for improvements in production methods and quality control, and for development of new products, will continue the demand for electrical machinery.

Because its presence, in most instances, is not apparent, we tend to overlook the fact that electrical machinery exists in everyday use. With a little thought, however, we soon realize that electrical machinery can be found in automobiles (e.g., alternators, starters, windshield wipers), in the home (e.g., clocks, turntables, dishwashers, washing machines, electric knives, can openers), in offices (e.g., pencil sharpeners, typewriters, copying machines, floor polishers) and in other applications as computer printers, word processors, tape recorders, video recorders, blueprint machines, elevators, electric drills, movie projectors, trains, and toys (and you probably can add dozens of additional uses).

A clear understanding of the basics of electrical machinery and controls is essential now, and undoubtedly will become more so in the future as new products are developed.

### METRIC SYSTEM 1.2

Before beginning our study of electrical machinery, it is necessary to introduce the metric system of units known as SI (for *Système International d'Unités*). Although the metric system was authorized for use in the United States by Congress in 1866, it was only recently that a major step was taken to implement the system. Currently we are in a stage of transition from the English system of units to the metric, and will probably remain in this stage for quite some time. For this reason, this text will use *both* systems, and will indicate conversions from one system to the other as required.

It is assumed that prior courses in electrical circuits, mathematics, and physics have been studied, and that problems have primarily been expressed in terms of the SI system. Should this not be the case, it is not of serious consequence, since the most frequently encountered electrical units

TABLE 1.1. Conversion constants.

Multiply	By	To Obtain
hours	3600	seconds
minutes	60	seconds
seconds	0.016667	minutes
feet	0.3048	meters
inches	0.0254	meters
meters	39.37	inches
meters	3.281	feet
ounces	0.278	newtons
pounds	4.448	newtons
newtons	0.2245	pounds
pound-feet	1.356	newton-meters
newton-meters	0.7376	pound-feet
horsepower	746	watts
revolutions per minute	0.1047	radians per second
maxwells	$10^{-8}$	webers
tesla	$6.452 \times 10^4$	lines per sq in.

have remained intact, e.g., the volt, the ampere, the ohm, and the watt. The bases upon which these and other units are now defined do indeed differ from the previous definitions, but the actual usage of the units remains the same.

Magnetic units have changed very little, except by name and order of magnitude. Thus the weber (Wb) is now the unit of flux and is equal to  $10^8$  previously used maxwells or lines. Its derived unit, flux density, is now the tesla (T), or webers per square meter ( $\text{Wb}/\text{m}^2$ ). The standard unit for magnetomotive force is now the ampere, but we will exercise the license of employing the previously used unit, the ampere-turn, because of its more practical value in some of the explanations of transformer theory.

Thus, some exceptions will be taken in the use of the SI system of units. However, *all* relationships and equations will be developed using basic SI units. Subsequent examples will be expressed in terms of both SI and practical English units, and problems at the ends of the chapters will also require SI and specified English units. In certain instances, SI units, after being indicated, will rarely be used thereafter. One such unit is given here, namely that for rotational speed. The SI unit for rotational speed is radians per second ( $\text{rad}/\text{s}$ ). Since dynamos continue to be rated in revolutions per minute (rpm), and will probably be so rated for some time to come, we will continue to use this unit. Other units will be encountered and defined as the student proceeds.

It is not our purpose to give a complete listing of conversion constants, but merely to give those that are most frequently used in this text or indeed to assist in the conversion of machinery ratings from one system to the other.

Many of the conversion constants shown in Table 1.1 are quite familiar. Others are possibly more familiar in the fractional form, as, for example

horsepower =  $\frac{\text{watts}}{746}$

or

hp =  $\frac{W}{746}$

Use of this table is rather simple. To convert from any unit in the left-hand column, *multiply* by the factor in the center column to convert to the unit in the right-hand column. On the other hand, should information be given in terms of a unit in the right-hand column, the inverse procedure is followed, i.e., *divide* the term in the right-hand column by the conversion constant in the center column in order to obtain the unit in terms of the left-hand column. This has already been demonstrated in the horsepower-watt conversion given above.

Table 1.2 contains a partial list of SI and English units and abbreviations.

TABLE 1.2. Partial list of abbreviations and symbols.

Unit	SI	English
ampere	A	amp
centimeter	cm	
cycles per second	Hz	c or spell out
foot		ft
horsepower		hp
hour	h	hr
inch		in.
kilovolt-ampere	kVA	kva
kilowatt	kW	kw
lines per square inch		lines per sq in.
maxwell		maxwell
meter	m	
minute	min	min
newton	N	
newton-meter	N·m	
ohm	Ω	Ω or ohm
ounce		oz
pound		lb
pound-foot		lb-ft
radian	rad	radian
radians per second	rad/s	
reactive volt-ampere	VAR	var
revolutions per minute	r/min	rpm
revolutions per second	r/s	rps
second	s	sec
tesla	T	
volt	V	v
watt	W	w
weber	Wb	