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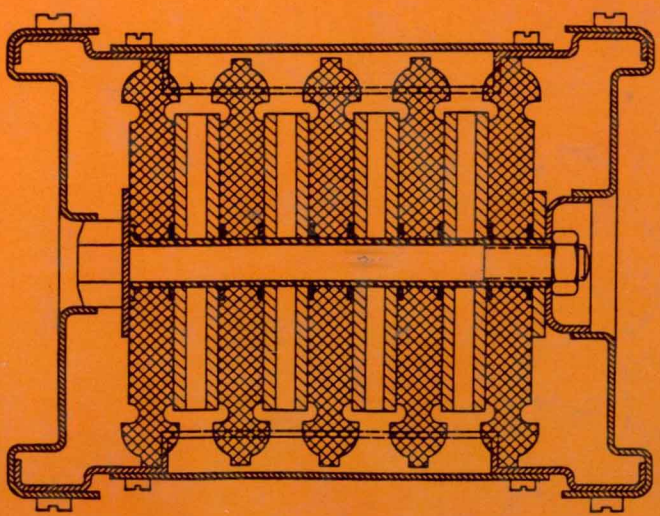
Design Fundamentals for Low-Voltage Distribution and Control



Frank W. Kussy
Jack L. Warren

Design Fundamentals for Low-Voltage Distribution and Control

FRANK W. KUSSY
Consultant
Randallstown, Maryland

JACK L. WARREN
Chrysler Corporation
Highland Park, Michigan

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A Series of Reference Books and Textbooks

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For the children,

Tamara and Joshua

Preface

This book is written for the electrical engineers and graduate students who will design low-voltage distribution and control equipment. To our knowledge, there is no other comprehensive book on this subject published in the United States. This fact seems astonishing since this equipment is vital to modern factory automation in this country. Each year more than $8 billion worth of such equipment is sold in the U.S.

There are several books and papers available that treat design problems for specific devices. Yet, no single book has included the basic design fundamentals for this family of equipment. The engineer who wanted an overview of this information would have had to collect several papers together. Even then, the engineer had to rely on experience plus trial-and-error design. A more systematic approach is needed if our engineers are to be leaders in this field.

This book describes the design fundamentals for several types of electrical equipment: circuit breakers, contactors, safety switches, panels, starters, relays, bus duct conductors, switchboards, switchgear, and control gear. Also discussed are recent developments that have caused significant progress in this field. Among these developments are new techniques for: heat transfer calculation, contact design, arc chamber construction, magnet efficiency, arc interruption in a vacuum, fuse design, fault and ground fault detection, and terminals for aluminum connections.

Dr. Kussy first wrote a book on this subject in 1950 (Elektrische Niederspannungsschaltgeräte und Antriebe, Technischer Verlag Herbert Cram, Berlin). A completely revised edition was published in 1969. In the years since, science and engineering have made tremendous progress in this field. Electronic and electromechanical devices have been combined in different ways to form new, innovative systems. A completely new book seemed necessary. The need for this book was not to discuss the detailed development of any single device. Since these devices are mainly used together in systems, the new book would address design fundamentals for the whole family of equipment.

The design fundamentals of electronic equipment are not included in this book. Basic devices such as transistors, triacs, silicon-controlled rectifiers, microprocessors, and PC boards have been adequately described in other recent books. It seems that publications about electronic equipment are frequent because progress in this field has been revolutionary.

By contrast, progress in the field of electromechanical equipment has been only evolutionary. Still, the changes have been significant and frequent. The scope of change is broader than the management of most American companies realizes or appreciates. This fact is evident if we look at modern current-limiting circuit breakers, contactors, relays, or fuses—size has been reduced significantly, while both electrical performance and production costs have markedly improved (compared to an equivalent device built 25 years ago). It is also evident that research and development have been conducted on a worldwide basis—all industrial nations have been involved in this effort.

The market for this equipment has also changed, becoming more international. While there are still differences between equipment designed for Europe and the United States, the differences have diminished. The International Electric Commission (IEC) has made significant efforts to standardize this equipment. In the U.S., standards are written by Underwriters Laboratory (UL), National Electrical Manufacturers Association (NEMA), Institute of Electrical and Electronic Engineers (IEEE); industry groups such as American Air Conditioning Institute; and by large corporations such as Ford Motor Company. This book recognizes and discusses how these differing standards affect the design requirements for these devices and systems.

To compete in the international market, American manufacturers must devote much more effort and money to research and development. Engineers will need to have knowledge of both the design fundamentals and the current state-of-the-art practices. This book is written for senior engineers and graduate students who will direct the future research effort. It is our hope that they earn their share of patents in this field.

The authors wish to thank the two people who contributed so much effort to the typing and editing of the original manuscript, Laura Grzeskowiak and Mary Krebsbach.

Frank W. Kussy
Jack L. Warren

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1
Impedance of Conductors

The impedance of electrical conductors has a significant effect on the design of most electrical equipment. The conductors in such apparatus include bus bars, cables, terminals, contacts, pigtails, resistant wires, and coils. Often, the overall size, cost, and feasibility of the entire apparatus is determined by the size of these conductors. In turn, physical size is usually determined by the permissible temperature rise or heat capacity, mechanical function, and electrical impedance requirements.

In this chapter we discuss the two components of conductor impedance, resistance and reactance. Temperature considerations are addressed in Chapters 2 and 3.

1.1 RESISTANCE OF CONDUCTORS

The calculation of electrical resistance is straightforward in direct-current (dc) circuits. The resistance R, in ohms, is given by

$$R = \frac{\ell \rho}{A} \qquad [1.1]$$

TABLE 1.1 Resistivity of Common Metals

	Resistivity[a] at 20°C (Ω-mm^2/m)	Percent change in resistivity per °C
Copper	0.0175	0.40
Silver	0.0163	0.41
Aluminum (EC grade)	0.0280	0.4
Aluminum (6101)	0.0318	0.4
Iron	0.1008	0.5
Cast iron	0.6 to 1.6	—
Tungsten	0.055	0.5
Molybdenum	0.056	0.3
Nichrome (V) (80% Ni-20% Cr)	1.085	0.011
Manganin (13% Mg-87% Cu)	0.48	0.0015
Constantan	0.5	-0.005
Karma (73% Ni, 20% Cr,+ Fe + Al)	1.32	0.001
Radiohm	1.32	0.001
Brass	0.065 to 0.085	0.12 to 0.2
Graphite	12 to 40	-0.05 to -0.1
Iron wire	0.125	0.5

[a]There are many existing alloys with resistivity in the range 0.05 to 1.35 Ω-mm^2/m.

where ρ is the material resistivity in Ω-mm^2/m or 10^4 Ω-cm, and ℓ and A are the length and area of the conductor in meters and square millimeters, respectively. Values of resistivity for most metals (and their common alloys) can be found in material handbooks, material data sheets, or in manufacturers' specifications. Table 1.1 lists the resistivity ρ of the more common conductor materials. Also included are the temperature coefficients, given as the percent change in resistivity per degree Celsius.

In alternating-current (ac) circuits, resistance calculations can be complex. Unfortunately, there are many instances where these complex

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