Rotating Electric Machinery and Transformer Technology

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Preface

The last generation since World War II has seen two major forces develop in engineering education. On one hand, the traditional four-year engineering courses have become more generalized and analytical and, at the same time, less equipment oriented. This results in competent practicing engineering graduates who cannot comfortably work with actual apparatus although they are trained in the design analysis of equipment to be developed. On the other hand, technically oriented new courses of study have appeared around the country in the community colleges, technical colleges, and private two-year institutions. These courses of study are designed to turn out the student who can both analyze and work with actual apparatus.

Many excellent texts exist that cater to the needs of the new type of four-year college student as far as the engineering study of transient conditions in rotating electric machinery. However, prior to this book, few really suitable texts have been available that cater to the needs of the two-year technical college student or to the four-year bachelor of engineering technology student. No other electrical machinery text has yet appeared in System International units. Therefore, this text and its accompanying synchronized laboratory text, *Laboratory Operations for Rotating Electric Machinery*, are specifically prepared to enable the technical college student and the practicing engineer to recognize, understand, analyze, specify, connect, control, and satisfactorily apply the various existing types of electric motors and generators.

In the current and still worsening energy crisis, there is a new emphasis on the efficiency of all machine processes. For this reason, strong emphasis is placed upon the production and measurement of horsepower or its watt equivalent and the isolation of the accompanying losses. The intended result is that the reader who is trained by these methods will be competent and comfortable with the requirements to analyze or test the power required by a specific machine. The reader will also be able to determine the accompanying losses and specify the most effective machine for the job. He or she will be competent to connect the motor, generator, or transformer with its correct controls and safety devices. Finally, he or she will be able to test the installation with a wide variety of methods in order to realistically use the facilities on hand in a specific laboratory or industrial situation.

To educate a student in these directly applicable methods so that he or she may be qualified to fit into an early employment situation requires that the text subjects be assembled in a sequence that appears at first to be obsolete as far as electrical machinery texts are concerned. In reality, the older four-year texts were the way they were because the then-student, who is now an experienced practitioner, was required to work with real-world equipment. The older texts were almost all concerned with steady-state conditions. New unified treatment texts are now primarily concerned with transient conditions that are met in automatic control systems. The transient-condition studies are vital in new control system design, but their analysis requires mathematics that are beyond the skills acquired in a two-year college. This text is specifically aimed at filling the gap that has been left by a whole generation that has neglected or ignored the requirements to define, install, test, and control steady-state power equipment. The requirement to apply motor and generator equipment is greater than ever and will continue to grow in importance as the use of motor-driven equipment increases.

This text uses *both* English and unified System International (SI) units so that the inevitable transition can be approached with confidence.

The unit conversion tables are designed to take advantage of the higher data accuracy obtainable with modern digital instrumentation. Five significant figures are provided in all situations.

Pocket calculators that have significant scientific computation capability have proliferated to such an extent that the slide rule has become obsolete. As a result, the inclusion of trigonometric and logarithmic tables is no longer required. All examples and problems herein can still be solved by use of a slide rule, but the tabular and conversion data are such that full advantage can be taken of the scientific pocket calculator.

As the basis of electrical machine understanding progresses, experiments that illuminate and clarify the principles under discussion are referred to as they are presented in the synchronized laboratory text. This enables a school with almost any degree of electric machinery laboratory equipment to actually have its students perform the most relevant possible experiments.

The experimental methods and computational procedures described enable the practicing engineer and maintenance technician to perform useful development work without specialized apparatus, such as dynamometers. Efficiency calculations can be readily performed on machine tools, conveyors, and other installed and working equipment.

It is not proposed that the students in any one school perform all the course study or the related experiments since more than an academic year's work is included. Rather, the material to be covered should be related to the experiments that use the highest level of equipment available and that most nearly fill the portion of the academic year to be used. The solutions manual offers suggested material to include or delete to match available time.

It has been the author's experience that the student or practicing engineer who is experienced in this material is well prepared either to go on to a four-year engineering degree or to take a responsible position in industry. He is able to make use of motors, generators, and transformers on a confident basis and without needing the help of some intermediary to make the needed installations.

In the preparation of any textbook certain major areas of aid and decision stand out. I wish to acknowledge the help and confidence of Mr. Weldon Rackley, editor, Mr. Lawrence Benincasa, regional editor, and Ms. Linda Weigle, production editor, all of Reston Publishing Company. Professor Joseph Aidala of Queensboro Community College has given very significant advice.

The decisions used in the handling of System International metric units or SI came from the give and take of the System International Metric Unit Conference for Authors, Editors, and Publishers. This was held at Rensselaer Polytechnic Institute under the auspices of the American Society for Engineering Education.

On a more personal basis, the freely given permission to use the laboratory and other facilities at the Waterbury State Technical College was offered by President Kenneth W. Fogg, Dean of Instruction John J. Nowicki and his successor Dean Kenneth E. DeRego, and the Department Head for Electrical Technology, Professor Edward P. Kearney.

The manuscript has been edited, proofread, and typed by my wife, Betty, whose partnership in time and effort has fully matched my own. My father, John W. Richardson, who is a retired mechanical engineer, has also proofread the entire manuscript and checked all worked example solutions.

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Introduction

Some major electrical developments that took place nearly a century ago started a chain of interlocking developments that have permanently changed our lives. Thomas Alva Edison experimentally developed a useful electric light. He immediately foresaw that widespread and effective use of his light would require a practical source and distribution of large amounts of electric power. His development work on steam-engine-driven direct-current (dc) generators enabled the commercial expansion of electric lighting. Figure 1-1 shows a very early dc generator.

Overlapping the early use of electric lighting was the development by Sprague and others of practical dc motors and motor speed controls. This enabled the building of what would now be called urban electric railroad systems. These early trolley cars enabled mass commuting to work and business toward the end of the last century. An early trolley car using dc motors is shown in Fig. 1-2.

1-1 CHANGE OF MAJOR USE TO ALTERNATING CURRENT

The widespread distribution of direct-current electric power has virtually disappeared. The single-unit street-surface electric rail car, as distinguished from the multiple-unit subway car, is about gone. Alternating-current electric distribution became nearly universal by the second half of the twentieth century.

The advantage of alternating current over direct current in power distribution is based on the ease of changing the ac voltage level. High-voltage power lines carry their energy with a correspondingly lower current. From the very basic Ohm's law, the voltage drop in a resistance is related to the current and the resistance. Since the resistance of a power line, or any conductor, is related to its cross-sectional area, a larger-sized wire will have less resistance. On the other hand, a long-distance line will cost a prohibitive amount if it is made of a large cross section. A modern high-voltage ac distribution line is shown in Fig. 1-3.