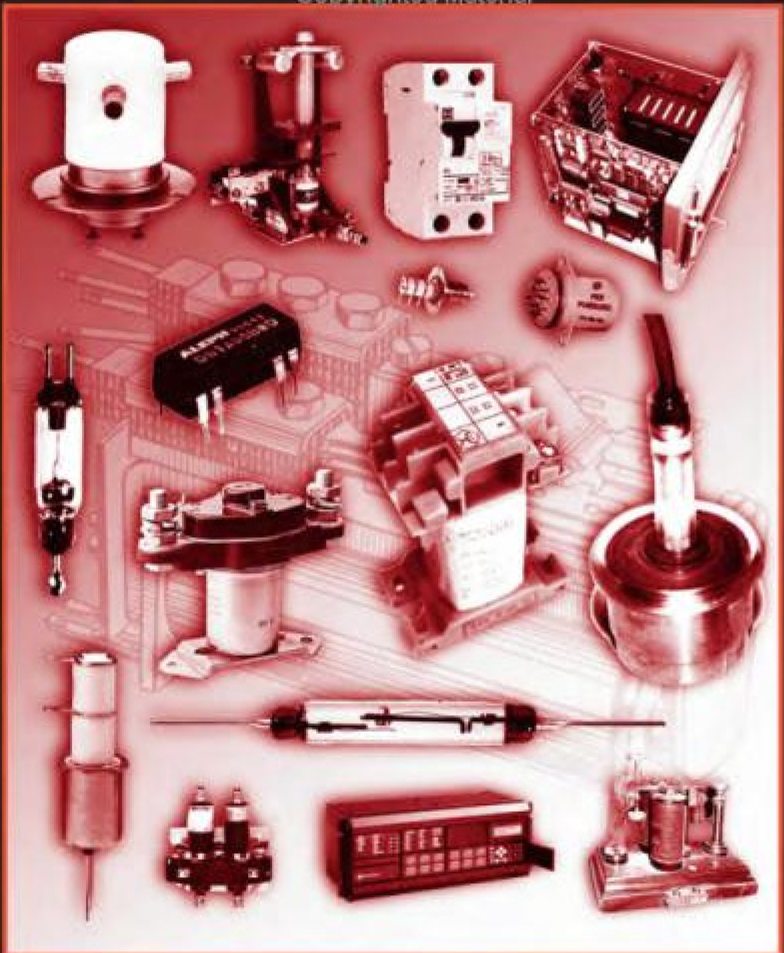


Electric Relays

Principles and Applications

Vladimir Gurevich

ELECTRIC RELAYS

PRINCIPLES AND APPLICATIONS

ELECTRICAL AND COMPUTER ENGINEERING

A Series of Reference Books and Textbooks

1. Rational Fault Analysis, *edited by Richard Saeks and S. R. Liberty*
2. Nonparametric Methods in Communications, *edited by P. Papantoni-Kazakos and Dimitri Kazakos*
3. Interactive Pattern Recognition, *Yi-tzuu Chien*
4. Solid-State Electronics, *Lawrence E. Murr*
5. Electronic, Magnetic, and Thermal Properties of Solid Materials, *Klaus Schröder*
6. Magnetic-Bubble Memory Technology, *Hsu Chang*
7. Transformer and Inductor Design Handbook, *Colonel Wm. T. McLyman*
8. Electromagnetics: Classical and Modern Theory and Applications, *Samuel Seely and Alexander D. Poularikas*
9. One-Dimensional Digital Signal Processing, *Chi-Tsong Chen*
10. Interconnected Dynamical Systems, *Raymond A. DeCarlo and Richard Saeks*
11. Modern Digital Control Systems, *Raymond G. Jacquot*
12. Hybrid Circuit Design and Manufacture, *Roydn D. Jones*
13. Magnetic Core Selection for Transformers and Inductors: A User's Guide to Practice and Specification, *Colonel Wm. T. McLyman*
14. Static and Rotating Electromagnetic Devices, *Richard H. Engelmann*
15. Energy-Efficient Electric Motors: Selection and Application, *John C. Andreas*
16. Electromagnetic Compossibility, *Heinz M. Schlicke*
17. Electronics: Models, Analysis, and Systems, *James G. Gottling*
18. Digital Filter Design Handbook, *Fred J. Taylor*
19. Multivariable Control: An Introduction, *P. K. Sinha*
20. Flexible Circuits: Design and Applications, *Steve Gurley, with contributions by Carl A. Edstrom, Jr., Ray D. Greenway, and William P. Kelly*

21. Circuit Interruption: Theory and Techniques, *Thomas E. Browne, Jr.*
22. Switch Mode Power Conversion: Basic Theory and Design, *K. Kit Sum*
23. Pattern Recognition: Applications to Large Data-Set Problems, *Sing-Tze Bow*
24. Custom-Specific Integrated Circuits: Design and Fabrication, *Stanley L. Hurst*
25. Digital Circuits: Logic and Design, *Ronald C. Emery*
26. Large-Scale Control Systems: Theories and Techniques, *Magdi S. Mahmoud, Mohamed F. Hassan, and Mohamed G. Darwish*
27. Microprocessor Software Project Management, *Eli T. Fathi and Cedric V. W. Armstrong (Sponsored by Ontario Centre for Microelectronics)*
28. Low Frequency Electromagnetic Design, *Michael P. Perry*
29. Multidimensional Systems: Techniques and Applications, *edited by Spyros G. Tzafestas*
30. AC Motors for High-Performance Applications: Analysis and Control, *Sakae Yamamura*
31. Ceramic Motors for Electronics: Processing, Properties, and Applications, *edited by Relva C. Buchanan*
32. Microcomputer Bus Structures and Bus Interface Design, *Arthur L. Dexter*
33. End User's Guide to Innovative Flexible Circuit Packaging, *Jay J. Miniet*
34. Reliability Engineering for Electronic Design, *Norman B. Fuqua*
35. Design Fundamentals for Low-Voltage Distribution and Control, *Frank W. Kussy and Jack L. Warren*
36. Encapsulation of Electronic Devices and Components, *Edward R. Salmon*
37. Protective Relaying: Principles and Applications, *J. Lewis Blackburn*
38. Testing Active and Passive Electronic Components, *Richard F. Powell*
39. Adaptive Control Systems: Techniques and Applications, *V. V. Chalam*
40. Computer-Aided Analysis of Power Electronic Systems, *Venkatachari Rajagopalan*
41. Integrated Circuit Quality and Reliability, *Eugene R. Hnatek*
42. Systolic Signal Processing Systems, *edited by Earl E. Swartzlander, Jr.*
43. Adaptive Digital Filters and Signal Analysis, *Maurice G. Bellanger*
44. Electronic Ceramics: Properties, Configuration, and Applications, *edited by Lionel M. Levinson*

45. Computer Systems Engineering Management, *Robert S. Alford*
46. Systems Modeling and Computer Simulation, *edited by Naim A. Kheir*
47. Rigid-Flex Printed Wiring Design for Production Readiness, *Walter S. Rigling*
48. Analog Methods for Computer-Aided Circuit Analysis and Diagnosis, *edited by Takao Ozawa*
49. Transformer and Inductor Design Handbook: Second Edition, Revised and Expanded, *Colonel Wm. T. McLyman*
50. Power System Grounding and Transients: An Introduction, *A. P. Sakis Meliopoulos*
51. Signal Processing Handbook, *edited by C. H. Chen*
52. Electronic Product Design for Automated Manufacturing, *H. Richard Stillwell*
53. Dynamic Models and Discrete Event Simulation, *William Delaney and Erminia Vaccari*
54. FET Technology and Application: An Introduction, *Edwin S. Oxner*
55. Digital Speech Processing, Synthesis, and Recognition, *Sadaoki Furui*
56. VLSI RISC Architecture and Organization, *Stephen B. Furber*
57. Surface Mount and Related Technologies, *Gerald Ginsberg*
58. Uninterruptible Power Supplies: Power Conditioners for Critical Equipment, *David C. Griffith*
59. Polyphase Induction Motors: Analysis, Design, and Application, *Paul L. Cochran*
60. Battery Technology Handbook, *edited by H. A. Kiehne*
61. Network Modeling, Simulation, and Analysis, *edited by Ricardo F. Garzia and Mario R. Garzia*
62. Linear Circuits, Systems, and Signal Processing: Advanced Theory and Applications, *edited by Nobuo Nagai*
63. High-Voltage Engineering: Theory and Practice, *edited by M. Khalifa*
64. Large-Scale Systems Control and Decision Making, *edited by Hiroyuki Tamura and Tsuneo Yoshikawa*
65. Industrial Power Distribution and Illuminating Systems, *Kao Chen*
66. Distributed Computer Control for Industrial Automation, *Dobrivoje Popovic and Vijay P. Bhatkar*
67. Computer-Aided Analysis of Active Circuits, *Adrian Ioinovici*
68. Designing with Analog Switches, *Steve Moore*
69. Contamination Effects on Electronic Products, *Carl J. Tautscher*
70. Computer-Operated Systems Control, *Magdi S. Mahmoud*
71. Integrated Microwave Circuits, *edited by Yoshihiro Konishi*

72. Ceramic Materials for Electronics: Processing, Properties, and Applications, Second Edition, Revised and Expanded, *edited by Relva C. Buchanan*
73. Electromagnetic Compatibility: Principles and Applications, *David A. Weston*
74. Intelligent Robotic Systems, *edited by Spyros G. Tzafestas*
75. Switching Phenomena in High-Voltage Circuit Breakers, *edited by Kunio Nakanishi*
76. Advances in Speech Signal Processing, *edited by Sadaoki Furui and M. Mohan Sondhi*
77. Pattern Recognition and Image Preprocessing, *Sing-Tze Bow*
78. Energy-Efficient Electric Motors: Selection and Application, Second Edition, *John C. Andreas*
79. Stochastic Large-Scale Engineering Systems, *edited by Spyros G. Tzafestas and Keigo Watanabe*
80. Two-Dimensional Digital Filters, *Wu-Sheng Lu and Andreas Antoniou*
81. Computer-Aided Analysis and Design of Switch-Mode Power Supplies, *Yim-Shu Lee*
82. Placement and Routing of Electronic Modules, *edited by Michael Pecht*
83. Applied Control: Current Trends and Modern Methodologies, *edited by Spyros G. Tzafestas*
84. Algorithms for Computer-Aided Design of Multivariable Control Systems, *Stanoje Bingulac and Hugh F. VanLandingham*
85. Symmetrical Components for Power Systems Engineering, *J. Lewis Blackburn*
86. Advanced Digital Signal Processing: Theory and Applications, *Glenn Zelniker and Fred J. Taylor*
87. Neural Networks and Simulation Methods, *Jian-Kang Wu*
88. Power Distribution Engineering: Fundamentals and Applications, *James J. Burke*
89. Modern Digital Control Systems: Second Edition, *Raymond G. Jacquot*
90. Adaptive IIR Filtering in Signal Processing and Control, *Phillip A. Regalia*
91. Integrated Circuit Quality and Reliability: Second Edition, Revised and Expanded, *Eugene R. Hnatek*
92. Handbook of Electric Motors, *edited by Richard H. Engelmann and William H. Middendorf*
93. Power-Switching Converters, *Simon S. Ang*
94. Systems Modeling and Computer Simulation: Second Edition, *Naim A. Kheir*
95. EMI Filter Design, *Richard Lee Ozenbaugh*
96. Power Hybrid Circuit Design and Manufacture, *Haim Taraseiskey*

97. Robust Control System Design: Advanced State Space Techniques, *Chia-Chi Tsui*
98. Spatial Electric Load Forecasting, *H. Lee Willis*
99. Permanent Magnet Motor Technology: Design and Applications, *Jacek F. Gieras and Mitchell Wing*
100. High Voltage Circuit Breakers: Design and Applications, *Ruben D. Garzon*
101. Integrating Electrical Heating Elements in Appliance Design, *Thor Hegbom*
102. Magnetic Core Selection for Transformers and Inductors: A User's Guide to Practice and Specification, Second Edition, *Colonel Wm. T. McLyman*
103. Statistical Methods in Control and Signal Processing, *edited by Tohru Katayama and Sueo Sugimoto*
104. Radio Receiver Design, *Robert C. Dixon*
105. Electrical Contacts: Principles and Applications, *edited by Paul G. Slade*
106. Handbook of Electrical Engineering Calculations, *edited by Arun G. Phadke*
107. Reliability Control for Electronic Systems, *Donald J. LaCombe*
108. Embedded Systems Design with 8051 Microcontrollers: Hardware and Software, *Zdravko Karakehayov, Knud Smed Christensen, and Ole Winther*
109. Pilot Protective Relaying, *edited by Walter A. Elmore*
110. High-Voltage Engineering: Theory and Practice, Second Edition, Revised and Expanded, *Mazen Abdel-Salam, Hussein Anis, Ahdab El-Morshedy, and Roshdy Radwan*
111. EMI Filter Design: Second Edition, Revised and Expanded, *Richard Lee Ozenbaugh*
112. Electromagnetic Compatibility: Principles and Applications, Second Edition, Revised and Expanded, *David Weston*
113. Permanent Magnet Motor Technology: Design and Applications, Second Edition, Revised and Expanded, *Jacek F. Gieras and Mitchell Wing*
114. High Voltage Circuit Breakers: Design and Applications, Second Edition, Revised and Expanded, *Ruben D. Garzon*
115. High Reliability Magnetic Devices: Design and Fabrication, *Colonel Wm. T. McLyman*
116. Practical Reliability of Electronic Equipment and Products, *Eugene R. Hnatek*
117. Electromagnetic Modeling by Finite Element Methods, *João Pedro A. Bastos and Nelson Sadowski*
118. Battery Technology Handbook, Second Edition, *edited by H. A. Kiehne*
119. Power Converter Circuits, *William Shepherd and Li Zhang*

120. Handbook of Electric Motors: Second Edition, Revised and Expanded, *edited by Hamid A. Toliyat and Gerald B. Kliman*
121. Transformer and Inductor Design Handbook, *Colonel Wm T. McLyman*
122. Energy Efficient Electric Motors: Selection and Application, Third Edition, Revised and Expanded, *Ali Emadi*
123. Power-Switching Converters, Second Edition, *Simon Ang and Alejandro Oliva*
124. Process Imaging For Automatic Control, *edited by David M. Scott and Hugh McCann*
125. Handbook of Automotive Power Electronics and Motor Drives, *Ali Emadi*
126. Adaptive Antennas and Receivers, *edited by Melvin M. Weiner*
127. SPICE for Power Electronics and Electric Power, Second Edition, *Muhammad H. Rashid and Hasan M. Rashid*
128. Gaseous Electronics: Theory and Practice, *Gorur G. Raju*
129. Noise of Polyphase Electric Motors, *Jacek F. Gieras, Chong Wang and Joseph Cho Lai*
130. Electric Relays: Principles and Applications, *Vladimir Gurevich*

Electric Relays

Principles and Applications

Vladimir Gurevich
Israel Electric Corporation
Haifa, Israel

Taylor & Francis
Taylor & Francis Group
Boca Raton London New York

A CRC title, part of the Taylor & Francis imprint, a member of the Taylor & Francis Group, the academic division of T&F Informa plc.

Published in 2006 by
CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-10: 0-8493-4188-4 (Hardcover)
International Standard Book Number-13: 978-0-8493-4188-5 (Hardcover)
Library of Congress Card Number 2005049392

Library of Congress Cataloging-in-Publication Data

Gurevich, Vladimir, 1956-
Electric relays : principles and applications / Vladimir Gurevich.
p. cm.
Includes bibliographical references and index.
ISBN 0-8493-4188-4 (alk. paper)
1. Electric relays. I. Title.

TK7872.R38.G87 2005
621.31'7--dc22 2005049392

informa
Taylor & Francis Group
is the Academic Division of Informa plc.

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

In memory of my beloved father Igor Gurevich who tragically perished in January 2003

If we do not find anything very pleasant,
at least we shall find something new
Voltaire

Introduction

This book contains a description of electrical relays, their principles of operation, and applications for all basic types, for as widespread as knowledge of the subject is, it is still not abundant.

The scope of this book is very broad and unique in the sense that this book represents the first illustrated encyclopedia of electrical relays.

The historical background of the design of many different types of relays, not always known even to specialists, has been included and given much attention not only because it is interesting, but more importantly because of the frequent need for a display of expertise on the subject, enhancing the perception of competency of the specialist.

In describing some of the complicated types of relays (for example, electronic relays), the related issues of design and principles of operation of the relay components are discussed too (in our case vacuum, gas discharge, and semiconductor devices), which allows the reader to better understand the principles of operation of the described relays, without having to refer to additional information sources.

The book is written in a clear and easy-to-understand language, without mathematical treatment, and includes numerous illustrations, making it attractive not only for specialists in relays, but also for a wide range of engineers, technicians, and students interested in extending their knowledge in electric relays. Lecturers and university teachers will also find a lot of valuable material for their lectures in the book.

Acknowledgments

I wish to thank Mary Malinkovich for her enormous assistance in translating this manuscript to English and Haim Ron for reading and editing the final manuscript.

Acknowledgment is also made to the following firms and organizations for their kind permission to allow me to use various information and illustrations:

ABB Oy
ABB Switzerland Ltd — Semiconductors
Airpax Corp.
AutomationDirect
Behlke Electronic GmbH
CIGRE Central Office
Comus Group Companies
Dowetron GmbH
Eaton Corp.
EHG Elektroholding GmbH (AEG)
General Electric Co.
Gigavac
Gruner AG
Hermetic Switch, Inc.
Instrumentation & Control System, Inc.
Jennigs Technology
Leach International
LEM Components
Magnecraft & Struthers-Dunn
Maxim Integrated Products, Inc.
Moeller
NxtPhase Corp.
Olympic Controls Corp.
OPTEK Technology
Phoenix Contact GmbH & Co. KG
Powerex, Inc.
Precision Timer Co., Inc.
Rockwell Automation
Ross Engineering Corp.
Siemens AG
Smithsonian Institution Archives (Joseph Henry Papers)
Teledyne Technologies
Texas Instruments
Toshiba Corp.
Tyco Electronics
Yaskawa Electric America

Finally and most important, my utmost thanks and appreciation to my wife Tatiana, who has endured the writing of this (my third!) book, for her never-ending patience.

Preface

The electric relay is one of the most frequently used devices in modern technological systems. It can be found in cars, washing machines, microwave ovens, and medical equipment, as well as in tanks, aircraft, and ships. Practically no industry would function without relays. In some complex automatic control systems in industry, the number of relays is estimated in hundreds and even thousands. In the power-generation industry, no power device is allowed to operate without special protection relays. Certain electrical equipment, such as power transformers, may be protected by several different kinds of relays, each controlling different functions.

Because relays are so widely used and there are so many types, the broad population of engineers is unfamiliar with most of them. Generally speaking, engineers in a specific technical field are usually only familiar with relays that are applicable for specific devices. The same is true of specialists involved in the design and production of relays. Therefore, obtaining information on relays is a problem both for students whose future profession involves relay application, and for teachers in technical colleges or extension courses, who need up-to-date information about relays for their students.

Where can we find extensive publications that equally meet the needs of engineers, teachers, and students?

Various publications and books about relays currently on the market can be divided into two groups. One is generally called ''Low Power Relays'' or ''Power Relays'' (both terms mean the same, that is, a low-power electromagnetic relay with a switching current not exceeding 30 A). The second group is ''Protective Relaying'' (protective relays for protection of power networks), where the emphasis is placed not on a description of the principles and construction of relays, but on schematic principles of protection of electrical networks and calculation of their operating modes.

On the one hand, dividing the entire ''world of electric relays'' into two groups excludes some important relay implementations, for example relays with a switching current of hundreds of amperes, high-voltage relays, mercury relays, reed switch relays, solid-state relays, electric thermal relays, time-delay relays, safety relays, and many others. On the other hand, such an artificial division within the same field frequently results in separate treatment of common questions regarding relays which may be of different kinds, but are actually related and should be dealt with together. Experience accumulated for one type of relay is not always taken into account regarding other types of relays, even if the analogy is obvious. Moreover, modern protection relays usually contain electromagnetic, reed switch, or solid-state relays as output elements and experts in relay protection must be aware of their idiosyncrasies. In addition, in many particularly powerful and high-voltage modern electronic systems (power supplies, powerful lasers, radars, etc.) experts face challenges of providing protection against emergency states (overload, overcurrent, etc.), similar to challenges encountered by specialists in relay protection.

Another disadvantage of current publications is that they rarely meet the full range of engineering requirements. Some are intended mainly for experts and are abundant in equations and calculations for relays; others emphasize standards, methods of quality control, and other issues concerning production of relays; and still others are for engineers and technicians who are not experts in relays but only use relays in their equipment. Most of these publications provide the information in such a simplified and limited way that they are of little practical benefit, as they do not give simple and understandable answers to many questions concerning the implementation of relays, such as the following:

- Is it possible to switch on an electric light bulb having a nominal current of 0.3 A with the assistance of a reed switch relay with a nominal switching current of 1 A? (The correct answer is NO!)
- Why does a relay, which has worked well for a year, begin to drone and to malfunction? (The reason is that the relay has been incorrectly installed with respect to the vertical line.)
- Why does the ground fault relay (''residual current device'') malfunction? Does it mean that the relay is out of order? (Not necessarily. Most often the reason is changes in insulation resistance of the equipment under exposure to moisture or high temperature.)

To answer these questions, it is essential to have a clear understanding of how relays function. That brings us to the question of what is necessary for effective study of the basic principles of relays of certain types. Is it enough just to analyze the specific construction of a certain relay? The author is convinced that it is not. The reason is that when a relay of a similar type but with a different construction is next encountered, the learning process must begin all over again.

For each type of relay, this book includes descriptions of several types of relay constructions, each functioning on a different basis. Moreover, readers will find full coverage here of the historical development of relay construction — from the earliest to modern times. The author is convinced that only such an approach can ensure understanding of principles applicable of all types of relays.

The author aimed to write a comprehensive book about relays without the disadvantages of other books and publications listed above. This book covers the diversity of the ''world of electric relays'' and reveals the dynamics of their development — from the earliest ideas to modern constructions and applications. In order to make the book understandable, not only for experts but also for laymen, the author utilizes the ''picture-instead-of-formula'' principle. Such an approach enables engineers, technicians, teachers, and students who are interested in relay construction to use the book as an encyclopedia of electric relays.

Furthermore, general readers who are interested in the history of engineering will discover many interesting historical facts about the invention of relays. Inquisitive readers will be able to enrich their knowledge in the field of electronics by reading the chapters devoted to electronic relays.

It is for the readers to decide whether the author has succeeded in attaining his objective.

This book consists of 16 chapters. The first four chapters cover the basic principles of relay construction and its major functional parts, such as contact systems, magnetic systems, etc. The following 12 chapters are devoted to various specific types of relays. Each of these chapters includes a description of the principles of relay functioning and construction as well as features of several different relays belonging to a certain type, but operating on different principles and developed at different times.

The information in the book is arranged such that the reader can work with any specific part without having to refer to another part of the book. It is also structured to function as an encyclopedia of relays by facilitating consultation when the need arises. It helps the reader find answers to particular questions, and avoids the pitfall of forcing the reader to read the whole book even though certain parts may be of only marginal interest.

The author will be grateful for any suggestions and remarks aimed towards improvement of the book. Please send all comments to the publisher.

Vladimir Gurevich, Ph.D.
vladimir.gurevich@gmx.net

Contents

1

History

1.1 Relays and Horses

What is a relay?

There is probably no engineer or technician who would admit to his colleagues that he does not know what a relay is. It is an element so widely used in engineering that every engineer has had an opportunity to deal with it to some extent. Just for the sake of experiment try to define the notion ''relay''... I don't think you will be able to do so at the first attempt, nor the second, and if you try to look up the word in a dictionary you will be puzzled even more.

See for yourself:

Relay

1. A fresh team of horses, posted at intervals along a route to relieve others
2. A series of persons relieving one another or taking turns; shift
3. To work in shifts
4. A sport race
5. A system of shifts at an enterprise
6. To provide with or replace by fresh relays
7. To retransmit
8. A switch.

Quite unexpected, so many different definitions of a word so widely used in the field of engineering. What's the explanation?

Let us start from the very beginning...

America's first ''railway line'' from Baltimore to Ellicott's factory was constructed in 1830. Its rail mileage was 13 miles. Trains consisted of several vans with wooden wheels pulled on wooden rails by a team of horses. Before long, such trains began to take people to far more distant towns. At the same time there had to be stopovers, for breaks to feed and rest horses. Such breaks considerably prolonged the journey until it occurred to someone that horses could be relieved at midpoint so that the journey could proceed with hardly any breaks at all. Each fresh team of horses was known as a ''relay,'' from the French word ''*relais*,'' which means replacement. The same name was given to the small town located at the ''relay'' point where the horses were changed for the first time.

Although horsed vans may have little to do with modern trains, the date of that event, August 28, 1830, is considered to be the beginning of the era of railroads in the U.S.A. It

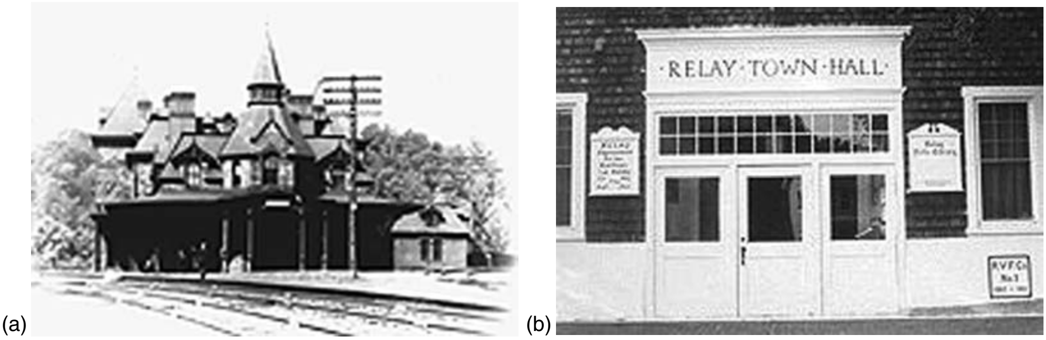


FIGURE 1.1
(a) Railroad station ''Viaduct Hotel'' and (b) the Town Hall in Relay.

was on that day that horsed vans began to circulate regularly via Relay station. In 1872, a special railroad station (a retransmitting station) was built in Relay (Figure 1.1). It had comfortable rest rooms for passengers along with a view of a viaduct, Viaduct Hotel, and the Town Hall.

At about the same time, some other remarkable events occurred, mostly in the same country but in quite a different field of human activity.

1.2 From Oersted to Henry

In 1820, the Danish physicist Hans Christian Oersted demonstrated for the first time that the interaction between a magnetic field and an electric current shows a slight impact of a single conductor on a compass needle. A few months later, during his experiments with a compass, the German scientist Schweigger, Professor of Chemistry at the University of Halle, noticed the fact that it is impossible to strengthen that influence by lengthening the conductor, because the compass will only interact with the nearest part of the wire. At that point it occurred to him to try to create a structure that would enable all the sections of the long wire to interact with the compass needle. He wound the long wire on a mandrel consisting of two studs, Aa and Cc, with the slots *t* and *d* in the form of several coils, attached outputs *K* and *Z* to a galvanic battery, and inserted the coils into the compass. He called this device a galvanic multiplier (Figure 1.2).

This was how the first prototype of an electromagnet was created, and if we put the compass in the *B* area as Professor Schweigger did, the multiplier becomes a galvano-

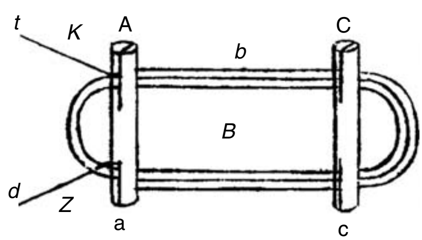


FIGURE 1.2
Schweigger's galvanic multiplier (From *Journal für Chemie und Physik* 31, Neue Reihe, Bd. I, 1821.)

FIGURE 1.3
William Sturgeon (1783–1850).

meter, enabling us to measure current strength and voltage. But this fact was unknown at that time, even to the inventor himself, the creator of this idea.

Unfortunately such a considerable decrease in the deflection of the needle was observed, even within 200 lb, that it was obvious that the scheme was inadequate.

At that point it seemed that Barlow's merciless verdict had put paid to the new telecommunication system suggested by Ampere.

The idea was appreciated to some extent by the outstanding French physicist Andre-Marie Ampere, who suggested applying Schweigger's multiplier to something similar to a telegraph or telephone system, where every letter and figure was transmitted through a separate circuit, with the compass needle becoming an indicator of current in circuits corresponding to the letters and figures.

Ampere declared that his experiments were successful, although he did not provide any commentary. Perhaps there was no need to comment. At any rate, in 1824 the English scientist Peter Barlow, commenting on Ampere's experiments, wrote that the components of the device were so obvious and the principle on which it was based so clear, that the only discovery needed was to find out whether electric current would be able to deflect the needle after passing through a long wire.

Fortunately the English scientist William Sturgeon (Figure 1.3), was unaware of Barlow's point of view. He did not give up his research on electromagnetism. On the contrary, he made every possible effort to try to find a way to increase the power of the electromagnet. Success was immediate. In 1824 he published the description of his new electromagnet, consisting of an iron core and a coil of bare copper wire. In order to enable winding a large number of turns, Sturgeon coated the surface of the horseshoe-shaped iron core with varnish, and then wrapped the spiral coil of bare copper wire, with the turns not touching each other (Figure 1.4).

At that point a new personage appeared in this tale: Joseph Henry, Professor of Mathematics and Natural Philosophy at the Albany Academy in New York (Figure 1.5).

Even from the point of view of modern science Henry's idea could be considered brilliant. He suggested insulating wire for an electromagnet by wrapping it with silk, and thus electrical wire was invented. From then on electromagnet coils were wound in hundreds of turns of insulated wire, and electromagnets were to become powerful devices widely used in many different experiments (Figure 1.6).

Soon after, Henry constructed the most powerful electromagnet in the world up to that time, which carried the weight of 750 lb. He sent descriptions of his experiments to Benjamin Silliman, Professor of Chemistry and Natural History at Yale College and editor of *The American Journal of Science.* Silliman appreciated Henry's work and in January 1831 he published in *The American Journal of Science* an article titled ''Henry's Albany magnet

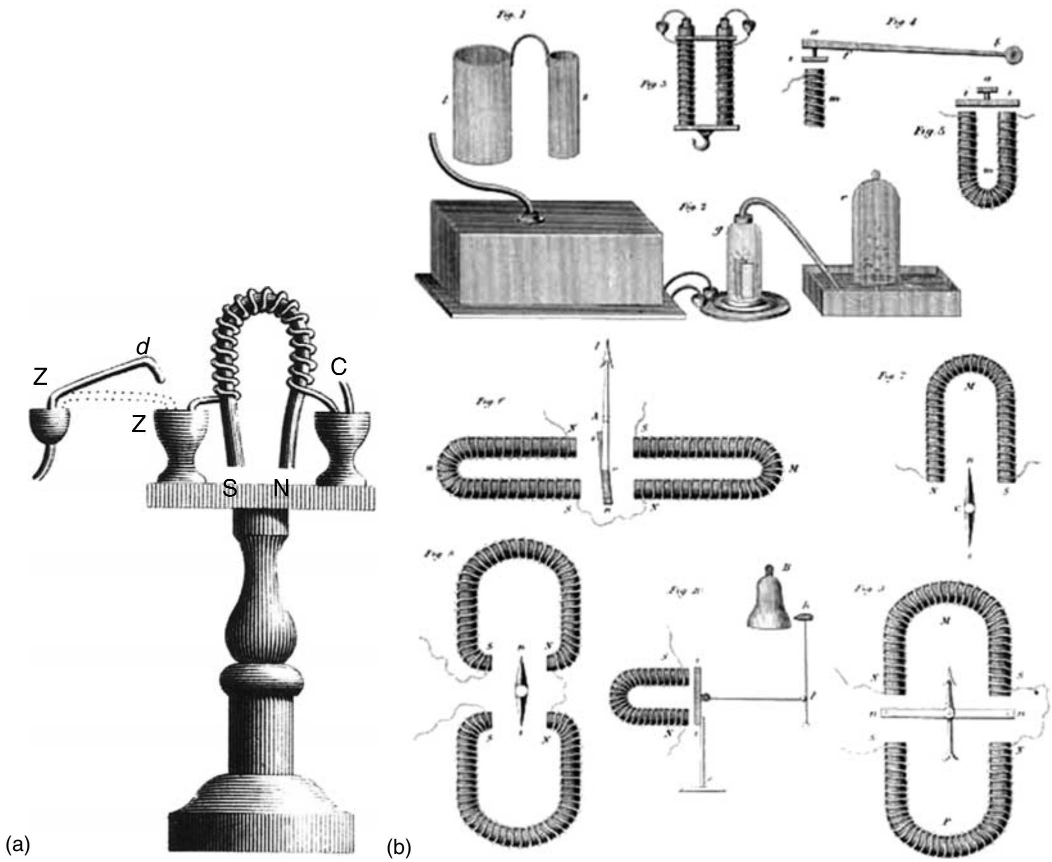


FIGURE 1.4
(a) Sturgeon's electromagnet. The horseshoe-shaped core with winding is at the top of the construction. (From *Transactions of the Society for the Encouragement of the Arts*, 43, 1824.) (b) Sturgeon's electromagnets. (From William Sturgeon, *Scientific Researches, Experimental and Theoretical, in Electricity, Magnetism, Galvanism, Electro-Magnetism and Electro-Chemistry*, Bury, T. Crompton, 1850.)

with its battery and apparatus for measuring its strength.'' In addition to his report, Henry proposed making a demonstrational electromagnet for his future experiments and lectures, which would lift 1000 or 1200 lb.

Benjamin Silliman accepted his proposal and in a few months Henry constructed his magnet, which surpassed even his own expectations.

This ''Yale magnet'' with an iron core weighing 59 lb could carry the unprecedented weight of 2063 lb. As a token of gratitude Benjamin Silliman published a detailed description of Henry's latest and most powerful magnet. In his editor's notes he mentioned that Henry had managed to create an electromagnet eight times more powerful than ever before.

Some time later, in another one of his articles, Henry put forward the idea of making a machine that could be moved by an electromagnet, an idea closely connected with the future idea of transmission of power at a distance with the help of an electromagnet.

In the summer of 1831, Henry described technical solutions for these problems in a short article titled, ''On a reciprocating motion produced by magnetic attraction and repulsion.'' This was a simple device with a straight electromagnet rocking on a horizontal axis (Figure 1.7). Its motion automatically reversed its polarity as two pairs of wires

FIGURE 1.5
Professor Joseph Henry.

projecting from the ends made connections, alternately, with two electrochemical cells. Two vertical permanent magnets, C and D, alternately attracted and repelled the ends of the electromagnet, making it rock back and forth at 75 vibrations per minute. In fact, this device already comprised all of the basic components of an electric device known today as a polarized electromagnetic relay: a coil, a ferromagnetic core, a permanent magnet, and contacts for switching the electric circuit. Unfortunately, Henry failed to distinguish that he had a prototype for a modern relay in his device. He considered it merely a ''philosophical toy,'' although useful for demonstrating the principles of electromagnetism to his students.

He continued improving it. In particular, instead of an iron core and two vertical magnets, his ''motor'' used one straight magnet with windings for the oscillating electromagnet. The description of this device was not published, but we have models based on these principles, which have lasted.

Before long Henry discovered that it was impossible to increase the power of his electromagnet due to the growth of the windings. He then tried dividing the windings into separate coils and studied the influence of parallel and series connections of coils on

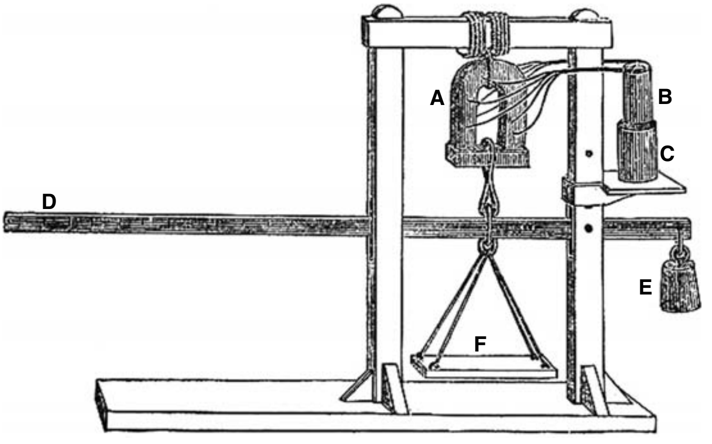


FIGURE 1.6
Henry's Albany magnet with battery and device for measuring its strength. (From J. Henry, *Silliman's American Journal of Science*, v. 19, 1831, 408.)

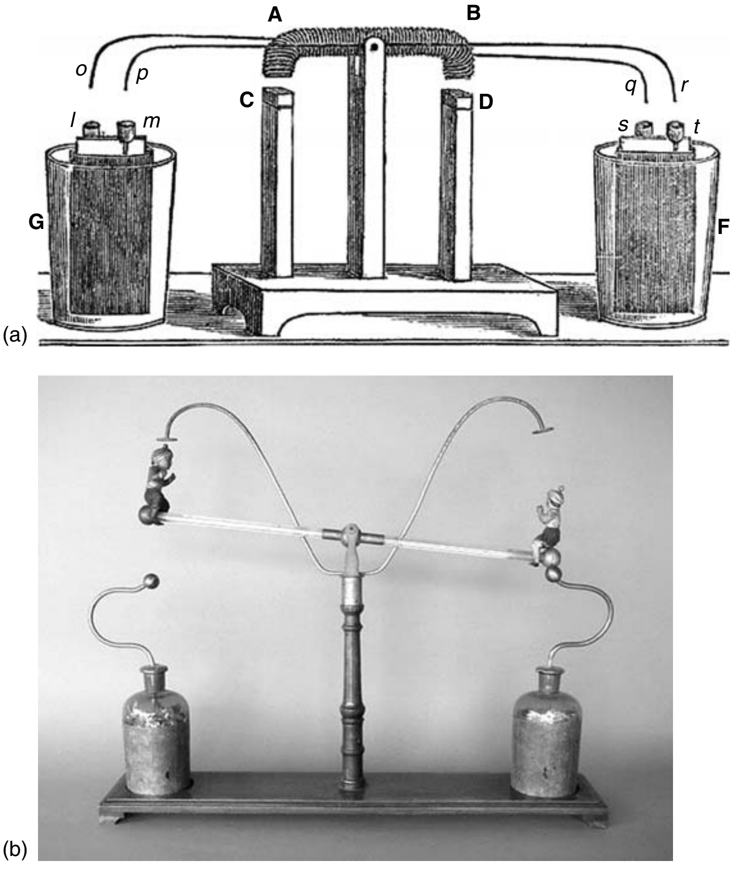


FIGURE 1.7
(a) Henry's oscillating electromagnet motor (From J. Henry, *Silliman's American Journal of Science*, v. 20, 1831, 342). **(b)** A toy of that time based on the principle of Henry's oscillating electromagnet motor.

the power of the electromagnet (Figure 1.8). He established an important interaction between the way the coils are connected and the number of galvanic cells placed in series, although some of the results he came up with in his experiments were quite astonishing and inexplicable. For example, the first experiments verified Barlow's conclusions that sensitivity of the compass needle decreases considerably when the wire connecting a galvanic battery with the electromagnet is lengthened, but further experiments showed an absolutely abnormal increase of sensitivity of the compass needle to the electromagnet attached not to one, but to a group of 25 galvanic cells connected in series. At the same time it was possible to transmit a distinguishable signal through wire that was hundreds of feet in length. Henry thought that the reason for this was that chemical qualities of galvanic cells change in such connections, but he did reach the proper conclusion that connections of galvanic batteries in series can compensate for lengthening of the wire connecting the electromagnet and the battery, thus creating a working telegraph.

Henry published the results of his research in the *American Journal of Science* in 1831 and made a model of a telegraph, which he demonstrated to students at his lectures until 1832. In his model Henry used an electromagnet with a horseshoe-shaped iron core, and a coil that perfectly matched the galvanic cell in the number of turns. Between the ends of the horseshoe he installed a permanent magnet on an axle swinging at the stimulation of the coil.

In fact he had produced that same Schweigger multiplier, but a much more powerful one. In addition, Henry placed a small bell near the turning magnet (Figure 1.9). The bell

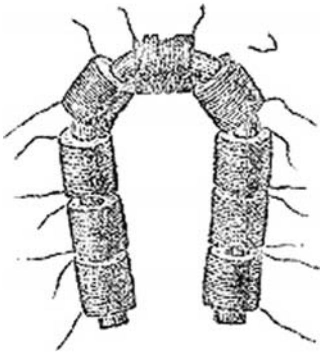


FIGURE 1.8
Henry's electromagnet with separate windings connected in series or parallel.

rang every time the magnet hit it. The electromagnet was attached to the battery with the help of copper wire about a mile in length, which was drawn through the lecture hall.

Joseph Henry became more and more popular in the American scientific community. In 1832 he was named Professor of Natural Philosophy at Princeton College. He restored his model of the telegraph, but this time the wire was drawn not in a lecture hall, but between campuses. Considering his teaching as foremost to conducting research, Henry created more and more new models for his lectures.

In 1835 he decided to combine his sensitive telegraph electromagnet. Working from a remote battery his superpower magnet lifted a record weight supplied by a powerful battery. In this new construction, instead of using a bell as in his telegraph, a permanent turning magnet closed contacts and connected the powerful electromagnet into the circuit.

As you may have guessed, this was *the very first relay in the world.* But neither Henry nor the others knew that it was a *relay*. Professor Henry enthusiastically demonstrated his new ''toy'' to his students: first he would turn on the whole system and fix a heavy weight on the electromagnet, then he turned it off from a long distance by means of the sensitive telegraph electromagnet. The turning electromagnet broke the supply circuit of the powerful electromagnet and the heavy weight came hurtling down followed by students' enthusiastic exclamations. Being far from practical, Professor Henry told students about prospects of his new device to be used for remote control of bells in churches, but it was not only his students who knew about his advances. Some famous and less famous

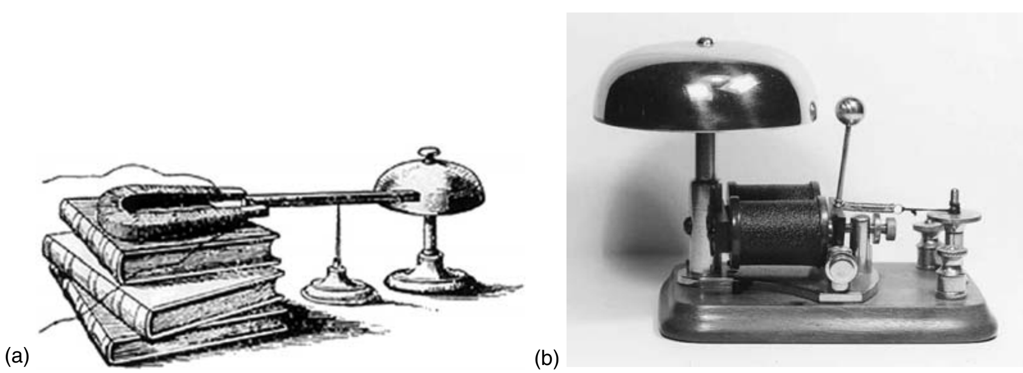


FIGURE 1.9
(a) A demonstrational model and (b) a later model of the receiving apparatus of Henry's telegraph, constructed in 1831.

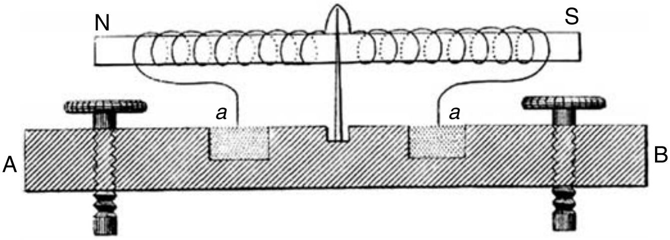


FIGURE 1.10
The diagram of William Ritchie's revolving electromagnet motor with cup for mercury commutator. (From Ritchie W., Experimental researches in electro-magnetism and magneto-electricity, *Philosophical Transactions*, v. 123, 1833.)

scientists and engineers followed his footsteps, applying his ideas to their own scientific and technical research and endeavors. In 1833, only 2 years after the publication of Henry's description of the oscillating electromagnet motor with a rocking electromagnet, an English clergyman unknown at that time, William Ritchie, published in ''Philosophic Notes'' an article titled, ''Experimental researches in electro-magnetism and magneto-electricity'' (*Philosophical Transactions*, 1833, v. 123) in which he describes a device with a continuously revolving electromagnet (Figure 1.10).

In this device the electromagnet moved not on a vertical axis as in Henry's model, but on a horizontal one. He caused its polarity to reverse twice in each revolution by an arrangement of wires grazing across two semicircular troughs filled with mercury. The mercury in both troughs was electrically connected to the poles of the galvanic cell with the help of additional wires.

It is still unknown whether Ritchie had heard of Henry's researches while inventing his oscillating electromagnet motor, since he made no reference to Henry's publications. Henry refused to accept Ritchie's ideas, as he considered himself to be the discoverer.

In the ensuing years Henry kept vigilant watch on his colleague's advances, and time and again engaged in controversy with them, even on pages of scientific journals contesting his pioneer status. The most notable instance was his longstanding dispute with Samuel Finley Breese Morse who used a rocking electromagnet and some other of Henry's ideas in his telegraph apparatus, without any references to Henry's publications.

Ritchie's device, like Henry's other devices, was in the first place just a didactic instrument and could not be used in practice.

1.3 Art Professor Samuel Morse

Meanwhile Henry continued his experiments on enhancement of electromagnets, in spite of his bitter dispute with his colleague Samuel Morse.

Professor Henry never ''sank to the level of commercial profit'' based on his inventions, and that is why he showed no interest to patenting his devices and apparatus. Samuel Morse (Figure 1.11), a professional portrayer, from 1832 Professor of Painting and Sculpture at New York University, with little formal grounding in technical sciences (on the contrary) never really gave his mind wholly to scientific research. He was a much more pragmatic man, with a remarkable capacity for work.

Morse just continued to construct and produce new and improved apparatus for his telegraph, while simultaneously patenting them. He consulted with famous scientists of that time, including Henry, but it was he who patented the devices. He believed that patents were to be granted not for fine theories but for constructing practical applications and it was he who applied and joined theory with practice. Many court hearings regarding

FIGURE 1.11
Samuel Finley Breese Morse.

Morse's numerous patents based on Henry's ideas and inventions made Henry's life a misery, and continued until his death. But Professor Henry remained firm, determined, and virile, continuing his research even under such pressure.

It was only from 1832 on that Samuel Morse really became interested in the electric telegraph, and by that time Joseph Henry had already created all of the necessary prerequisites for his successful construction of a telegraph. Morse's tenacious mind immediately grasped the enormous commercial potential hidden in the concept of instantaneous transmission of messages over large distances. He took off his coat and went to work. Not only did he have to be a scientist, but also an engineer, as he was forced to work even harder since he did not have enough money to purchase many of the necessary components.

He could not even afford insulated wire for coils. In spite of his high capacity for work it still took him 5 years to construct a first model of a telegraph that could be demonstrated to the public, and more important, to Congress, which could allocate money for further research. Rich men to whom he demonstrated his apparatus considered it as just an interesting toy, and were in no haste to invest in the project. It was only Alfred Vail, a student, who became interested in the invention. Vail's father and brother were proprietors of an iron and copper manufactory and were quite wealthy. Alfred promised to raise the necessary funds for an improved model of the apparatus, and Morse was forced to take him on as a partner. From then on Alfred Vail and William Baxter, another Morse assistant, took an active part in the construction of some Morse apparatus. Some sources even alleged that it was Morse's assistants who were the real inventors of many of Morse's devices, including his famous Morse Code alphabet. At any rate, by 1838 the apparatus had been demonstrated to Congress, which in fact took no interest in the invention. That failure did not put off Morse, who decided to prepare a new demonstration. Using pitch, tar, and rubber he made 2 miles of waterproof insulated wire. He planned to lay a submarine cable by means of which messages could be transmitted between two ships, but he failed again. During the demonstration one of the ships touched the cable and broke it.

At the same time Karl Gauss and Verner Weber in Germany, and Shilling von Kapstatt in Russia, were also attempting to design and construct a telegraph. That stimulated Morse's interest even more. Between 1839 and 1842, he frequently consulted Henry regarding technical problems, seeking his support. Henry readily helped Morse as he considered Morse's device to be just a practical application of his own research. Commercial profit did not attract him much; he just desired that his scientific achievements be implemented in practice and that is what he expected from Morse. In February 1842, making use of his reputation and influence, he appealed to Congress to assist Morse in funding his project.

Later on that same year (1842), after Henry's appeal, Morse succeeded in gaining the support of Congress and was able to obtain $30,000. In May 1844, he successfully demonstrated his telegraph to the public. ''What hath God wrought?'' was the first message officially transmitted by telegraph. The daughter of the Head of the Patent Authority had chosen that message.

Twelve years of hard work were crowned with triumph and international fame, and Morse was acknowledged as the inventor of this new means of communication. Unfortunately, he did not acknowledge Henry's contribution to the invention in his publications and patents, and this greatly soured the relations between them.

As a result, Morse and Henry became involved in a long series of litigations, and were to continue struggling for what each considered his rights, until their deaths.

Practically all components of Morse's apparatus were only slightly improved Henry's demonstrational models. For example the so-called sounder was a prototype of a loudspeaker (see Figure 1.12) used for sounding of Morse Code (dots and dashes) conveyed by the key. It helped in reception of vocal messages encoded by Morse Code.

Each key had a normally closed (NC) and a normally open (NO) contact (Figure 1.13). Every time the key at one end of the line (Station 1) was pressed, the tip of the turning beam of the sounder at the other end of the line (Station 2) was gravitated to the core of the vertically installed coil.

It simultaneously hit the metal element, producing a signal. Later, one more resonator was added to the sounder to intensify that signal (Figure 1.14).

As one can observe the sounder comprised all components of Henry's electromagnetic apparatuses: a coil, an iron core, a beam rocking on a vertical axis, and even a sound indicator, but Morse used two coils instead of one. It made the apparatus and the pole terminals of the beam more sensitive and considerably improved the entire construction. This scheme proved to be so effective that from then on it was used in all similar devices, produced by many different companies over the years (Figure 1.15).

Later Morse (and perhaps one of his numerous assistants) inserted a pencil in the sounder and attached to it a spring winding mechanism, which stretched paper tape under the pencil. As the telegraph became easier to use, its use quickly spread throughout the world. At first, telegraph lines in the U.S.A. were built only alongside railroad lines, because the land belonged to the railroad authorities. It was only natural that the first telegraph services were provided to railroads. By 1854, 20,000 miles of telegraph lines had been constructed in the U.S.A. The German engineer Siemens, who made his career and fortune in the construction of telegraph lines, was the founder of the company that later became a super concern of the same name.

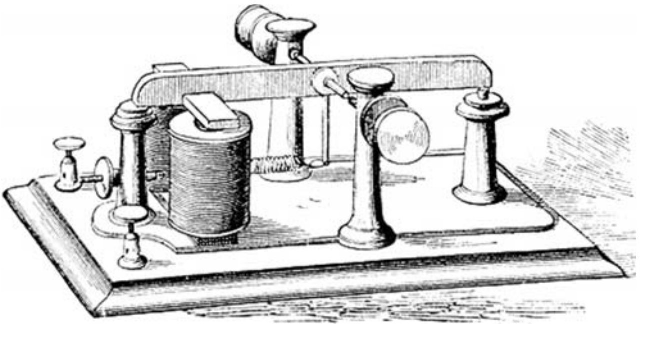


FIGURE 1.12
Sketch of Morse sounder used in his telegraph apparatus. (From Prescott George B. *History, Theory, and Practice of the Electric Telegraph*, Boston, 1860.)

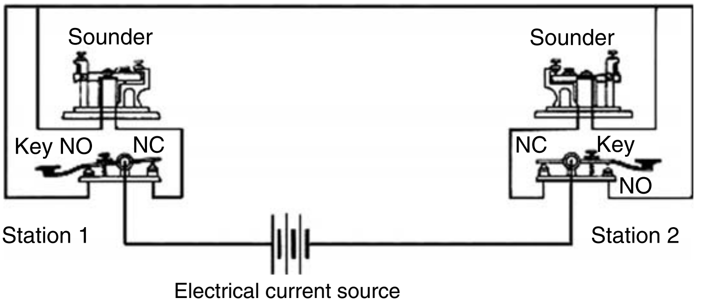


FIGURE 1.13
Scheme of Morse's telegraph.

As the length of telegraph lines constantly increased, the signal reaching the other end of the line became weaker, until someone from Morse's team recalled Henry's demonstrational experiments on remote control of a powerful electromagnet with the help of an interjacent sensitive electromagnet with contacts. Here was the solution! Technically the idea could be easily implemented: the well developed and reliable construction of the sounder included practically all the necessary components (see Figure 1.16) required to make an auxiliary element that would repeat signals from the transmission key and connect a subsidiary power supply (another galvanic battery) placed at the midpoint of

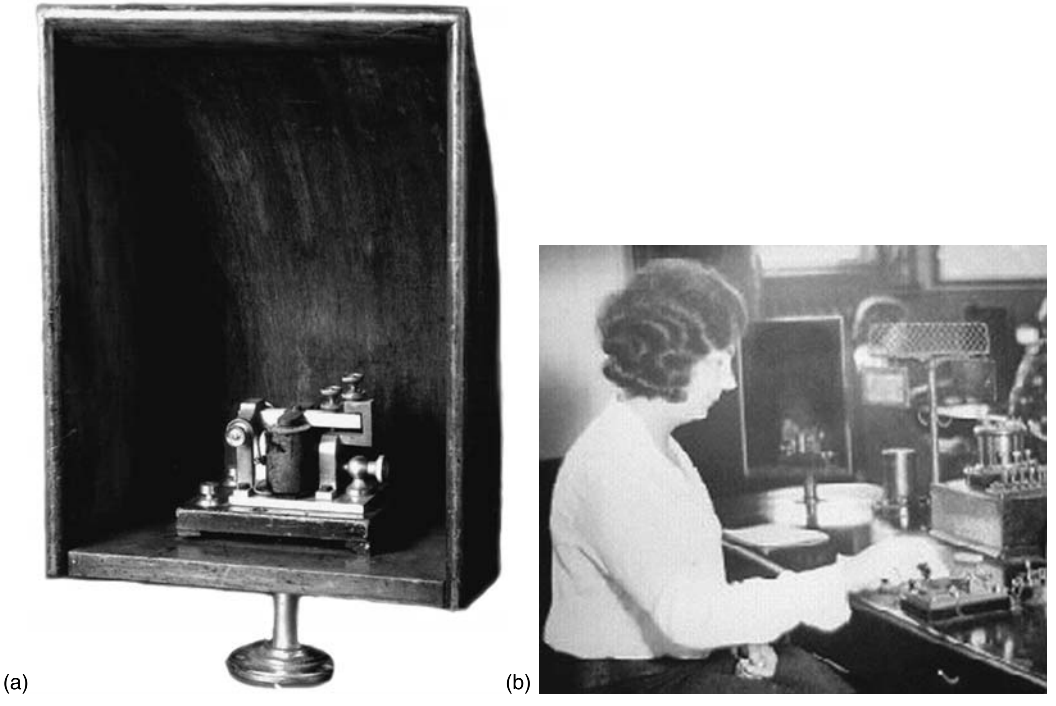


FIGURE 1.14
(a) Sounder supplied with a big wooden resonator. **(b)** Operator at work on telegraph key. On the rear plan a visible sounder with wooden resonator can be seen, standing on the table.

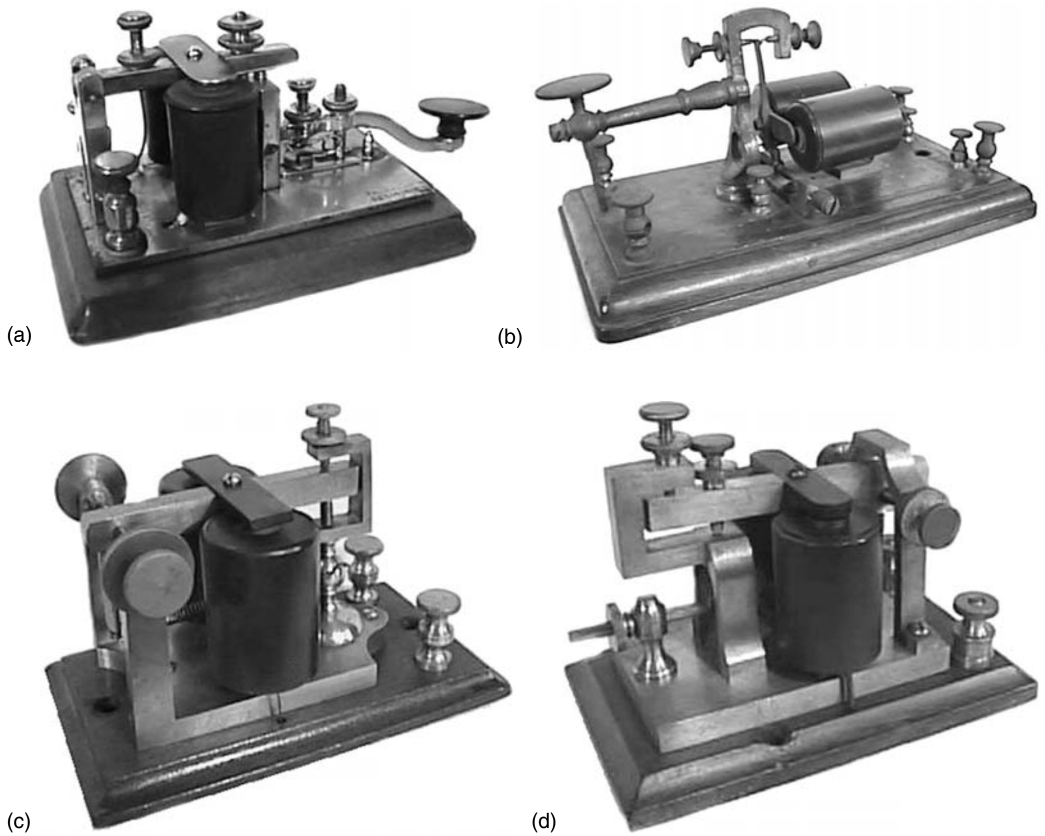


FIGURE 1.15
(a), (b), (c), and (d) Sounders produced by different companies in different years.

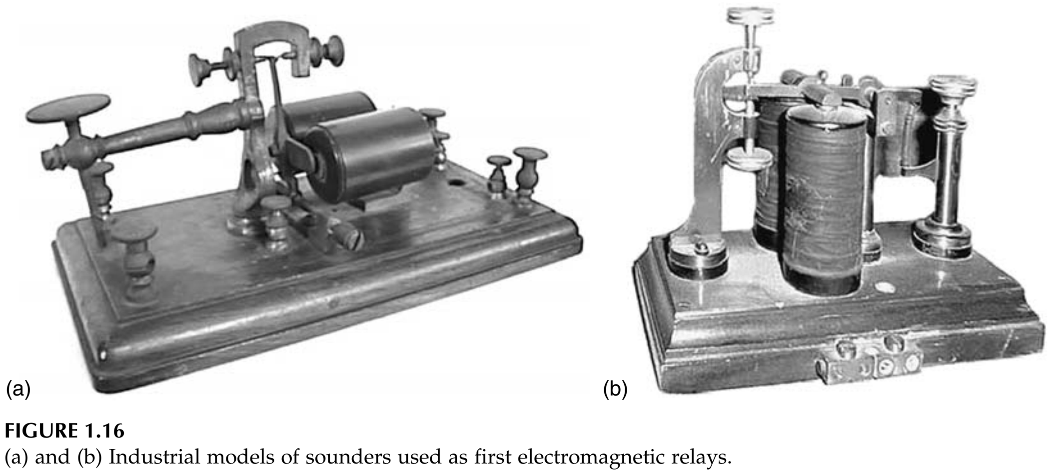


FIGURE 1.16
(a) and (b) Industrial models of sounders used as first electromagnetic relays.

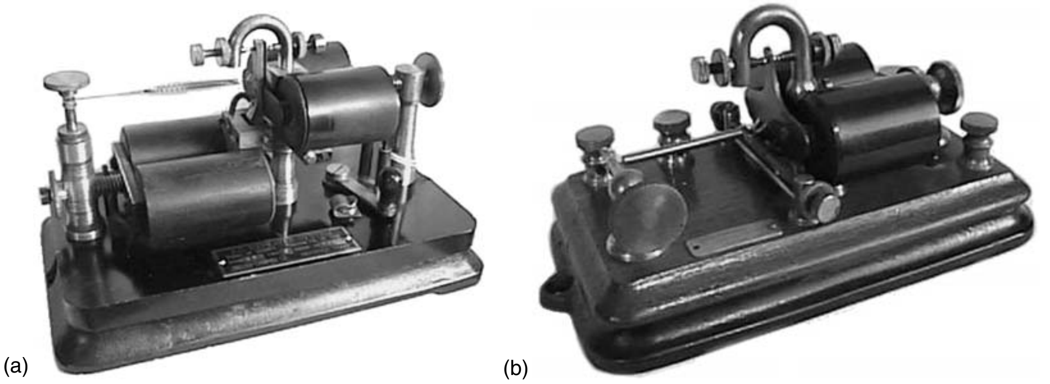


FIGURE 1.17
(a) and (b) Multi-wound and polarized (with an additional permanent magnet) relay produced in the 19th century.

the line, in time with the signals. Long distances between transmitting and receiving stations were no longer a problem as one or even several repeaters of the signal with ''full'' batteries could be installed on different telegraph stations.

At first such devices were called ''repeaters'' and ''registers'' but then someone noticed that the functions of such devices in the telegraph were similar to those of ''relay stations'' where horses were relieved. Such devices replaced a weak signal (run-down horses) with a more powerful one, connecting a ''full'' battery (another horse) at the midpoint of the line. As the term ''relay'' gradually caught on, it replaced all of the previously used terms.

Relays began to develop rapidly. New brands appeared, multiplying like clones. More and more companies began to specialize in the construction and production of relays (Figure 1.7) but for quite a long time relays remained just a part of the telegraphic system.

1.4 Edison's Relay

The outstanding inventor Thomas Alva Edison also could not help but contribute to this new field of science (Figure 1.18).

FIGURE 1.18
Thomas Alva Edison.

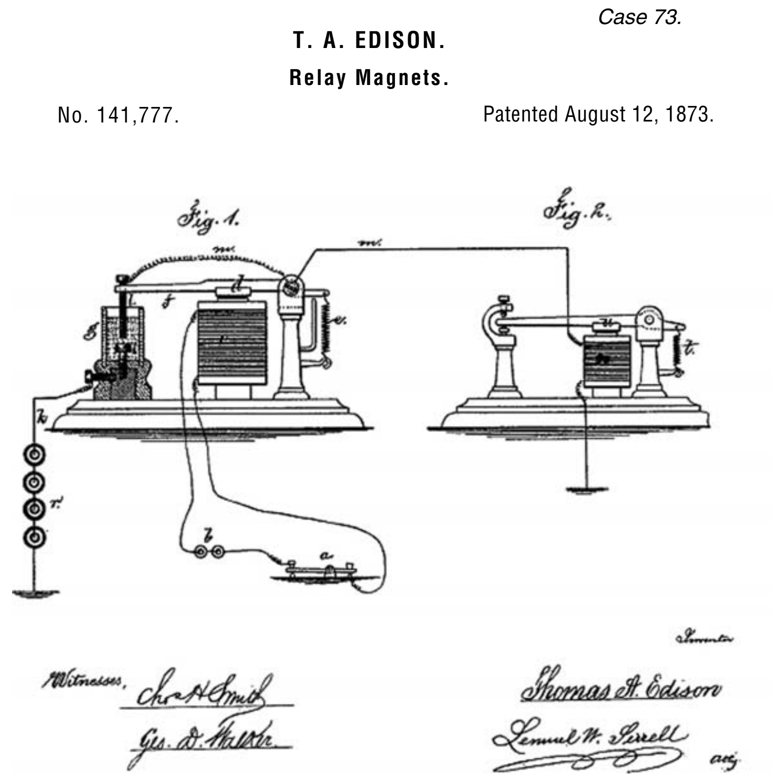


FIGURE 1.19
Page copied from one of Edison's 200 patents relating to relays.

More than 200 of Edison's patents were devoted to relays and to other electromagnetic switching centers of telegraph apparatuses (Figure 1.19). By Edison's time the term "relay" had gained wide acceptance as the term most commonly used to denote this class of electric devices, and was the only term that Edison used. The relays designed and constructed by Edison gradually began to resemble the devices we use today in most industrial applications (Figure 1.20).

The invention of the telephone and further development of manually operated exchanges with hand-operated connectors; The American company Western-Electric used an electric relay in such switches for the first time in 1878.

1.5 The First Industrial Relays in Russia

At the end of the 19th century, the first manually operated telephone exchanges began to appear in the larger cities of Russia. As there were not yet domestically produced telephone systems, the construction and operation of such exchanges were carried out by foreign companies.

The Swede, Lars Eriksson, the proprietor of one of such companies, founded the first telephone factory in Russia in 1897, in Petersburg. With a staff of 200 people it produced

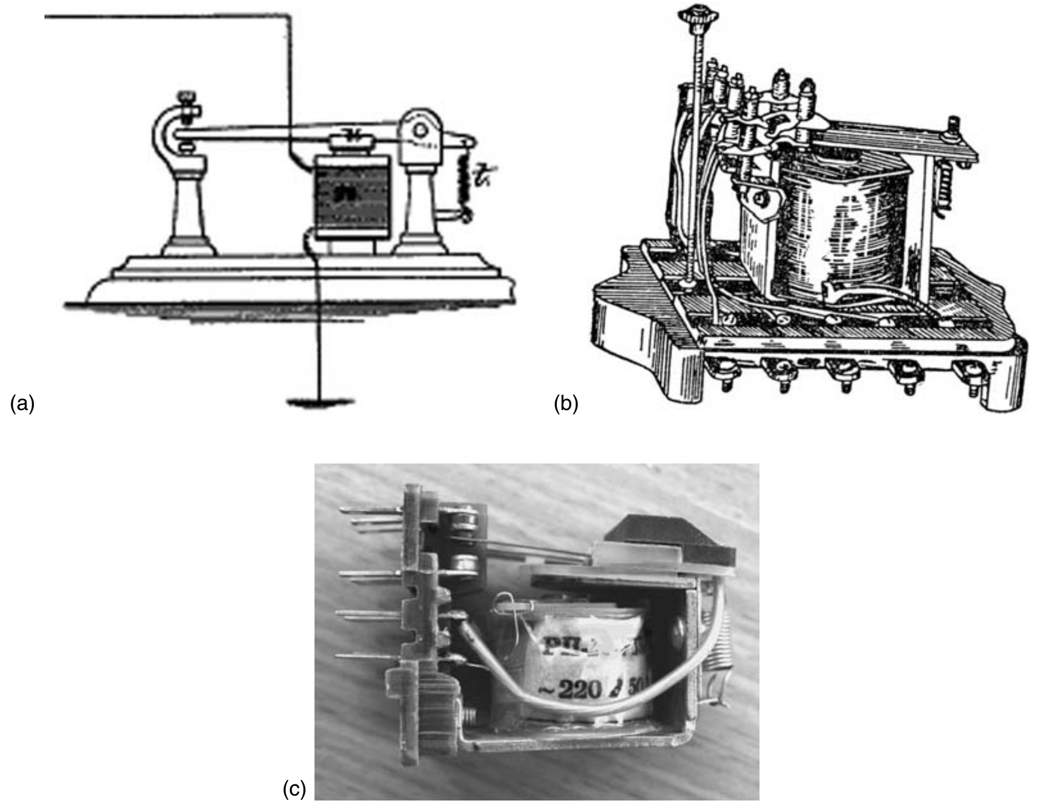


FIGURE 1.20
(a) Diagram of a relay from Edison's patent of 1873 and (b) and (c) its ''descendants'': Russian relays ER-100 (produced in 1940–1950s) and the modern one RP-21.
How little relays have actually changed in the course of more than a century of development. Nowadays we use the same principles and the same design schemes (RP-21 type).

12,000 telephone sets and about 100 switches over a period of 4 years. Later on it increased its capacity to produce over 60,000 telephone sets and a few hundreds of switches annually.

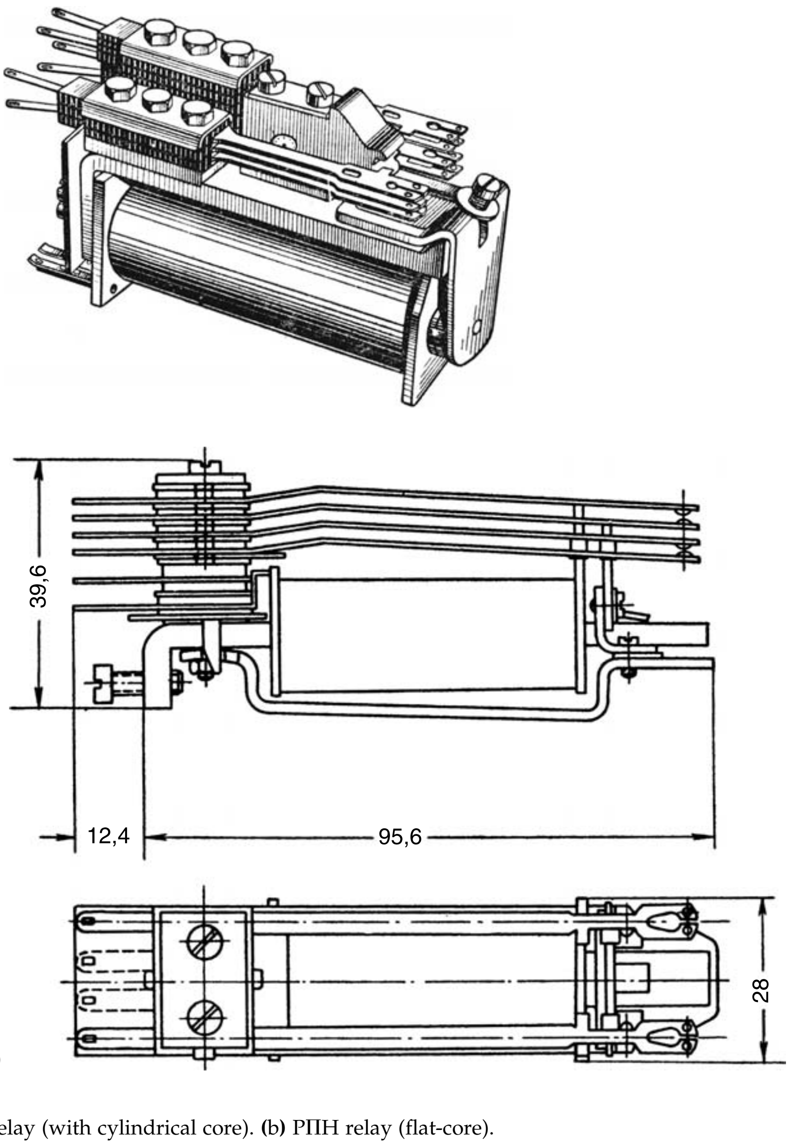
During the Russian–Japanese war the factory first began to produce military goods: field stations with phonic calls and outpost telephones. On January 1, 1905, it was renamed ''The Russian Incorporated Company, L. Eriksson and Co.''

When the First World War broke out, two more departments — naval and technical — were opened there for scientific and technical research. By 1915 the factory had evolved into a large plant, with a staff of more than 3000 people. The plant used mostly Swedish components for assembly of the various items it produced, among which were also relays.

In 1919, the plant was nationalized and transferred to the state-owned enterprises of weak-current electric industry. In 1922 the plant was renamed the Petrograd Telephone plant ''Krasnaya Zarya'' and joined the State Trust of weak-current electric plants (called the 9th Central Administrative Board of Ministry of Communication Industry in the closing stages of the Soviet Union), which also included the other 11 companies of the U.S.S.R. This marked the beginning of production of telephone relays in Russia.

The first models of relays, produced by ''Krasnaya Zarya'' until 1925, were of the clapper type, and almost exact reproductions of the ''Eriksson'' relays (Figure 1.21). Still,

FIGURE 1.21
Eriksson relay, produced by the ''Krasnaya Zarya'' plant until 1925.



(a)

(b)

FIGURE 1.22
(a) PKH type relay (with cylindrical core). **(b)** PПH relay (flat-core).

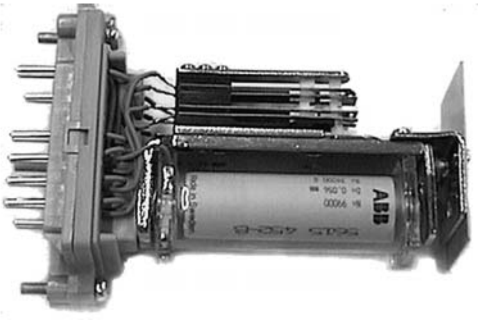


FIGURE 1.23
The modern relay RXMA-1 produced by the concern ABB, one of the world leaders in the relay field, is a practically identical copy of the PKH type relay and its ''predecessors.''

they were produced manually, in small series, and the materials for their production came from abroad.

Due to their lack of experience, Russian scientists at first attempted to obtain general knowledge and experience regarding the most common relay designs in use at that time around the world.

In 1934, Professor Matov of The Moscow Institute of Energy published the book *Telephone Relays, their Construction and Design*, which was the first Russian publication to present general knowledge and experience from around the world in the design of electromagnetic relays.

Being aware of Russia's technological gap, and realizing the importance of development of relay devices for modern communication and automation systems, the People's Commissariat of the Defense Industry created the Scientific-Research Institute of Electromechanics.

One of its main tasks was the invention and development of new types of relays for different fields of application, including defense technology. The Head of research was B. Sotskov. At the same time, in 1928, the Kharkov Electromechanical Plant began to produce relays for the power-generation industry and the electric drive industry. In a few years it was able to produce several different types of such relays, though still reproducing the best examples of foreign equipment. That policy lasted many long years. Copies of new German relays taken from captured German V-2 rockets were especially popular at that time. PKH and PПН type relays (Figure 1.22) produced in millions since 1946 were only copies of German and English relays.

It is interesting to note that although those relays were not used in telephone and telecommunication equipment, they ''were revived'' in systems of relay protection of electric networks. One of the biggest and most famous concerns producing all kinds of technical equipment for the power-generation industry still produces and utilizes analogs of RKH relays (Figure 1.23). Of course these relays are made today using new materials (they have a winding for 220 V of continuous current and contain 99,000 turns of 0.056 mm wire with a coil resistance of 39 kΩ). Also, today's model comes with a nice-looking transparent case, but that does not change the fact that it is still quite an ancient device.

The number of relay plants grew rapidly. Weak-current relays were then produced in Kharkov (by the production association ''Radiorele''), S. Petersburg (by the research-and-production association ''Severnaya zarya''), Irkutsk, Alatyr, Porhov, Krasnodon, Penza, and in many other cities.

About that same time there were many plants producing larger industrial relays (the electric equipment plant in Cheboksary, the production association of ''Automation and Relays'' in Kiev, the production association of electric equipment in Tiraspol, electric equipment plants in Moscow and Yerevan, etc.) and some plants that produced aircraft

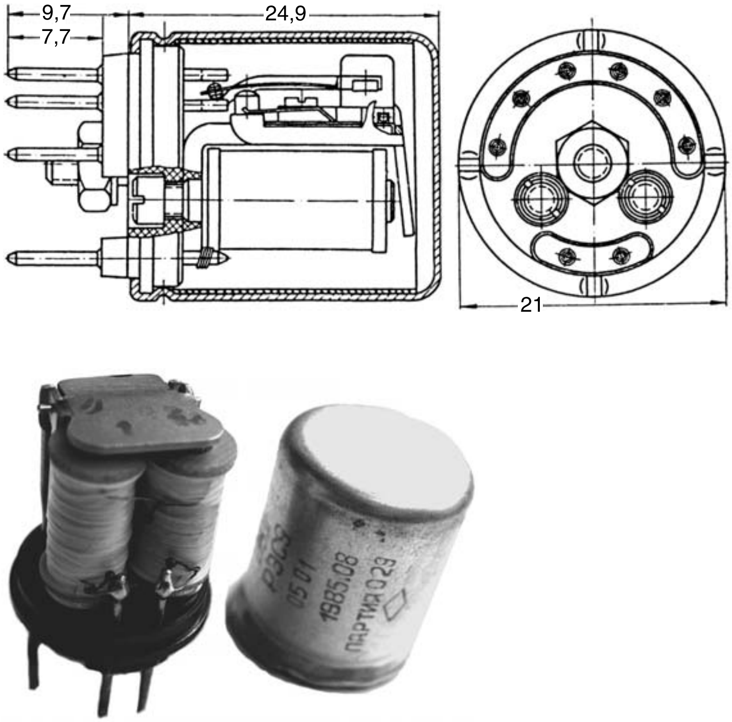


FIGURE 1.24
The design of a compact relay REC-9 produced by Kharkov Production Association ''Radiorele'' and some other plants in Russia is very much like that of an ancient sounder.

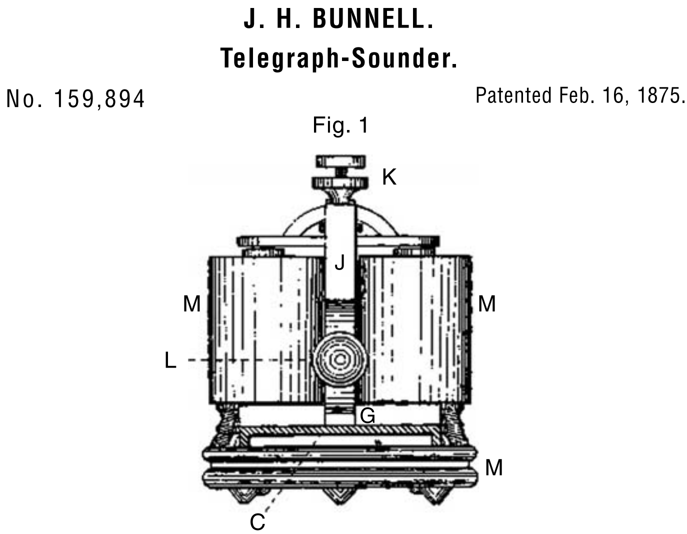


FIGURE 1.25
Diagram of a sounder from a patent of J.H. Bunnell (1875), a famous inventor of electromagnetic devices at that time.

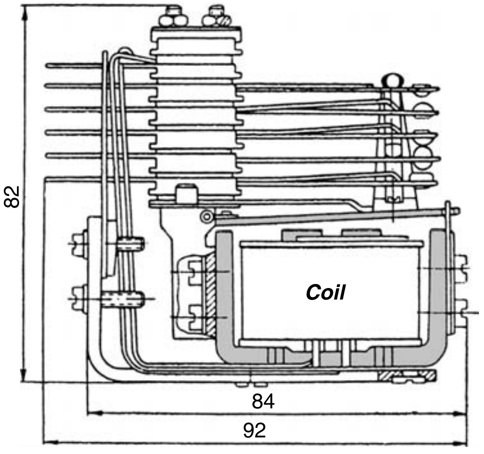


FIGURE 1.26
Out-of-date MKU-48 type relay for automation industry systems still produced by the Irkutsk Relay Plant.

switching equipment. In order to coordinate scientific activities in the field and to support the production of relays, the Scientific Research Institute of Switching Equipment, specializing in weak-current relays, was created in Leningrad, the All-Union Scientific Research Institute of the Relay Construction specializing in industrial automation relays and protective relays for the power-generation industry, in Cheboksary, and the Central Scientific Research Institute Number-22, coordinating researches in relay equipment for defense industry in Mytishi, situated near Moscow.

In the final stages of the U.S.S.R., relays were produced by dozens of big plants belonging to three Ministries: the Ministry of Communication Industry, the Ministry of Electrical Industry, and the Ministry of Aircraft Industry.

Today the range of types of electromagnetic relays produced by plants of the former Soviet Union is quite wide. It is possible, for instance, to come across REC-9 type relays, which used to be regularly produced by Kharkov Production Association ''Radiorele'' (Figure 1.24). The magnetic system of this two-coil relay is quite similar to many ancient sounders of the 19th century (Figure 1.25). Nevertheless, it was quite a reliable universal relay, applied in all fields of engineering. The author even happened to come across such relays in a reentry missile vehicle 9K21, fitting all types of charges.

The Irkutsk Relay Plant still continues producing such ''veteran'' relay devices, as the MKU-48 (Figure 1.26), which are in fact to be placed in a museum of technical equipment history.

Today Russian plants also produce many quite up-to-date relays, corresponding to their foreign analogs (Figure 1.27).

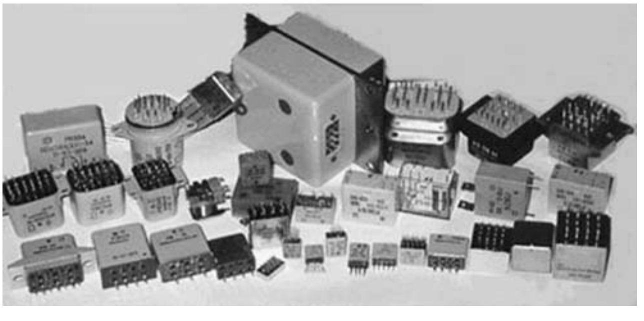


FIGURE 1.27
Modern Russian relays.

2

Magnetic Systems of Relays

2.1 Basic Components of an Electromagnetic Relay

An electromagnetic neutral relay is the simplest, most ancient, and widespread type of relay. What are its basic elements? As a rule, most people asked this question would probably name the following: a winding, a magnetic core, an armature, a spring, and contacts.

This all is true of course, but if you begin to analyze how a relay works, it might occur to you that something is missing. What is the purpose of a magnetic system? Apparently it is used to transform input electric current to the mechanical power needed for contact closure. And what does a contact system do? It transforms the imparted mechanical power back to an electric signal.

Don't you think that something is wrong here?

Everything will become more obvious if the list of basic components of a relay includes one more element, which is not so obvious from the point of view of the construction of a relay, for example, a coil or contacts. Very often, it is not just one element, but several small parts, that escape our attention. Such parts are often omitted on diagrams illustrating the principle of relay operation (Figure 2.1). I am referring to an insulation system providing galvanic isolation of the input circuit (winding) from output one (contacts). If we take such an insulation system into account, it becomes clear that an input signal at the relay input and the output signal at the relay output are not the same. They are two different signals that are completely insulated from each other electrically. Note that if you use Figure 2.1, which is often used to illustrate principles of relay operation, as the

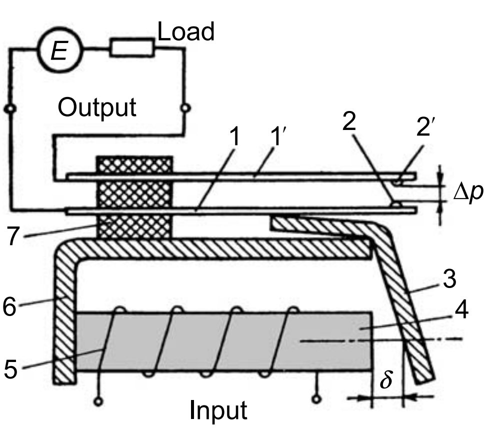


FIGURE 2.1
Construction of a simple electromagnetic relay.
1 — springs; 2 — contacts; 3 — armature; 4 — core; 5 — winding; 6 — magnetic core; 7 — insulator.

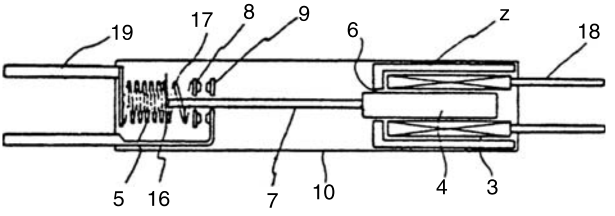


FIGURE 2.2
High-voltage relay from a Japanese patent, No. 62-32569. 3 — control winding; 4 — solenoid-type armature; 7 — insulation rod; 8, 9 — contacts; 5 — spring; 18 — outlets of input circuit; 19 — outlets of output circuit.

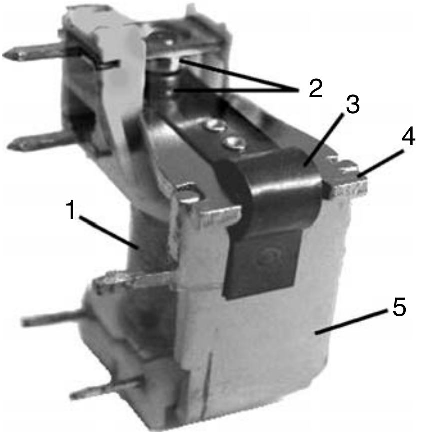


FIGURE 2.3
Construction of a relay with a noninsulated contact system. 1 — coil with an insulating bobbin; 2 — contacts; 3 — spring; 4 — armature; 5 — iron circuit.

only guide while constructing a relay, the relay will not operate properly since its input circuit (the winding) is not electrically insulated from the output circuit (the contacts).

In simple constructions used for work at low voltage, insulating bobbins with winding (not shown in Figure 2.1) provide basic insulation (apart from an insulator). In a relay with a free bobbin coil, it is necessary to use a special insulating baffle pin between the armature (3) and the contacts (not shown in Figure 2.1, but it can be seen on the blueprint of the construction of an MKU-48-type relay (see Figure 1.26).

In more expensive constructions used for work at higher voltages (over 300 to 500 V) both elements are included. In high-voltage relays the insulating baffle pin usually comes in the form of a long rod (7) linking the armature with the contacts (Figure 2.2).

In relatively low-voltage relays (up to 220 V), in order to simplify the construction and to make it more compact, a coil from a magnetic core is insulated with the help of an insulating bobbin and connects a movable contact directly to the armature (Figure 2.3). Note that the contact spring and the restoring spring of the armature are the same component; a flat bent beryllium bronze plate. Since the magnetic core of the relay is not insulated from the contacts and is alive, the relay is put into a hermetic plastic case.

Let us consider the basic types of electromagnetic relays.

2.2 Hysteresis and Coercitive Force

The magnetic system of a typical low-voltage electromagnetic relay comprises first of all a control winding (1) made in the form of a coil with insulated wire, a magnetic core (2), and a movable armature (3) (see Figure 2.5). Elements of the magnetic circuit of the relay

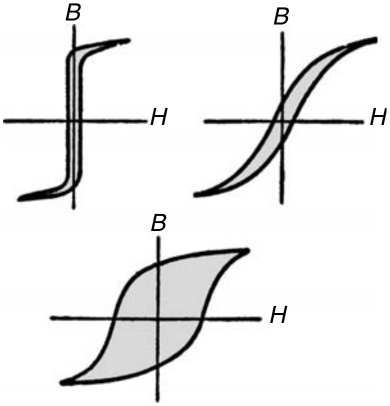


FIGURE 2.4
Hysteresis loops for soft and hard magnetic materials. B — flux density; H — magnetic field strength.

are usually made of soft magnetic steel, which is a type of steel that has a small hysteresis loop (Figure 2.4). ''Hysteresis'' can be translated as a ''lag.'' A hysteresis loop is formed from a magnetization curve and a demagnetization curve. These curves are not superimposed on each other because the same magnetic field strength is not enough to demagnetize the magnetized material. An additional magnetic field is required for demagnetization of the material to its initial (nonmagnetized) state. This happens because the so-called residual induction still remains within the previously magnetized model, even after removal of the external magnetic field. Such phenomenon takes place because magnetic domains (crystal structures of ferromagnetic material) expanding along the external magnetic field lose their alignment when the external magnetic field is removed. The demagnetizing field necessary for a complete demagnetization of the previously magnetized model is called the *coercitive force*. The coercitive force of soft magnetic materials is small, which is why their hysteresis loop is also small. This means that when the external magnetic field is removed (deenergizing the winding of the relay), the magnetic core and armature do not remain magnetized, but return to their initial stage. Apparently this lack of retentivity is a very important requirement for materials used in magnetic circuits of typical neutral relays. Otherwise, relay characteristics would not be stable and the armature might seal.

Electric steel used for the production of electric motors, transformers, and relays is composed of this very soft magnetic material. This is steel with a lean temper (and other admixtures like sulfur, phosphor, oxygen, nitrogen) and rich silicon (0.5 to 5). Apart from enhancing the qualities of the steel, the silicon makes it more stable and increases electrical resistance, which considerably weakens eddy currents (see below). The hardness and the fragility of the steel are mostly dependent on the silicon content. With a content of 4 to 5% of silicon, steel usually can withstand no more than 1- to 2-fold of 90°. For a long time only the hot rolling method was used for the production of such steel, until in 1935 Goss discovered the superior magnetic properties of cold-rolled electric steel (but only along the direction of rolling). This gave such steel a magnetic texture and made it anisotropic. The utilization of anisotropic cold-rolled steel requires such construction of the magnetic core, to enable magnetic flux to pass only in the direction of rolling. Machining of parts of a magnetic core entails high internal stress, and consequently higher coercitive force. That is why after processes of forming, whetting, and milling, parts must be annealed at 800 to 900 °C, with further gradual reduction of temperature to 200 to 300 °C.

Sometimes Permalloy is used for magnetic cores of highly sensitive relays. It is a ferroalloy with nickel (45 to 78%) alloyed with molybdenum, chrome, copper, and other elements. Permalloy has better magnetic properties in weak magnetic fields than electric steel; however, it cannot be used for work at great magnetic fluxes since its saturation induction is only half as much as that of electric steel. Magnetic cores for big AC relays are made of sheet electric steel, which is 0.35 to 0.5 mm thick.

2.3 Types of Magnetic Systems

Several types of the magnetic systems are used in modern constructions of relays (Figure 2.5).

2.3.1 The Clapper-Type (Attracted-Armature) Magnetic System

This is the most ancient type of magnetic systems. Its construction was already described in Edison's patents. It was used first in telephone relays, and later in industrial and compact covered relays. Today this type of magnetic system is widely used in constructions of middle and small-size relays, with a plastic rectangular cover that is often transparent. They are mostly designed for work in systems of industrial automation and the power-generation industry (Figure 2.6); and also in some relatively prominent electric open-type equipment (Figure 2.7). The disadvantage of relays with this type of magnetic system is sensitivity to external mechanical effects.

Considerable acceleration in certain directions can cause the armature of a relay to move spontaneously, thus provoking switching of external circuits by the contacts of the relay. When this happens, the magnetic system is called *unbalanced*. When this unpleasant characteristic of such types of relays was discovered scientists began to seek new

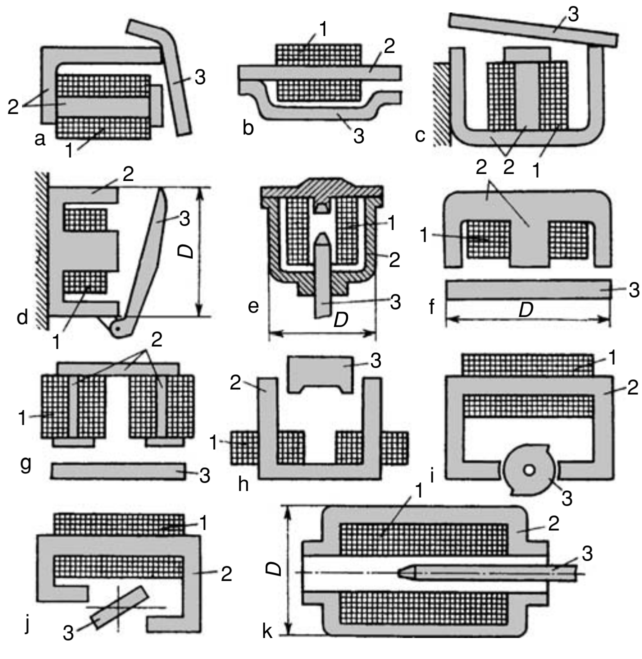


FIGURE 2.5
Types of the magnetic system of modern electromagnetic relays. 1 — control coil; 2 — magnetic core; 3 — armature; (a–d) — clapper-type (attracted-armature) systems; (f, g) — direct motion magnetic systems; (e, h, k) — systems with a retractable armature (solenoid type); (i, j) — systems with a balanced turning armature.

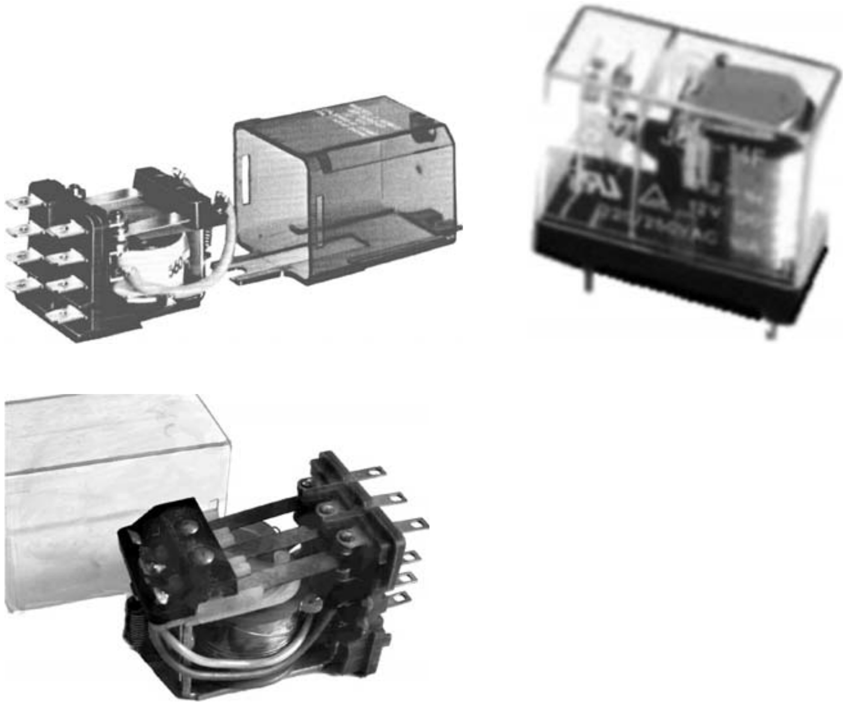


FIGURE 2.6
Modern attracted-armature relays with a transparent plastic rectangular cover for industrial usages.

technological solutions, which would enable the relay to work correctly within transportable equipment (mostly military equipment).

At first they tried the so-called ''frontal solution'': if there is some unbalanced weight it should be balanced, *but how?* The obvious solution: with the help of an additional weight — a counterweight placed in a certain position (Figure 2.8).

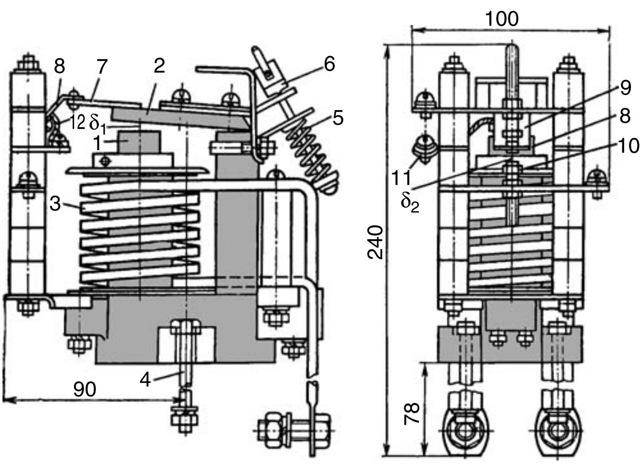


FIGURE 2.7
Large open relay (of REV-300 type) with clapper-type magnetic system. 1 — U-shaped magnetic core; 2 — flat armature rotating on the prism; 3 — winding (in this instance current winding wound by copper wire); 4 — fastening pins; 5 — spring; 6 — screw-nut regulating spring constrictor; 7 — insulating plate; 8 — movable contact; 9, 10 — stationary contacts; 11 — contact outlet; 12 — flexible copper conductor linking the contact with the outlet.

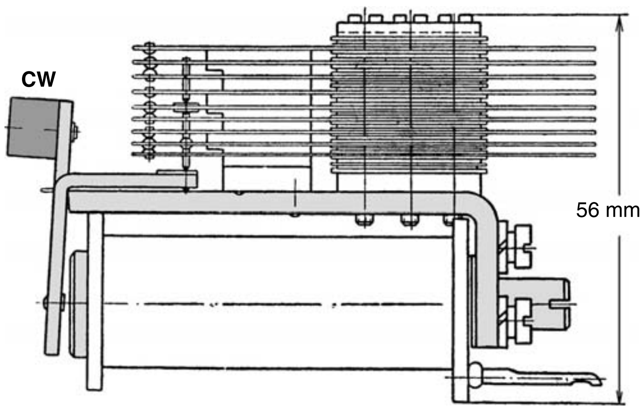


FIGURE 2.8
Multi-contact RKMP- type relay (Russia) with an attracted-armature magnetic system balanced by a counterweight (CW) fixed on the armature.

2.3.2 Systems with a Balanced Armature

Further research in this direction led to the invention of a new J-type magnetic system. In this system, a balanced turning armature was widely used in miniature hermetic relays for radio-electronic equipment, for work on movable units. In this magnetic system the rotation axis of the armature goes through its center of mass. As a result the relay becomes resistant to external mechanical impact and can sustain linear accelerations of 100 to 500 g, reiterated shocks at an acceleration of 75 to 150 g, and separate shocks at an acceleration rate of up to 1000 g. There are a lot of variants of this J-type magnetic system (Figure 2.9 and Figure 2.10).

Not only most modern miniature relays in plastic shells but also hermetic relays in metal shells (Figure 2.11), which have been produced for ages, have similar magnetic systems.

Such magnetic systems are typical of Russian relays RES47 (Figure 2.12), RES48, RES54, RES60, RES77, . . . , RES80, etc.

Miniature and micro-miniature relays of this type are really very small in size: for example, the RES49-type relay is 10.45 × 5.3 × 23.2 mm with a weight of 3.5 g, or the RES80-type relay is 10.4 × 10.8 × 5.3 mm with a weight of 2 g.

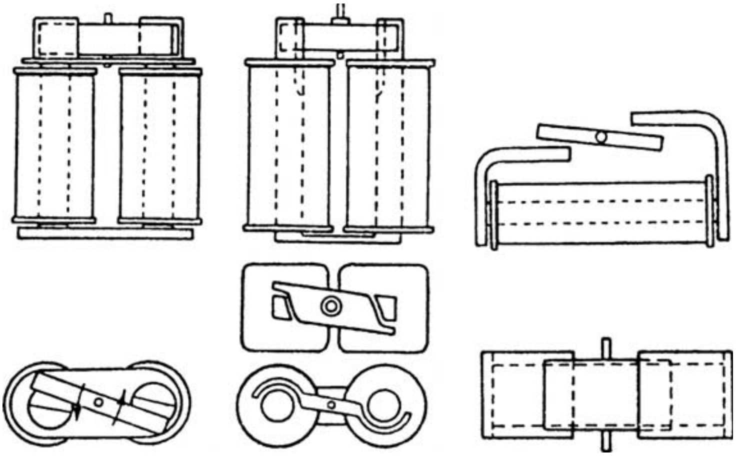


FIGURE 2.9
Some variants of construction of the J-type magnetic system.

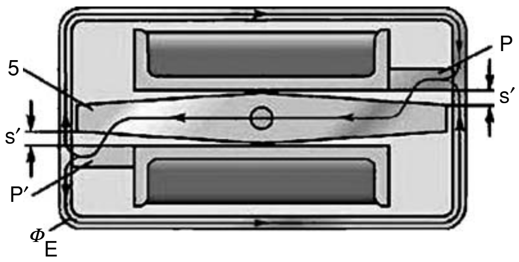


FIGURE 2.10
Another variant of construction of a magnetic system with a balanced turning armature placed inside the winding. P — stationary poles of the magnetic core; S — armature (magnetic pole) gape; F — magnetic flux in the magnetic core; 5 — turning armature.

Even power relays with switching currents of tens of amperes designed for use on movable units are often supplied with a magnetic system of this type. For example, the 8E-123M-type relay, Figure 2.13, designed by the All-Russian Scientific Research Institute of Electromechanics, and produced by one of the Moscow plants for many years for military applications only, has characteristic meeting the highest international standards.

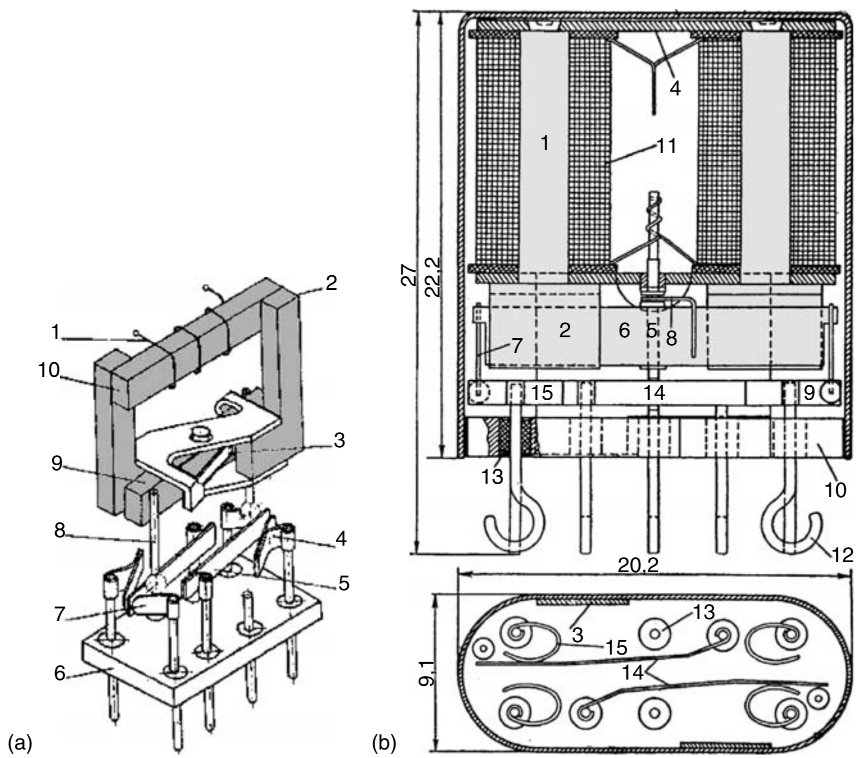


FIGURE 2.11
(a) One of the most popular variants of construction of the turning-type magnetic system, widely used in miniature relays. 1 — winding; 2 — pole of the magnetic core; 3 — restoring spring; 4 — fixed normally open contact; 5 — moving contact; 6 — heel piece of relay; 7 — fixed normally closed contact; 8 — pusher with a small insulating ball, weighted at the end; 9 — turning armature; 10 — core. (b) Miniature MV-type relay (weighing 14 g) produced by ''Elgin National Watch Co'' in the 1960s. 1 — core; 2 — pole; 3 — supporting bracket of the magnetic system; 4 — connecting plate of the magnetic core; 5 — rotary axis of the armature; 6 — armature; 7 — pusher of the armature with a small insulating ball, weighted at the end; 8 — restoring spring; 9 — restraining arm; 10 — heel piece of relay; 11 — winding; 12 — hook-shaped outlets of the relay (for point-to-point wiring by soldering); 13 — hermetic bushing glass insulators; 14 — movable contacts; 15 — fixed contacts.

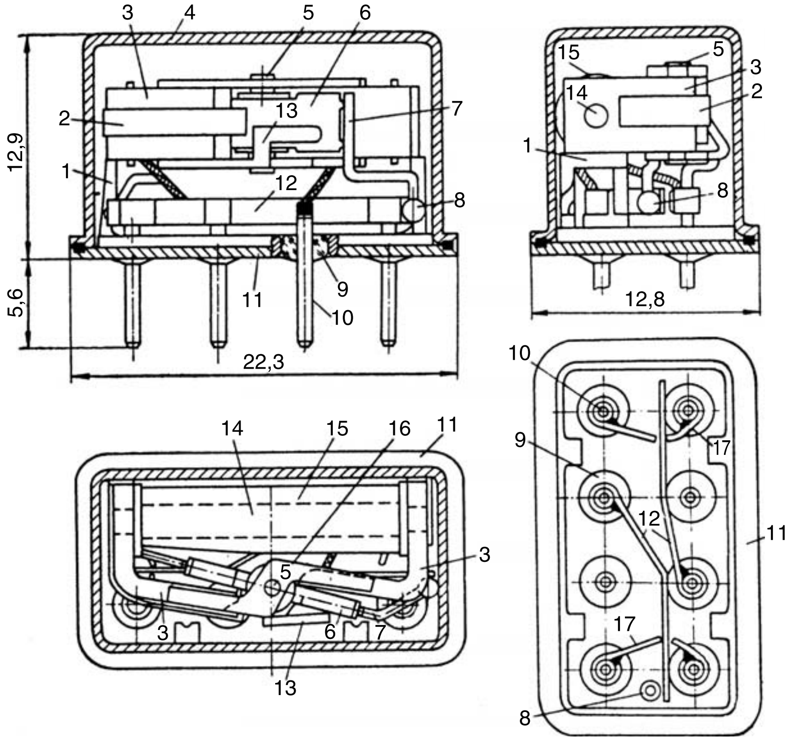


FIGURE 2.12
Miniature hermetic RES47-type relay (Russia) with two switching contacts at 1 A, 34 V, weight 9 g. 1 — post made from nickel silver; 2 — flat spring; 3 — Γ-shaped pole pieces; 4 — seamless copper case; 5 — axle journals (semiaxis); 6 — turning armature; 7 — pushers with small glass balls; 8 — weighted at the ends; 9 — glass insulators; 10 — outlet pins; 11 — heel piece of the relay; 12 — movable contact points; 13 — armature stop; 14 — iron core; 15 — free-bobbin coil; 16 — straps from nickel silver; 17 — stationary contact points (silver).

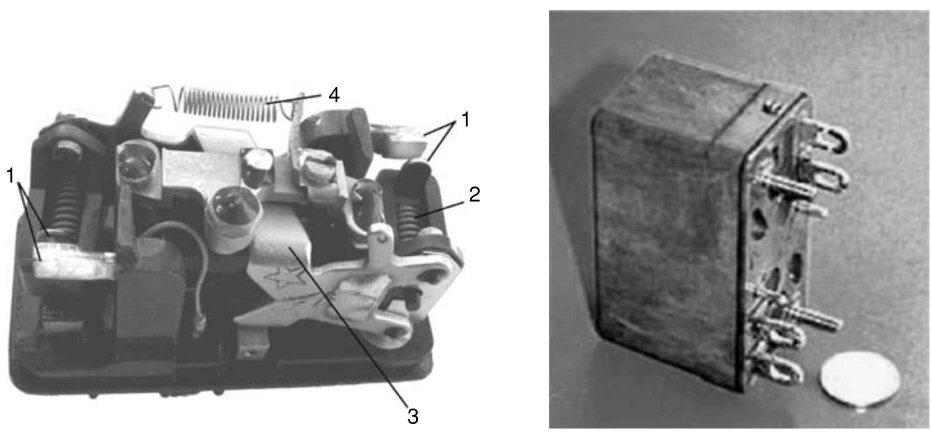


FIGURE 2.13
Relay 8E-123M type for military applications (Russia). 1 — closing contacts; 2 — spring for adjusting contacts; 3 — turning armature; 4 — restoring spring.

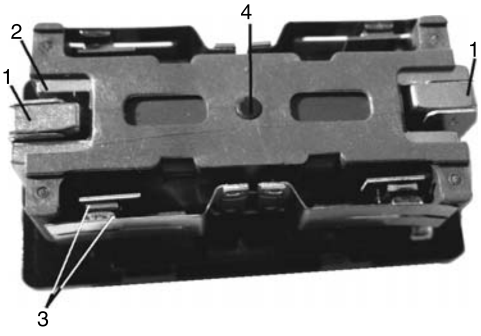


FIGURE 2.14
SP2-P-type relay produced by the SDS Relais company (16 A, 250 V). 1 — stationary core fixed coaxially inside the coil; 2 — movable poles of the armature; 3 — contacts; 4 — rotation axis if the armature.

This relay, with a switching current of 40 A (on each contact) can be used in temperatures ranging from –60 to +85 °C, on shock exposure of up to 100 g, and can also withstand exposure to dew, hoar-frost, salt, mist, mould, and other environmental factors, according to the Russian military standard B.20.39.404–81. At the same time the relay is of quite a small size (57 × 28 × 45 mm) and weight (80 g). Its service life is 20 years, with a storage life of 25 years. The core of such relay is fixed inside the coil with its ends going beyond the coil. A Π-shaped armature with movable contacts covers the coil. Such construction is quite typical of relays of this kind (Figure 2.14).

Magnetic systems with a turning armature are also widely used in protective (measuring) relays (current and voltage relays), which are often used in the electric power industry because one can accurately adjust the trip level by regulating volute spring force of the clockwork type (Figure 2.15). The Russian RES-8-type relay (Figure 2.16) also has a very interesting and original construction. Having one winding, the magnetic system of this relay has four poles (3), and an armature (2) in the shape of a cross, formed by four plates. The butt-ends of the plates are linked by means of a hollow muff with a molded axle. Another peculiarity of such relays is a protective case used as a magnetic core through which the magnetic flux is closed. This case is made of steel, making such relays quite heavy (110 g). One more interesting element is a magnetic armature damper consisting of two small stationary magnets (5) holding the armature in the initial position during vibrations that may affect the relay.

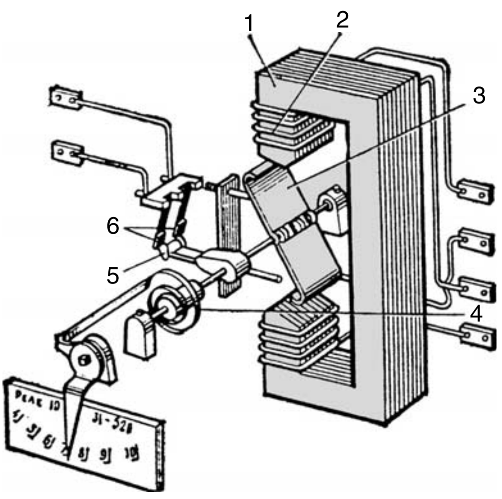


FIGURE 2.15
Magnetic system with a turning armature, used in protective relays. 1 — magnetic core; 2 — winding; 3 — turning armature; 4 — spring; 5,6 — elements of the contact system.

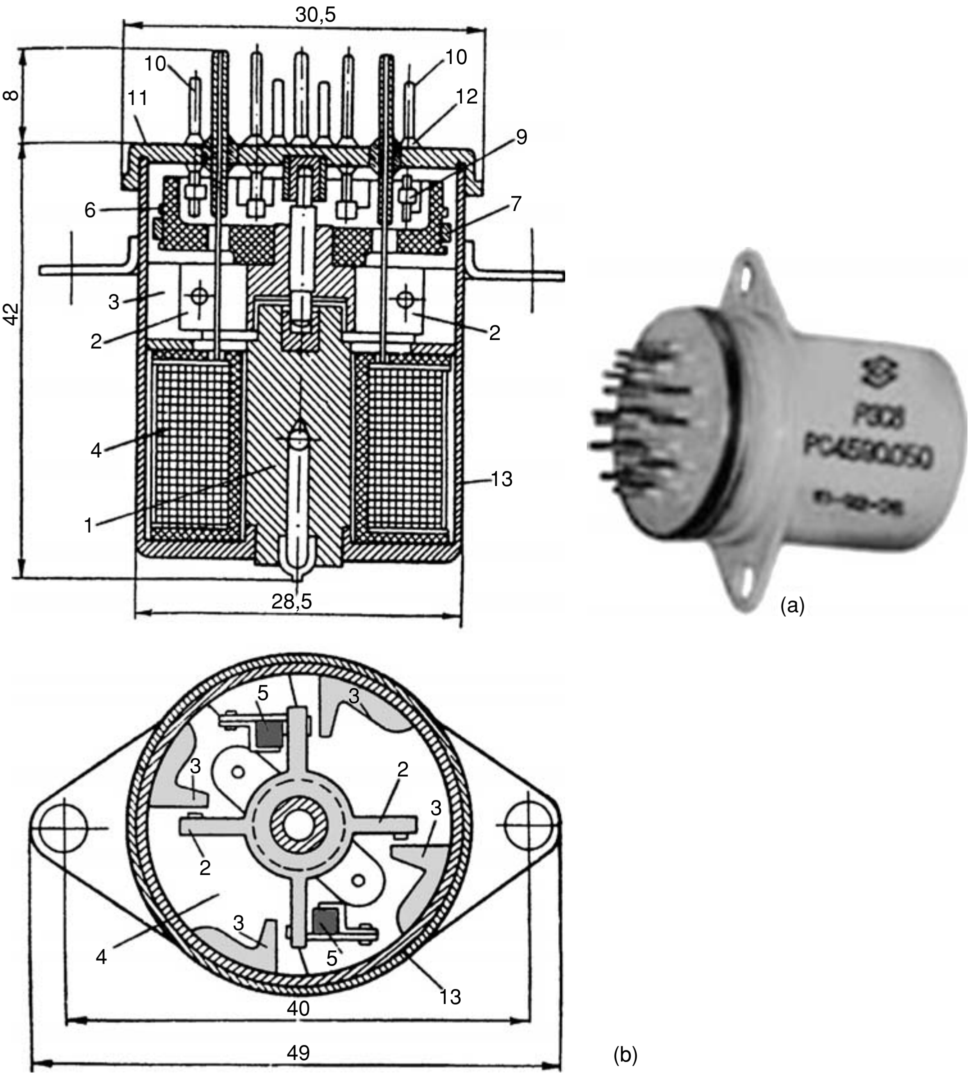


FIGURE 2.16
External view (a) and construction (b) of hermetic multi-contact RES-8 type relay. 1 — core; 2 — armature; 3 — poles; 4 — coil; 5 — stationary magnet; 6 — movable Teflon cup; 7 — damper circle; 8 — movable contact spring; 9 — stationary contact; 10 — outlet pin; 11 — heel piece from Kovar; 12 — glass insulators; 13 — steel case.

2.3.3 Direct Motion (Solenoid-Type) Systems and their Peculiarities

Direct motion systems of the ''f'' and ''g'' types are used in power relays, so-called ''magnetic starters.'' They have been so named because originally such relays were designed for direct start up of asynchronous motors, and were also used in time delay relays with an airtime delay mechanism, described below.

Solenoid-type (e, h, k type) systems are used both in miniature relays (Figure 2.17), and in large devices with greater mechanical force.

In 1952, the Bell Company together with Western Electric Company designed an original Ш-shaped magnetic system (Figure 2.18), with a П-shaped armature (contacts were also located on both sides of the winding — Figure 2.19). The ends of this armature

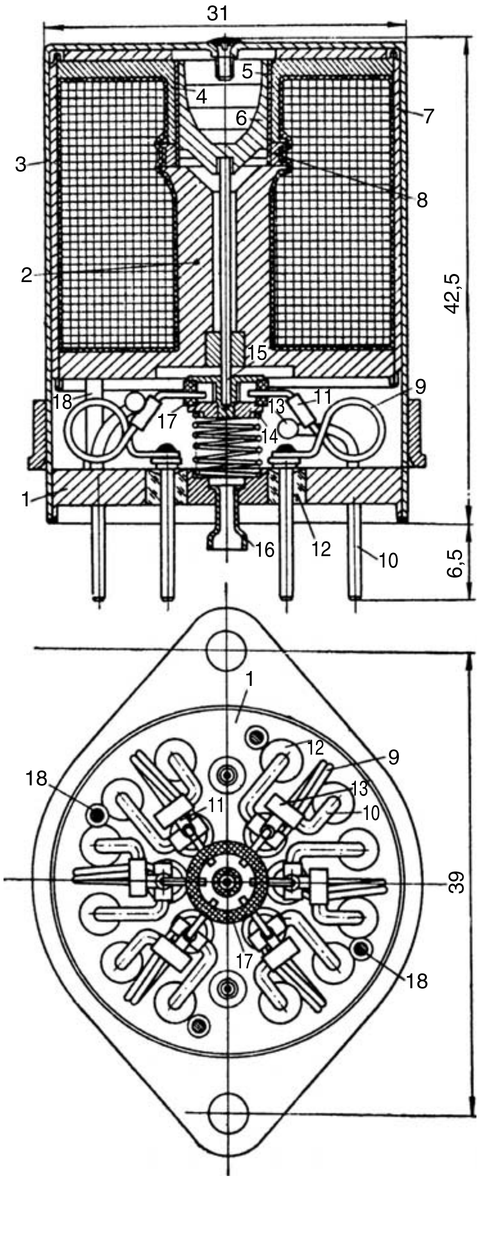


FIGURE 2.17
Miniature Mark-II-type relay produced by "Electro Tech Co." and an exact replica RES-39-type relay (Russia) with a retractable solenoid-type armature. 1 — heel piece; 2 — core; 3 — steel case; 4 — steel cup; 5 — guide brass tube; 6 — hollow retractable armature with a glass-shaped conical stopper; 7 — iron body; 8 — nonmagnetic bushing; 9 — movable contact springs; 10 — small pin; 12 — glass insulator; 13 — stationary contacts; 14 — cylindrical spiral spring; 15 — rod; 16 — union through which the relay is filled with dry air and sealed; 17 — pusher; 18 — steel posts with the magnetic system fixed.

were fixed on the free ends of a П-shaped flat spring. The core of the relay was Ш-shaped, its middle rod inside the coil and the outward ones outside of it. When the relay is energized, the П-shaped core lies level on the outward rods and the end of the internal rod sticks out of the winding, closing the magnetic circuit.

The advantages of this magnetic system are simplicity of production and a very slight magnetic resistance due to the absence of joints, the wide coupling surfaces of the armature and the core, which are the poles of this magnetic system. This relay was quite large, measuring 48.4 $\times$ 37.2 $\times$ 115 mm. (The year 2004 marks 52 years since it was invented.) It is all the more surprising to come across the descendant of this relay in a printed circuit card on a modern electric device. This is an A2440-type relay produced by

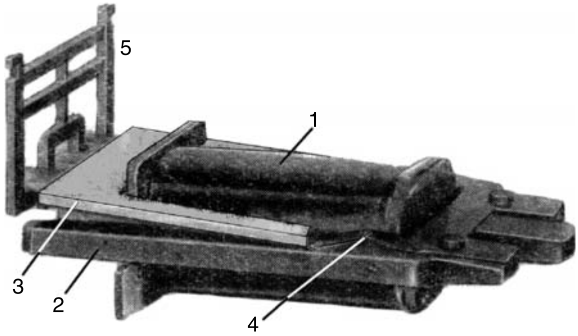


FIGURE 2.18
A magnetic Ш-shaped system for AF-type relay. 1 — winding; 2 — Ш-shaped core; 3 — П-shaped armature; 4 — flat П-shaped spring; 5 — pusher of c ontacts.

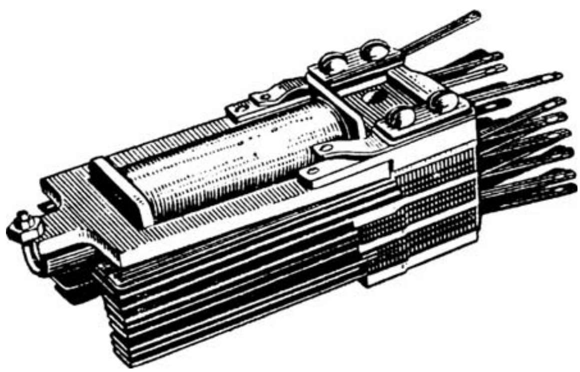


FIGURE 2.19
Relay produced by the ''Western Electric Company'' with a Ш-shaped magnetic system.

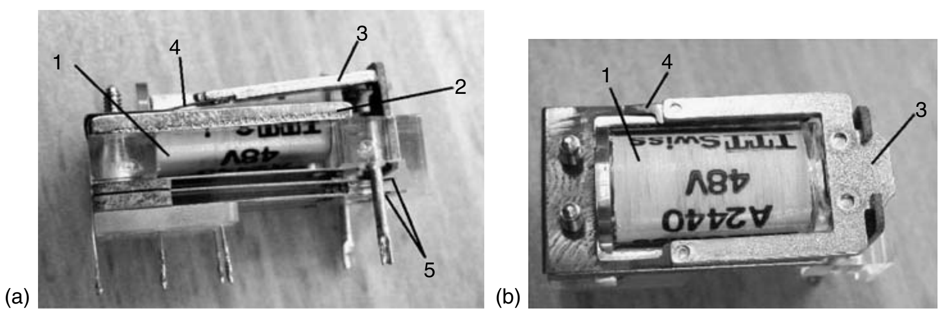


FIGURE 2.20
(a) Modern miniature A2440-type relay, (b) along with the original 52-year old design of the magnetic system. 1 — coil; 2 — Ш—shaped magnetic core; 3 — П-shaped armature; 4 — П-shaped spring linking the armature and the magnetic core; 5 — contact springs.

the firm ITT Swiss (Figure 2.20). At first sight it is difficult to recognize a construction with a 52-year history in this miniature device with a transparent plastic case whose size is 28 × 15 × 14 mm, but that is really so.

Some types of magnetic systems are rather sensitive to their position. Relays with unbalanced and heavy armatures without a restoring spring may not work properly when incorrectly located in space. Among these are, for example, RPN-type relays,

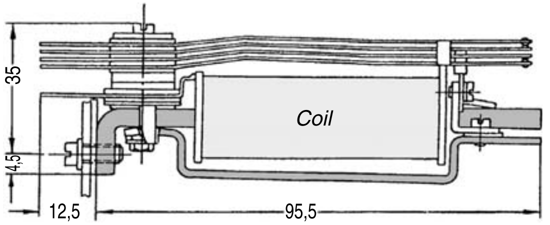


FIGURE 2.21
RPN-type relay.

which used to be quite popular with their analogs, produced for a long time in many different countries (Figure 2.21).

First, such relays can be used only in stationary equipment and second, they should be specifically located in space. For example, RPN-type relays should be located vertically. Some modern relays, especially relays with magnetic systems of alternating current, also have that same disadvantage, for example, popular relays of the DIL EM type, produced by the Klockner Moeller Company, have a forbidden position when the armature is located vertically at the bottom (Figure 2.22). This forbidden position is intentionally marked on the box (Figure 2.23). But then most people are reluctant to read instructions on boxes when dealing with such a ''simple'' and well-known device as a relay. If assembled incorrectly,

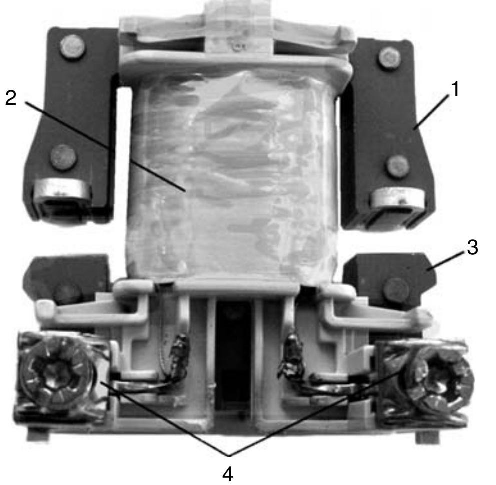


FIGURE 2.22
Ш-shaped magnetic system with a retractable armature of a DIL EM-type relay. 1 — stationary part of the magnetic core; 2 — coil; 3 — retractable armature; 4 — outlets of the coil (A1, A2).

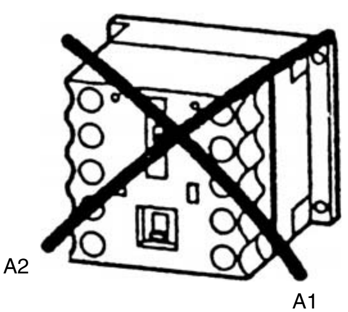


FIGURE 2.23
Notice on box warning of forbidden position when assembling a DIL EM-type relay.

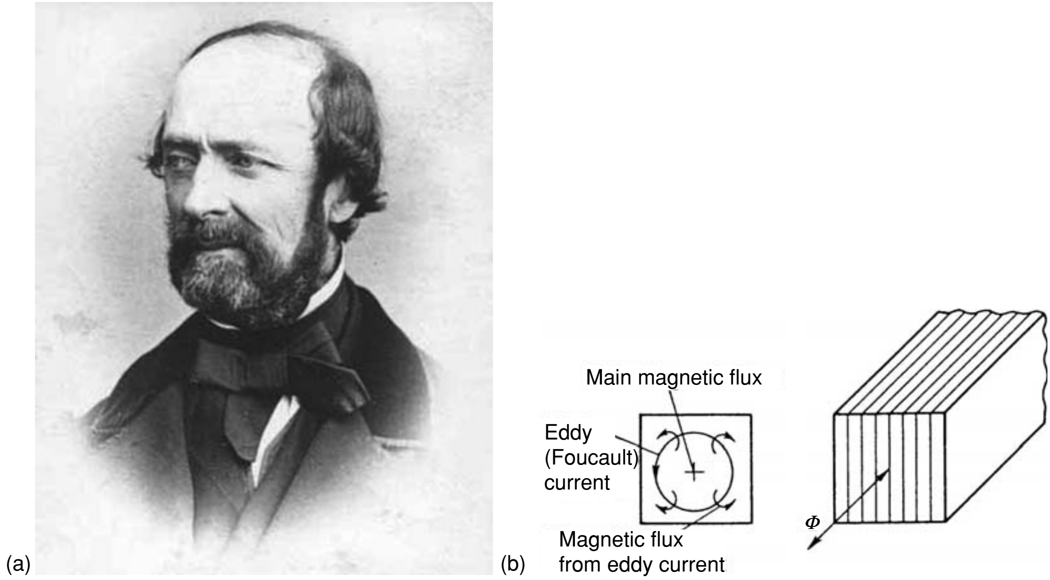


FIGURE 2.24
(a) Foucault Jean-Bernard-Léon; (b) eddy currents in an AC magnetic core.

the relay is not energized at all when switched on (the electromagnetic force created by the winding is not enough to lift the heavy armature located in the extreme bottom position of the magnetic system, with a big air-gap). It starts to chatter, or is not energized at all. If left switched on in that situation its winding will quickly burn down. The author himself experienced such an incident when such an automation system suddenly broke down, although it had worked properly for many years. Analysis of the reason for the malfunction showed that the relay had been improperly located. It was rather difficult to convince colleagues to believe it because the system had worked properly for a few years. This could be explained by the fact that at the initial stage of operation the relay was clean and friction between movable units weak. The relay became energized even in the incorrect position because its magnetic system was constructed with some reserve. When that reserve was overcome by growing friction, the relay malfunctioned. This was easily proven by the fact that when the malfunctioning relay was rotated 180°, the automation system started working properly again. Unfortunately we often hear people talking about bad relays, but not about bad engineers constructing automation systems without taking into account those peculiarities of the relay.

2.4 Differences between AC and DC Relays

It is well known that magnetic cores of any AC devices are laminated, that is, they are assembled from separate slim plates with a specific coating of high resistance. That is why *eddy currents* or *Foucault currents* (Foucault Jean-Bernard-Léon — French scientist, Figure 2.24), producing additional heating of the magnetic core, have small value.

FIGURE 2.25
Core with slits.

In constructions of existing relays, one can observe quite a strange phenomenon: some AC relays have solid magnetic cores (for instance, MKU-48-type relay) and other DC relays, quite on the contrary, have laminated ones.

In the first case, in order to reduce the price of such relays additional heating from eddy currents is simply neglected. Such an approach is used in relatively small constructions with a small section of the magnetic core (for instance, in the MKU-48-type relay mentioned above the magnetic core is made of pressed iron about 4 mm thick. It is only natural that they failed to take on the additional cost of a laminated magnetic core).

In the second case, a laminated magnetic core is used in large constructions of DC relays in order to boost the speed of operation. During the transient process of switching large relays on and off, the magnetic flux in the magnetic core, changing rapidly as it does in AC relays, can cause eddy currents to appear. The point of the laminated core is to prevent that. Of course this process is time-bound so the eddy currents will not produce considerable heating. The problem is in another area here. Eddy currents weaken the main magnetic flux and enlarge the make delay and release time of the relay.

In DC relays with a massive round core, which is difficult to laminate, the core is sometimes simply cut up (Figure 2.25). We can almost always see a copper turn (ring) on the pole of the laminated magnetic core of AC relays, and two similar turns on boundary rods on Ш-shaped magnetic cores (Figure 2.26c).

Calculations show that area covered by the ring should constitute 0.7 to 0.85 of the total area of the pole. That proportion typifies correctly designed relays, but sometimes one can also come across simplified constructions with a ring covering the half of the pole. Such a ring, covering part of the area of the pole, indicates that such a relay is meant for alternating current. Sinusoidal alternating current in the winding of a relay, $I_m \sin(\omega t + t)$, produces a magnetic flux, $\Phi_m \sin \omega t$, lagging from the current by the angle φ_m affected by the eddy currents (see Figure 2.27).

Magnetic flux of alternating current produces an electromagnetic force F_m fluctuating at double frequency that can take on only positive values, from zero to its maximum, even at the negative sign of the magnetic flux. At the same time a permanent counterforce of the restoring spring F_S affects the armature of the relay. When the fluctuating electromagnetic force is weaker than the counterforce of the restoring spring, the armature of the relay loses contact with the pole of the magnetic core, and is pulled back when the level of the electromagnetic force is restored (a deenergized armature is in the interval A–A). Thus, vibration will appear in the armature of an AC relay.

In a magnetic system with a shading ring the main flux Φ_0 branches out to two fluxes Φ_1 and Φ_2. The flux Φ_2 passing through the ring produces current which in turn produces its own magnetic flux Φ_r lagging by one phase from the main flux. Thus the total magnetic flux $\Phi_\Sigma = \Phi_2 + \Phi_r$ will pass through that part of the pole covered by the ring. Throughout the covered part of the pole, and the uncovered one, these fluxes produce the electromagnetic forces F_1 and F_2 (see Figure 2.28), each joined to the other by a specific angle.

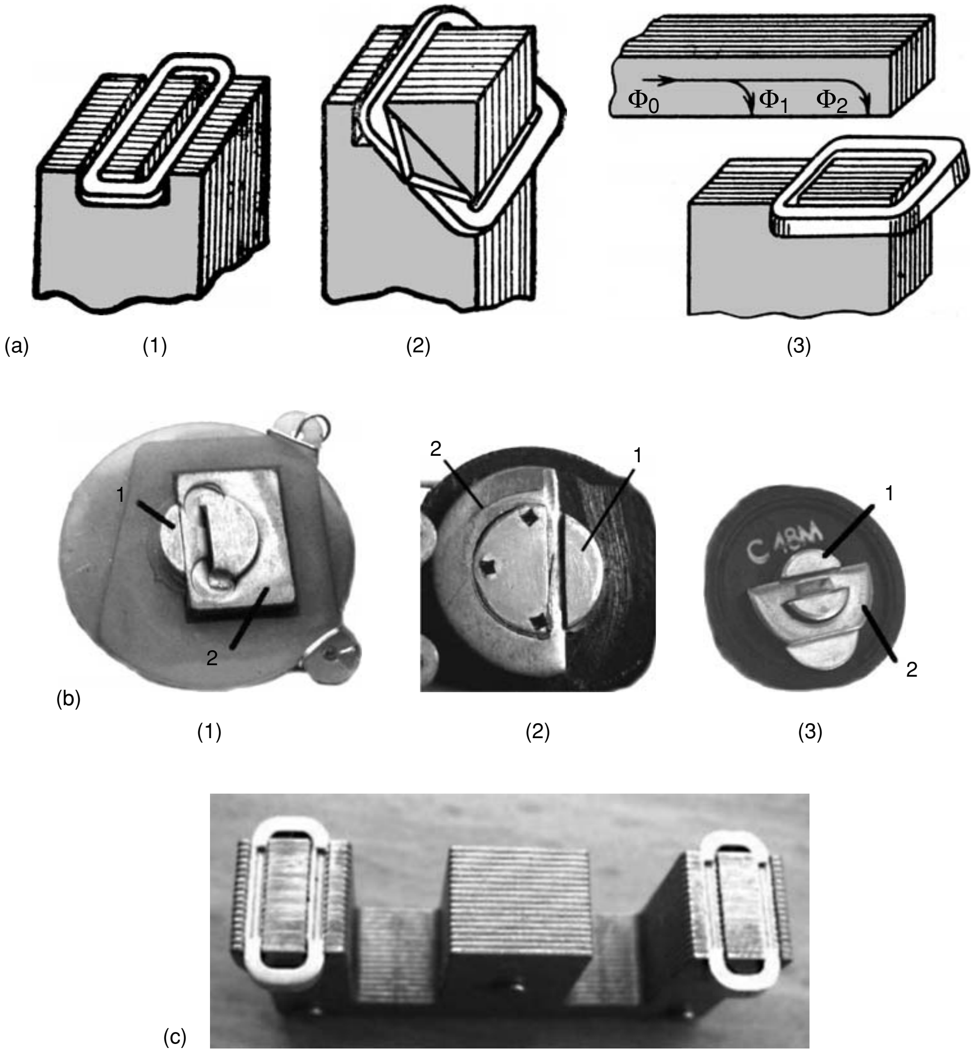


FIGURE 2.26
(a) Types of shading rings on the pole of the laminated magnetic core of an AC relay. (b) External design of shading rings of different form. 1 — pole of the core; 2 — shading ring; (c) Ш-shaped magnetic core with two shading rings.

Obviously, that angle can be no more than 90°. The lower the pure resistance of the turn (it is usually pressed in the form of a ring of tough-pitch copper), and the closer the proportion between that part of the pole uncovered by the ring and the covered one, to the optimal value 0.7 to 0.85, the less the lagging from this angle will be. In these cases the total electromagnetic force F_{Σ} fluctuates not from zero, as in a magnetic core without a ring, but from a certain minimum value F_0 up to the maximum one F_m (Figure 2.28). If the ring is installed properly, F_0 will always be greater than the counterforce of the spring, and the armature of the relay will not fall away. However, one should bear in mind

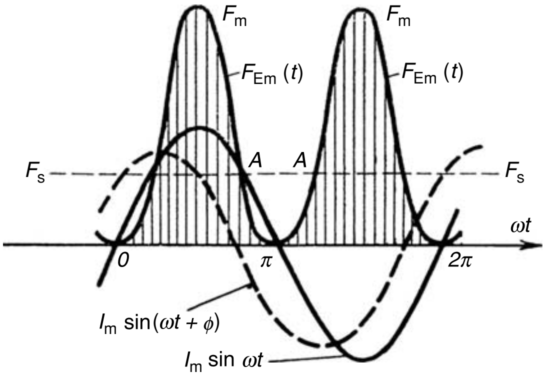


FIGURE 2.27
Fluctuations of magnetic flux and electromagnetic force in the magnetic system of an AC relay.

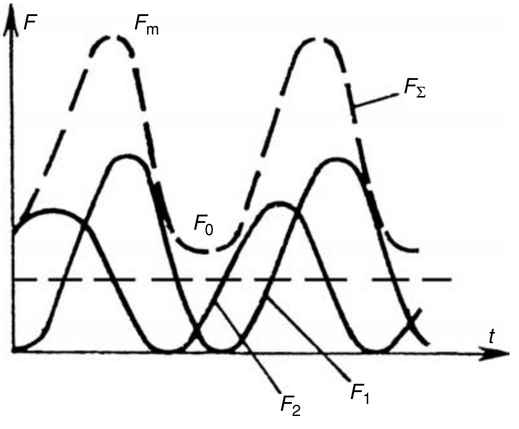


FIGURE 2.28
Electromagnetic forces in magnetic systems of relay with a shading ring.

that the use of a shading ring may lead to a certain attenuation of the average value of the electromagnetic force. This fact must be taken into consideration because due to the sinusoidal character of the changes in the current the average value of the electromagnetic force in an AC relay will be half as much as that in a DC relay, other conditions being equal.

2.5. Some Auxiliary Elements Improving the Relay Operation

In some *DC relays*, like the popular MKU-48-type relay, one may come across *a shading ring on the pole, made of electric steel*. Several questions emerge here. First, what is the purpose of such a ring in a DC relay? Second, since the resistance of steel is greater than that of copper, the effectiveness of the surge control of a magnetic flux with the assistance of such a ring will be less than if a copper ring were used, but what then is the effect of the use of such a ring?

You may have guessed that this ring has nothing to do with surge control of altering current, and if you guessed this, you are right! The point is that the core and the magnetic

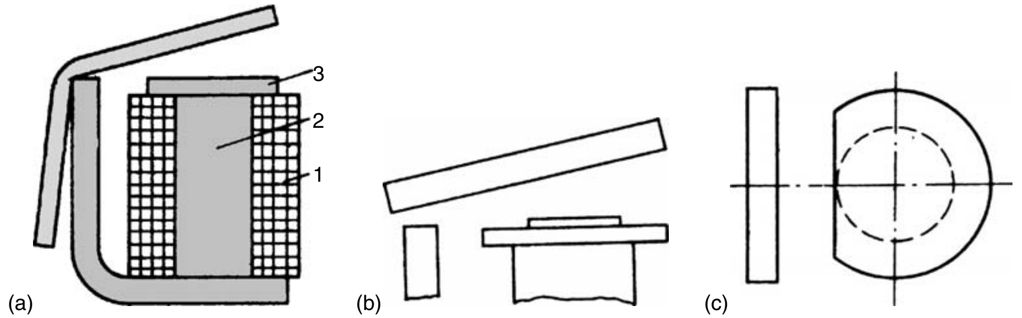


FIGURE 2.29
(a) Construction of the pole of a core. 1 — winding; 2 — core; 3 — pole packing; (b) lug on the pole packing; (c) notch on the pole packing.

core of the MKU-48-type relay are made of one piece of steel duly pressed and curved. Such a construction makes it difficult to create a pole lug, reinforcing the electromagnetic force of attraction of the armature. On the other hand there is already a notch for a copper shading ring at the end of the core of an AC relay, so that one needs a die for the production of copper rings and a press for molding these rings onto the pole of the core.

It occurred to some design engineers that one can already use existing equipment and technology to produce a pole lug. All that is needed to be done is to replace the copper with electric steel. This approach was applied in the production of the MKU-48-type relays.

Another component typifying a magnetic system whose purpose is not immediately obvious is a thin-walled copper tube placed directly on the core along the full length, between the core and the winding in some constructions of large relays. Such tubes are approximately 1.2 mm thick (sometimes these are separate shorted-circuit windings) enabling reduction of inductance 5 to 10 times more when a relay is supplied by alternating current of higher frequency (400 to 1000 Hz). This reduction of inductance increases relay performance and facilitates the switching conditions of the winding, along with other switching devices. The pole of the core is usually supplied by a lug (Figure 2.29), which increases magnetic flux in the gap, and increases pulling power as well.

Increased diameter of the core end (because of the pole lug) leads to an increase in tractive effort, and at the same time to contraction of the gap between the opposite polar elements of the magnetic system (that increase of leakage flux). That is why there is an optimal diameter of pole lug for each particular construction of relays (Figure 2.30). To weaken the negative effect caused by this increase of leakage flux, the edge of the pole lug is cut off.

In many relays, a nonmagnetic layer made of thin lamina is fixed to the end of the core touching the movable armature. As this layer is often transparent, sometimes it can only be found when the relay is taken to pieces. Sometimes instead of a layer a hole is drilled in the center of the armature, into which a thin copper pin, sticking out a bit from the armature, is molded. This too may be hard to notice as well.

The function of that small nonmagnetic component is the opposite of the function of the lug on the pole packing. It slightly weakens the main magnetic flux but also reduces the time for the drop out of the armature when the winding is deenergized. In small relays with a weak restoring spring, this will also prevent sticking of the relay due to residual magnetization of elements of the magnetic circuit.

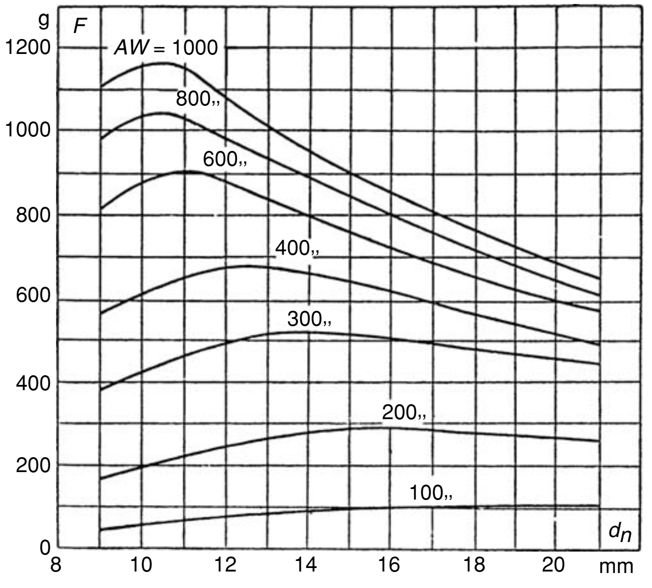


FIGURE 2.30
Curves illustrating the dependence of tractive effort of an RKN-type relay (in grams) from the diameter of the pole packing, with different ampere-turns of the winding (AW = 100–1000).

2.6. What Happens When a Relay is Energized

When a relay is energized one can observe some interesting variations of current in its winding (Figure 2.31). Just after the winding of a relay is connected to a power source the current increases according to the pattern of the 0–*a* curve, according to the exponential law as in a circuit with inductance. One may then observe a slight decrease of current on the interval *a*–*b* after which the current continues to increase until it reaches the steady-state value, but along another curve *b*–*c*. All of this becomes increasingly clear when one

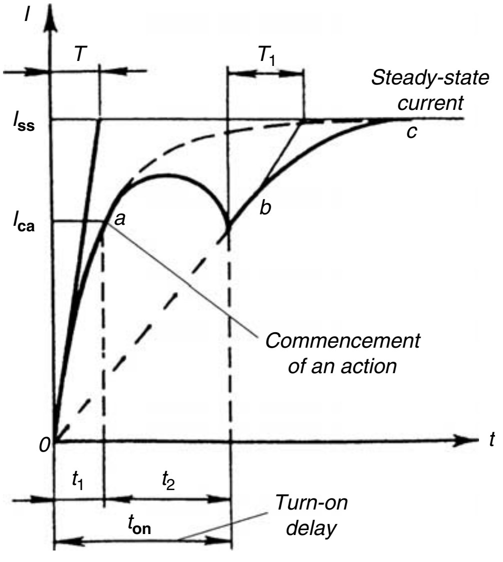


FIGURE 2.31
Current variation in the winding of a relay, when connected to a DC circuit.

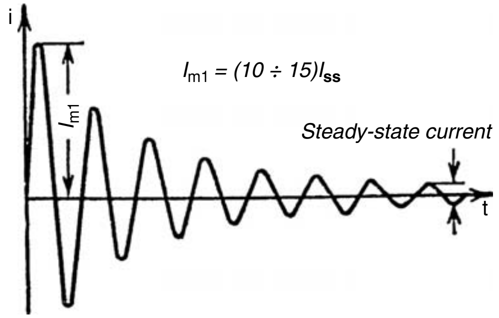


FIGURE 2.32
Transient process of switching on an AC relay.

takes into account the fact that during the energizing of a relay the inductance of the winding does not remain stable, but changes drastically as the armature is attracted to the core. If we place a nonmagnetic stopper between the armature and the core, preventing movements of the armature, and then switch the relay on, the current in the winding will vary according to the pattern of the 0–*a*–*c* curve which corresponds to the magnetic system with small inductivity and a rapid time constant T. If we press the armature against the core and then switch on the relay, the current will vary according to the pattern of the 0–*b*–*c* curve, corresponding to the magnetic system with greater inductance and a greater time constant T_1. When a relay is energized naturally the change from one curve pattern to the other is automatic which is why the current curve may look so strange. Figure 2.31 illustrates that the make delay of a relay t_{on} consists of two constituents t_1 and t_2. The first, $t_{1,}$ is the current-rise time in the inductive circuit (winding), up to the value at which the electromagnetic force becomes greater than the counterforce of the spring, and the armature begins to move towards the core (I_{CA} is the pickup current) and the second, $t_{2,}$ is the time of motion of the armature. This second constituent is also called the *travel time* of the armature. At point ''*b*'' the relay has already been energized and further current rise in the process of winding up to the steady-state value will not tell on the relay. Here a question may arise: If the relay has already been energized why does the current in the winding continue to rise, if it leads to further heating of the winding and increases electrical energy consumption, etc. Could it be that such relay was improperly designed and that point ''*c*'' should have been located on *the curve, much closer to the points ''a'' and ''b?''*

In fact the nominal voltage (current) of a relay will always be greater than its pickup voltage (current) because of the following three factors:

First, we must take into account the technological diversity of the values existing in relay production. It is almost impossible to tell the exact operating value. For example, for the same construction of a relay with a nominal voltage of 12 V, actual pickup voltage value may vary in the range of 6 to 9 V. The relay will always work at the 12 V mentioned in the specification, and will save a lot of trouble for its manufacturer.

Second, differences in characteristics of relays may emerge in the course of their operation: adjustment changes and sometimes new gaps in the magnetic system of the relay may appear.

Third, the relative height of the nominal voltage, compared with the actual pickup voltage, enables enhancement of the reliability of the relay operation. Just imagine that you have a relay of an unknown type and you want it to be energized from a power source of 6 V. A simple experiment will show that the relay is energized at 5.8 V. Is not that great? Now try to imagine that for some reason (and there can be really dozens of reasons) the power source voltage goes down by just 0.3 V. This is enough to prevent the relay from being energized. That same situation will occur if the temperature goes up in the course of its usual operation. Then, resistance of the winding and a voltage of 6 V may not be enough for the relay to be energized. Imagine how resistance of the winding will change in real conditions of exploitation of a relay in the standard range of temperatures varying from −20 to +40 °C (not to mention the military standard, which is −60 to +85 °C).

Fourth, an increase of voltage imposed on a relay above and beyond its operational voltage may considerably reduce the actuation time of the relay (that is, it enhances the operating speed of the relay). All this must be taken into account when relays are designed. There is a special coefficient called the ''safety factor for pick-up'' which characterizes the ratio of nominal values of a relay (current, voltage) to its actual pickup values. Usually this factor varies in the range of 1.2 to 1.8.

When an AC relay is energized one can observe a damping aperiodic process (see Figure 2.32), characterized by a strong initial current (the armature is not attracted and impedance of the winding is low) exceeding the steady-state value by 10 to 15 times. Because of this peculiarity of an AC relay, the operational mode of such a relay is almost optimal: at large gaps, with the great magnetic resistance of the magnetic circuit (low winding inductance and impedance), the winding produces a great electromagnetic force when the relay is energized (because of the great initial current). After that (when gap is zero and magnetic circuit closed) there is no need for such a great current and electromagnetic force. The winding automatically reduces it because its inductance (impedance) is high in this position.

Such operational mode enhances the operating speed of the relay (the so-called *self-forcing*) and provides the possibility of extension of a specific gap, but frequent switching on may lead to overheating of the winding by strong starting currents, and if the armature sticks in the initial or intermediate position the winding may quickly burn down.

It is clear even from speculative reasoning that the voltage (current) at which the armature of a relay is attracted to the core will always be a bit stronger than voltage (current) needed for its retention, let alone the voltage at which the armature falls off from the core. The ratio of dropout value to operating value is called the *release factor of relay*. The value of this factor is always less than 1 and can fluctuate in the range of 0.1 to 0.99 for real relay constructions. The less this release factor is, the more stable and effective the function of the relay is; however, this cannot be applied to measuring relays. In such relays, which are energized at predetermined values of current and voltage, the release factor is frequently very high, depending on the design values of the relays and the

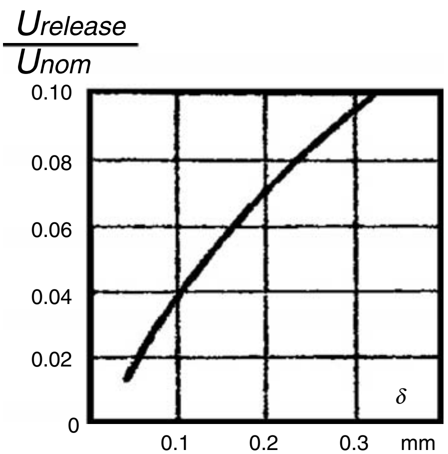


FIGURE 2.33
Typical dependence of the release factor from the value of the terminal nonmagnetic gap remaining in the magnetic system, after the relay has been energized.

character of the input value. The release factor of AC relays is usually higher than that of DC relays because two times a period ripple of magnetic flux creates conditions for easier separation of the armature from the core. Changes in the release factor in particular constructions of relays may be caused by modification of the terminal gap in the magnetic system (Figure 2.33 — thickness of nonmagnetic layer between the armature and the core, see above) or change of the restoring spring force.

There are also circuit means of increasing release factors of relays (Figure 2.34). After it has been energized one can connect in series, or parallel to the winding, an additional resistor or a semiconductor element with nonlinear voltage–current characteristics (a Zener diode, for instance) which rapidly changes its conductivity at the relay energizing point.

2.7 Windings of Relays: Types and Design Features

One of the most important elements of a magnetic system is winding. It is made in the form of a coil wound around with wire 0.02–2 mm in diameter (for power relays and contactors the diameter may be even larger). In the 1940–60's they mostly used wire with textile and silk insulation, in spite of their hygroscopic and a greater diameter. It was a forced measure because varnish of that time did not have enough mechanical strength especially on wire of greater diameter. At present, windings of relays are wound with wire with enamel or glass insulation. The latter has far better electric characteristics, not involving gas while being heated (which is essential for vacuum-processed relays), but it is more expensive.

In the course of operation of a relay, electromagnetic forces of interaction between turns and current cause mechanical stress in the coil, and heating and cooling of the coil causes thermal stress. Electric operating voltage is applied between turns of the coil, between the layers of winding, and also between the coil and the core. In transient processes of switching one must also deal with over voltage. Coils of relays can be affected by numerous negative environmental factors such as increased humidity of the atmosphere, salt spray, dew, mould, etc. The design of the coil should provide for safe performance of the relay under such circumstances.

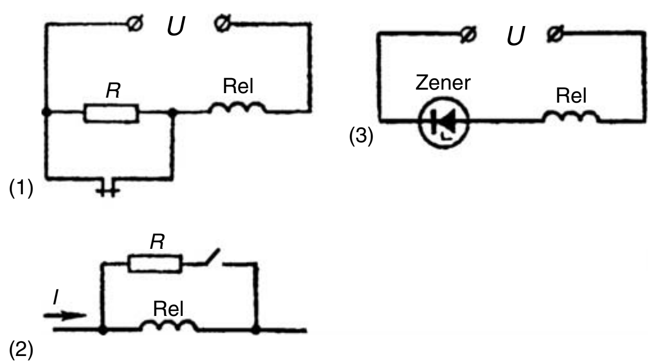


FIGURE 2.34
Circuit means of increasing release factor of relay. Variants 1 and 2 can be applied to AC and DC relays. Variant 3 is only for DC relay;

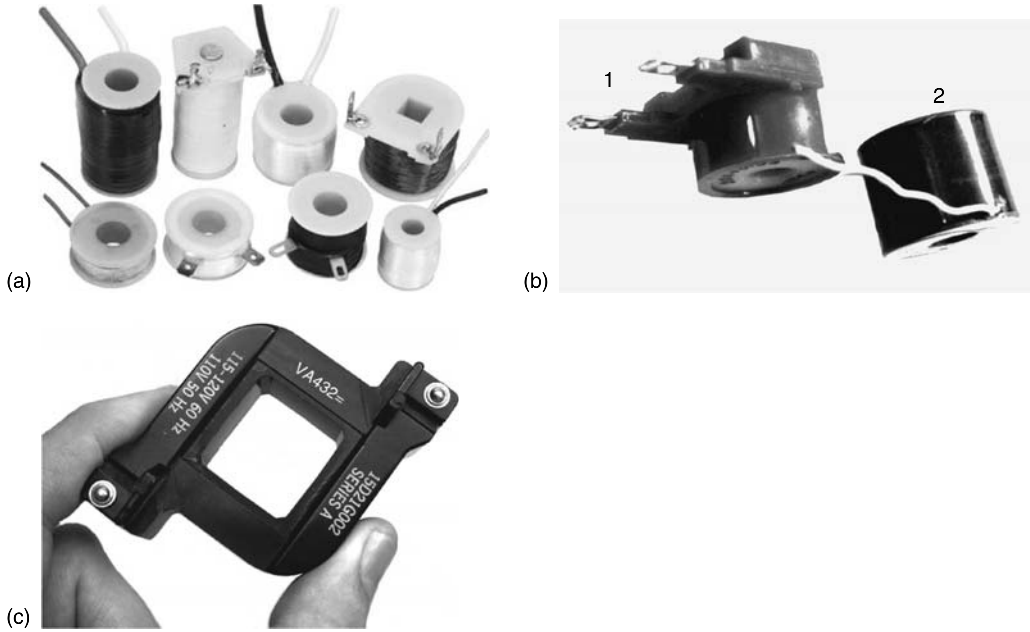


FIGURE 2.35
Constructions of coils of relays: (a) unimpregnated coils covered by protective film; (b) encapsulated coils (1 — coil molded with plastic; 2 — coil encapsulated by epoxide resin); (c) rectangular shape coil molded with plastic.

Coils can be bobbin and free-bobbin. In bobbin coils the winding is wound around a bobbin (made of insulating material or of metal with insulating lacquer). In free-bobbin coils, the wire is wound directly around the core of the magnetic system. In the past, in bobbin coils, paper impregnated with varnish and cardboard was widely used as a bobbin, but now it is usually replaced with plastic. Free-bobbin coils are rarely used in modern relays.

Depending on function and service conditions coils may also be covered by protective film and varnish, or impregnated with varnish or epoxy encapsulant (Figure 2.35). As the coils are encapsulated by epoxide resin, vacuum and increased pressure alternately affects them. This enables removal of unnecessary air bubbles from the winding and helps the encapsulant pervade between the turns of the coil. For impregnation epoxy encapsulant with low viscosity (for example, STYCAST 2651–40 type) is normally used. It is obvious that encapsulated coils provide better reliability of relays than unimpregnated ones, but they also increase the cost of the relay.

Coils may be square or round-shaped (in section) and very different in size (see Figure 2.35). There are special methods for optimal designing of relays, establishing

FIGURE 2.36
Elongated coil of a highly sensitive clapper armature relay with winding, containing 93,000 turns of wire with a diameter of 0.04 mm (resistance of 40 kΩ).

certain proportions between geometric sizes of coils. Obviously, it is impossible to endlessly increase the electromagnetic force of the coil with a core of small diameter by multiplying the number of turns of the coil (i.e., by increasing the external diameter of the coil or its length), because the core will quickly reach the saturation mode. In this case, further strengthening of the magnetic flux will not lead to strengthening of the electromagnetic effort of attraction of the armature to the end of this core; however, in some cases, when it is necessary to fulfill high requirements for relay sensitivity (i.e., in case of extremely small current in the coil) such a small working current must be compensated by considerable multiplication of turns.

Multiplication of layers of winding will not lead to considerable increase of sensitivity of a relay, because each following layer will be farther from the core than the previous one and its effect will be weaker than that of the previous layer. That is why in this case, the coils usually ''grow'' lengthwise and not in width (Figure 2.36).

The number of turns of a coil can be limited not only by the size of the bobbin, but also by a number of technical values characterized by *coil fill factor K1, coil correction factor K2, and winding fill factor K3.*

The coil fill factor is the ratio of copper section of the coil to the entire section of the coil. This factor depends on the type of winding, on the thickness and form of the bobbin of the coil, and on the thickness of the wire insulation (also on the form of wire section which is usually round for relays).

The coil correction factor is determined by the type of the winding of a coil with different winding densities. There can be the following types of winding:

- *Layer winding*: when turns of the same layer are placed densely to each other and turns of a higher layer are placed just above the turns of a lower layer (Figure 2.37)
- *Quincunx winding*: when turns of a higher layer are placed in gaps between turns of a lower layer
- *Pile winding*: when turns are placed without any specific order, in layers

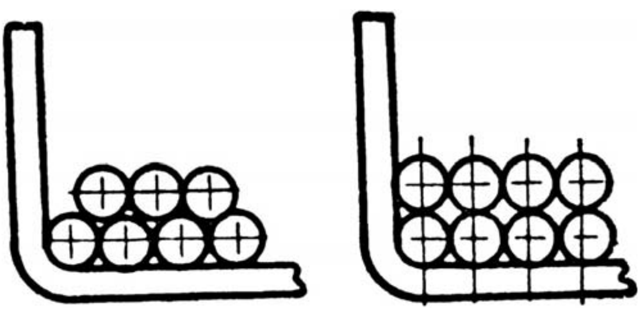


FIGURE 2.37
''Quincunx'' and ''layer'' winding of coils.

FIGURE 2.38
Laying of winding wire without spacers and with a dielectric spacer of thickness δ between layers.

Quincunx winding enables us to obtain the maximum value of coil correction factor (16% more than layer winding); however, it is rarely used because of difficulties of automatic winding for thin wire.

The winding fill factor is taken into account because in some types of power relays (though very rarely) dielectric spacers are used between some layers of winding (Figure 2.38).

In the course of operation of a relay, its coil is heated by the Joule effect of current passing through copper wire, and due to other reasons mentioned below. Since the coil of a relay is a heterogeneous body consisting of materials with different thermal conduction: copper, varnish, plastic, and air layers, it is only natural that there will be different temperatures in different layers of the coil. The more monolithic the coil, the less the differential temperature will be between the outer surface and the internal layers (Figure 2.39).

Impregnation and compounding increase total thermal conductivity of the coil, thus increasing its heat emission by 5 to 10%.

Distribution patterns of temperature in coils of AC and DC relays are different. This is because the iron core in a DC relay where the coil is placed plays the part of a heat sink, bringing down the temperature of the adjoining layer of winding. In an AC relay, the core is a source of heat emerging due to the action of eddy currents (see above). That is why while constructing a DC relay an effort is usually made to try to reduce thermal resistance (or intensify thermal contact) between the winding and the core, and in fact on the contrary, to insulate the winding from the core for AC relays.

According to experimental data for mid-sized relays, an air gap of 0.25 mm on the side between the bobbin of the coil and the core reduces heat transfer of the coil by

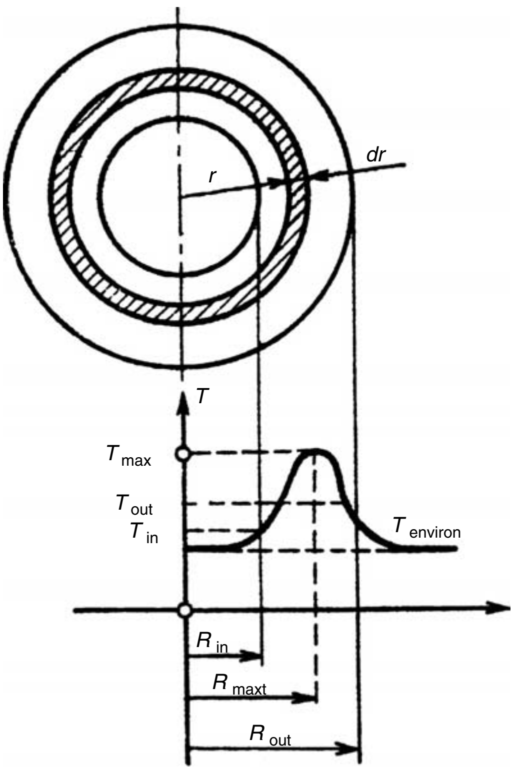


FIGURE 2.39
Radial distribution of temperature in winding of a DC relay. R_{in} — inner radius of the coil; R_{out} —, outer radius of the coil; R_{maxt} — zone of maximum heat; T_{max} — maximum heat temperature; T_{out} — temperature of the outer surface of the coil; T_{in} — temperature of the inner surface of the coil (adjoining to the core); $T_{environ}$ — ambient temperature.

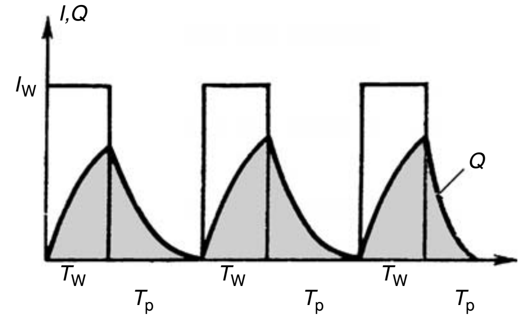


FIGURE 2.40
Diagram illustrating variations of temperature of the coil (Q) in the short-term mode when working current is passing through it. T_w — working time; T_P — pause time.

approximately 8%, and a gap of 0.5 mm — by 11%. A free-bobbin coil with direct winding on the core increases heat transfer by 10%. Maximum temperature of coil heating is limited mostly by the thermal endurance of the winding wire. Long-term effects of increased temperature may result in its rapid deterioration and decay. There are several classes of thermal-life characteristics of insulating materials (Table 2.1):

For copper winding wire insulating varnish and enamel corresponding to the classes A, B, and F is used. If high-temperature winding wire is employed, one also uses bobbins from heat-resistant plastic of the corresponding class, and the outer outlets of the coil are made of wire with Teflon insulation.

The heating of coils depends directly on the operational mode of the relay. One can distinguish the following modes of operation:

TABLE 2.1
Classes of Thermal-Life Characteristics of Insulating Materials

Classes of Thermal-Life Characteristics	Temperature Characterizing the Given Class, t (°C)	Materials Corresponding to the Given Class
Y	90	Unimpregnated fibrous materials made from cellulose and silk, and certain types of plastic: polyethylene, perspex (polyacrylate), polyurethane foam, and some others)
A	105	Impregnated fibrous materials from cellulose and silk or some types of plastic, varnish, enamel immersed into liquid dielectric material (transformer oil, for instance)
E	120	Some organic polyethylene films, plastic (polypropylene), and others
B	130	Materials based on mica, asbestos, glass fiber used with organic cohesive and impregnating encapsulate, varnish, enamel, plastics (glass fiber laminate, polystyrene, polycarbonate, etc.)
F	155	Materials based on mica, asbestos, glass fiber used with organic cohesive and impregnating encapsulate, varnish, enamel, and some brands of Teflon (polytetra-fluoroethylene)
H	180	Materials based on mica, asbestos, glass fiber used with organic-silicon cohesive and impregnating encapsulates, organic-silicon elastomer, poliarylate, polysulphone, etc.
C	>180	Mica, ceramic solids, glass, quartz, Teflon, polyamides, polyphenylene

- *Long-term mode:* when winding is under current for a long period of time
- *Short-term mode:* when winding is switched on for the period until its temperature reaches a steady-state value (this usually happens in a matter of seconds), and the pause between repeated switching is so long that temperature of the winding has time to come down to the ambient temperature (Figure 2.40)
- *Intermittent (cyclic) mode:* when performance periods of winding under current alternate repeatedly, with periods of silent state of the coil.

The latter mode is very popular and quite typical of relays used in technological automation and control systems.

For quantitative characteristics of such a mode we use the value called *''duty cycle.''* It is a ratio of duration of the ''on'' state to duration of the whole cycle. Sometimes in technical literature it is given in terms of percentage.

On the face of it the first (long-term) operation mode of a relay may seem the most difficult and the two others easier, but in practice this is not always so. It depends on the value of the duty cycle and the ambient temperature. If the duty cycle is more than 50% this means that the coil is in the on state for a longer period of time than it in the off state.

Depending on thermal balance in a particular construction of a relay, such conditions can be created that the total temperature of the winding will increase with each following cycle, and eventually the temperature of the winding will reach a steady-state value (Figure 2.41).

If we take into account the fact that the transient process of switching on an AC relay will be accompanied by great starting currents (see above), frequent switching of the relay may make the short-term mode even more difficult than the long-term is.

The heating of insulating materials may accelerate their deterioration, causing mechanical decay and electric breakdown. For example, according to M. Vitenberg an RES-6-type relay already has frequent breakdowns after 350 h of operation at a temperature of +85 °C and within 700 h 50% of such relays go out of order. That is why industrial relays are designed in such a way that temperature of the winding does not exceed normally ambient temperatures by more than 15 to 20 °C. In some cases, however, while constructing miniature relays it may be necessary to provide the desired value of electromagnetic effort of the armature for small-sized coils and lightweight relays. In such cases the manufacturer has nothing else to do but increase current density in the winding wire of the coil, in other words to let the big current pass through a small coil wound around by thin wire. In modern miniature hermetically sealed relays for military applications winding temperature may reach as much as to 180 to 200 °C. Usually such relays are not designed for long-term

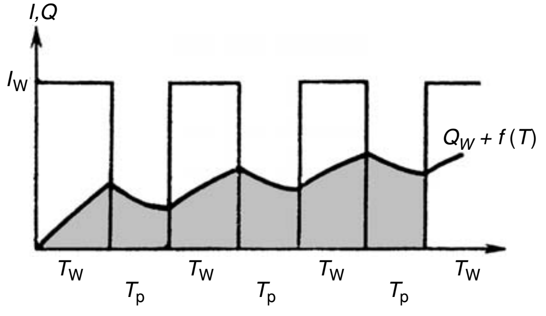


FIGURE 2.41
Diagram illustrating variations of temperature of the winding (Q) in the short-term mode when working current is passing through it. T_w — working time; T_p — pause time.

energization, and are used in on-board systems of single-mission weapons such as missiles, torpedoes, etc.

When browsing through specifications of such relays (only for relays produced in Russia) one may come across a value called ''continuous (or *total*) time of a relay under working voltage (current) at working ambient temperature.'' For some types of light-weight miniature hermetic relays this time may only be some hundreds of hours. Unfortunately, most of the western relay manufacturers do not usually mark this parameter in their catalogs.

3

Contact Systems

3.1 Designs of Basic Types of Contacts

A contact system is the second essential component of any relay. Usually it consists of several elements (Figure 3.1). Current-conducting elements are made of elastic materials (as a rule, beryllium bronze or phosphor bronze) providing not only current supply to contacting surfaces but also the necessary contact pressure. Contact straps (which are actually contacts) are made of materials of high electric conductivity and resistance to electric erosion. They are riveted, soldered, or welded on by silver solder to current-conducting springs. Contact straps are usually made in the form of rivets or pins (Figure 3.2). Riveted attachment of contact straps is less reliable than welded attachment, because of the considerable increase in transient resistance of a rivet at the point of its joint to the contact spring, caused by heat cycling in course of its exploitation. Such straps, which are often bimetallic (two-layer), consist of a copper base and contact material, an alloy based on silver. Bimetallic contacts of a relay were invented long time ago.

Strange as it may seem, it was radio engineering that made the greatest contribution to the creation of powerful bimetallic contacts resistant to an arc. This field of technology is usually associated in our minds with miniature electronic elements or radio sets. It may seem that radio engineering as a wireless communication facility must have replaced a telegraph with its posts, wire, and sounders and in the long run put an end to wide use of relays in telecommunication systems, but the point is that early radio communication systems differed greatly from those we are familiar with today. Remember, the first radio set was a ''storm indicator,'' that is, a device registering electric strikes of lightning, but in order to establish radio contact it is necessary to have not only a radio set, but also a radio-transmitter, and what can replace lightning? The answer is obvious: an electric spark, which may be regarded as miniature lightning.

Indeed, an electric spark turned out to be a source of electromagnetic radiation in a wide range of frequencies, including high frequencies, which are quickly spread over

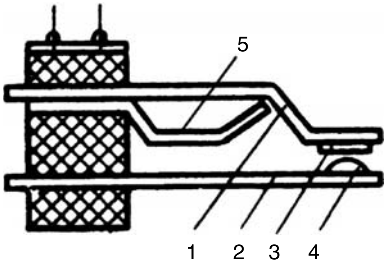


FIGURE 3.1
Popular types of relay contact systems. 1,2, — current-conducting elements; 3,4 — contact straps; 5 — stop.

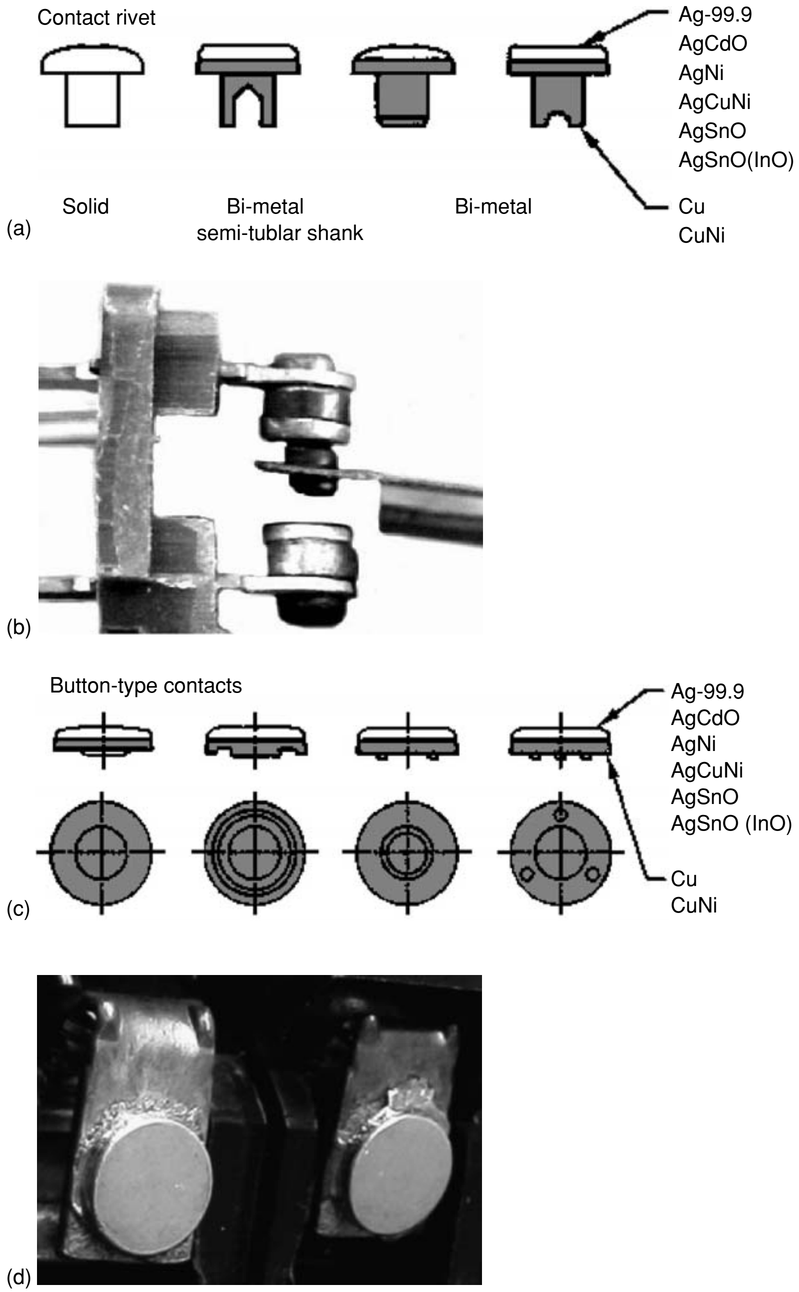


FIGURE 3.2
(a) Rivet-type contact straps; (b) rivet-type contact straps in an actual relay; (c) button-type contact straps; (d) button-type welded contact straps in an actual power relay.

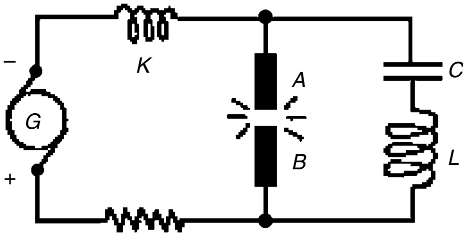


FIGURE 3.3
An oscillatory circuit with an arc is a power source of radio waves.

long distances. A continuous pulsating arc strikes an electric circuit consisting of a coil, a capacitor, active resistance, an DC power source, and two carbon electrodes (Figure 3.3), and is a power source of radio waves.

The first development of the oscillating arc was done by the Danish scientist, Valdemar Poulsen. Australian born and Stanford educated Cyril Elwell came across Poulsen's experiments and at once realized their commercial potential. In 1909, with the support of investors, he founded Federal Telegraph in San Francisco, in order to commercially exploit arc technology.

One technical drawback of that type of arc transmitter was that it was impossible to connect a Morse key directly to the circuit of the electric arc in order to receive a controlled (modulated) radio-signal, because the arc ran continuously and it was impossible to switch high powers (tens and hundreds of kilowatts) by means of a manual switch.

Here a relay came in useful. Being connected to a DC source, its winding was also in series with a Morse key. Referring to the schematic, note that the arc, denoted by ''X,'' is switched by relay contacts, ''K,'' between the antenna circuit and the dummy load tuned to the same frequency as the antenna circuit (Figure 3.4).

In 1913 Elwell developed and demonstrated this technology to the US Navy. By 1921, 80% of all commercial and military transmitters were of the arc variety. The capacity of such transmitters was continuously growing and eventually reached one million watt

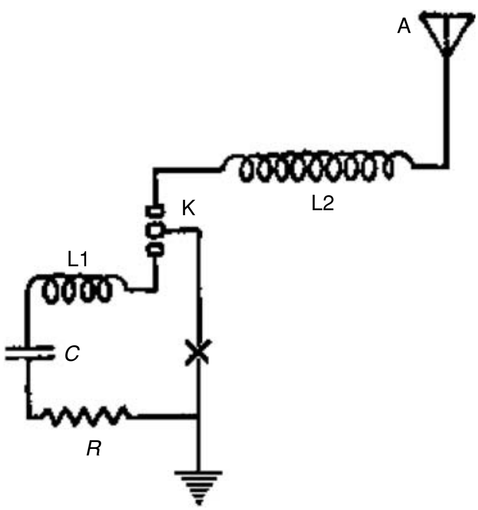


FIGURE 3.4
Schematic illustrating basic principles of operation of an arc transmitter of the early 19th century. X — arc; K — contacts of a modulator.

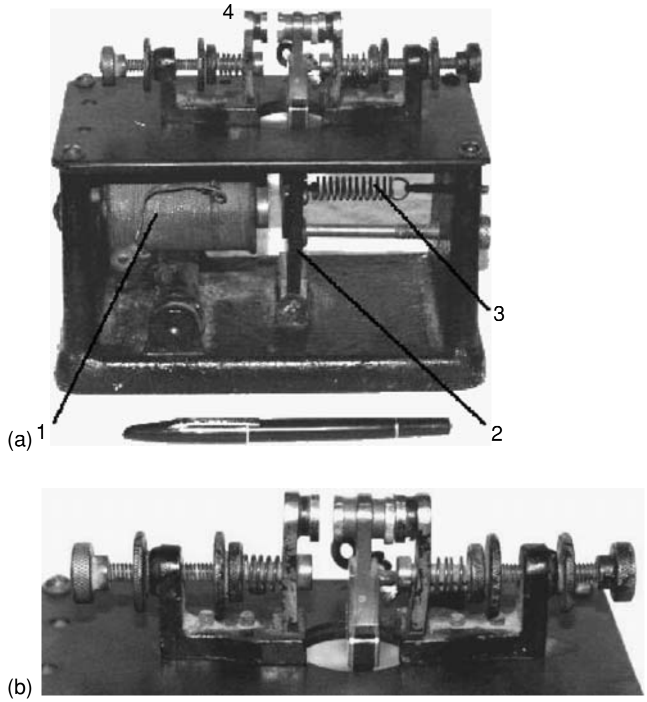


FIGURE 3.5
(a) A modulator relay for an arc transmitter control and its contact system. 1 — coil; 2 — armature; 3 — spring; 4 — contact system (increased magnified in (b)).

(a transmitter installed in Bordeaux, France). Obviously, to produce modulation arcs of such great power, relay transmitters must contain powerful wear-resistant contacts. As can be seen in photos and samples of relays of this type (not the most powerful ones) that have survived until today (Figure 3.5), such contacts consist of two layers of different metals and are quite wide in diameter (3/4 in.). Stationary contacts are supplied with spring-coupler dampers, extinguishing impact energy of a switching contact.

3.2 Silver, Gold, Platinum . . .

Silver (Ag) is the cheapest material used for this purpose. Due to its ductility, it is readily formed into various contact shapes. As a result of its high electrical and thermal conductivity, transient resistance of contacts is rather low. Silver's tendency to erode and be affected by arcing and its low hardness can be regarded as its main drawbacks. Sulfur-containing atmospheres will produce silver sulfide that increases contact resistance. That is why silver contacts are not recommended in constructions containing ebony, black rubber, or wire insulated with rubber, producing sulfuretted hydrogen (hydrogen sulfide) when heated. Silver contacts are used for switching of small and greater currents at low and medium voltages.

Platinum (Pt) has a quite high corrosion resistance, being much less prone to erosion in comparison with silver. In pure form it is low in hardness and therefore generally alloyed with other materials. Platinum–iridium alloy (PtIr) combines hardness with excellent resistance in the formation of arcs, and provides excellent performance in corrosive environments. It is widely used for low-power or average-power contacts.

Tungsten is a very hard and refractory material. It is resistant to mechanical wear and welding, but as a result of its tendency to form thick oxide surface films it also requires high contact forces. Its high resistance limits its area of application. Tungsten is usually used as an auxiliary contact in contact systems containing both main and auxiliary (arcing) contacts.

Silver–tungsten alloy (AgW) is hard, with high resistance to contact welding and a high melting temperature. Its drawbacks are a tendency to oxidation and elevated resistance.

Silver–nickel alloy (AgNi) possesses good arc extinguishing properties and low oxidation, as well as high electrical conductivity similar to silver; however, it tends to form sulfide surface films. It is widely used for average-power contacts.

Silver–copper alloy ($AgCu_3$) possesses high resistance to mechanical wear and a weaker tendency to welding when compared to silver. Contact resistance is higher than that of silver.

Silver–palladium (AgPd) has quite high corrosion and sulfitation resistance, and is not prone to contact welding. Among its drawbacks is a tendency to absorb organic gases and to form a polymeric surface film. To prevent this it should be overlaid with gold, which is quite expensive.

Gold–silver (AuAg) possesses quite low and stable contact resistance, even with low currents and voltages and low resistance to welding; therefore, this alloy is used for contacts of measuring circuits with low currents and voltages.

Silver–cadmium oxide (AgCdO) is not an alloy, but rather a ceramic–metal composition. Contacts are pressed from powder, then heated to high temperatures for sintering of the components, calibrated by additional swaging in molds and then annealed for relief of work hardening. This material possesses high resistance to arcing and to mechanical wear and is prone to welding. It has stable properties but its resistance is higher than that of pure silver and it tends to form sulfide surface films. It is widely used for average and power contacts.

Silver–tin oxide (AgSnO) has come to be considered a good alternative to the AgCdO contacts described above. Over the past years the use of cadmium in contacts as well as in batteries has been restricted in many areas of the world; therefore, tin oxide contacts (10%) which are about 15% harder than AgCdO are a good alternative. Also, the above contacts are good for high inrush loads, like tungsten lamps, where the steady-state current is low.

To save space in micro-miniature relays with gaps of hundredths of a millimeter, contacts are formed by pressing-out protrusions on the ends of a flat spring. Sometimes slightly deflected ends of such springs also serve as contacts. Obviously in such cases contact springs should be made of specific materials. As a rule those materials are complex alloys based on silver with admixtures of magnesium (0.15 to 0.3%), nickel (0.1 to 0.25%), gold (1.5 to 2%), or zirconium (0.1 to 0.4%). Specific resistance of such alloys is half as much as that of typical contact springs with a beryllium bronze base, and that is why they can pass greater current. It is very essential when working with micro-miniature relays, to take into account the small size of their springs.

To enhance surface behavior of contacts, they are sometimes covered by gold or rhodium. Gold cover provides a clean surface, low resistance, and high stability of weak-current contacts. Rhodium cover is much heavier than gold and provides higher resistance to mechanical wear, but due to its tendency to absorb gases and form polymeric surface films it can only be used in hermetic relays.

Contacts with a thin cover are not reliable because the thinnest layer protecting a contact from oxidation can easily be damaged in the course of exploitation, when contacts are stripped. Stripping without cover may be expedient only in cases of considerable surface erosion. Stripping of unworn contacts with the help of a file or sandpaper only damages and contaminates the contact surface. Even washing the contact with ethyl alcohol or carbon tetrachloride leaves deposits after drying up. The contact surface can only be cleaned by a hardened iron polished plate, degreased in alcohol, and wiped clean with a dry and clean chamois.

3.3 Contacts with Two-Stage Commutation

As it can be seen from properties of the materials mentioned above, there are no perfect materials possessing low resistance (like silver), high ductility, and at the same time high resistance to arcing at switching (like tungsten). That is why designers invented two-stage contact systems, in which the switching is carried out by tungsten contacts, with the current flowing through silver contacts in a stationary mode. Contact systems of this type have been known for a long time. They are used in average-power relays switching currents of 20 to 50 A, and in power contactors switching currents of hundreds of Amperes (Figure 3.6).

Open RKS-3 type relays with a two-stage contact system shown in Figure 3.6a, have been produced in Russia by the Irkutsk Relay Plant for a long period of time. At present some western companies produce enhanced constructions of relays supplied with a contact system of this type.

When a RKS-type relay is energized, first tungsten contacts 1 close and then, after further spring flexure, silver contacts 2 close. Opening is carried out in a reverse order. A similar algorithm is applied to the contact system of a contactor.

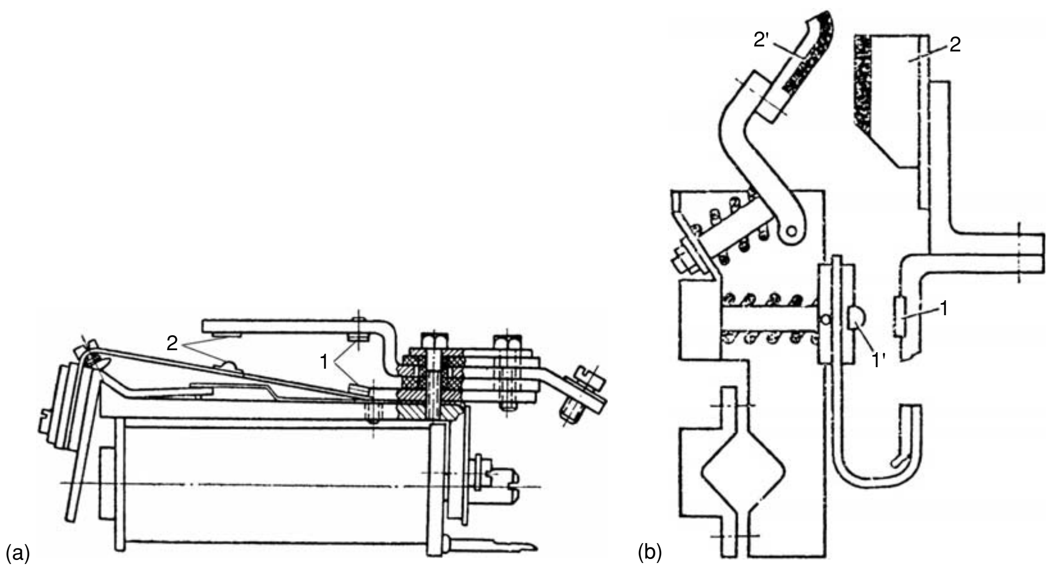


FIGURE 3.6
Two-stage contact systems used in (a) relays and (b) contactors. 1 — auxiliary tungsten contact producing switching; 2 — main silver contact.

3.4 What is the Purpose of "Contact Pressure?"

Relay contacts can have different forms. The most widespread contacts are of a flat, conical, and semicircular form (Figure 3.7) and can be applied in the same contacting pair in different combinations.

It may seem that the more contact area there is, the greater the current that can be passed through it, and that therefore a plane-to-plane contacting pair should be the most favorable contact, but in fact, things are much more complex.

As mentioned above, atmospheric oxygen, ozone, and sulfuretted hydrogen can provoke formation of oxide surface films of high resistance; however, it would be wrong to claim that such films cause only damage. Such films considerably constrain forces of intermolecular cohesion between surfaces from adjoining to each other under contact pressure, prevent interdiffusion of the contact materials, and assume the role of lubricant. Nevertheless, such films should be removed in order to provide more reliable contacts at relay energizing. Without a high-power arc on, contact film deteriorates under the heavy mechanical force caused by contact pressure.

In addition, the contact surface turned out to be very rough (Figure 3.8), and that is why electric contacts operate not along the entire osculant surface, but in only those points through which the current passes. Strengthening of contact pressure leads to an increase in the number of such points.

In spite of that, the bigger the contact area, the greater the effort that a magnetic system should develop in order to provide the required contact pressure, and vice versa. Pricking of this dense texture by a needle has been known to cause pressures equivalent to 1 t/cm^2 at that point. It is clear then that in small relays with weak effort developed by the magnetic system, one must reduce the contact area by changing forms of contacting surfaces.

With small switching currents and efforts not exceeding 25 to 40 g that are developed on contacts of a magnetic system that widely uses flat-pointed contacting pairs, increased specific pressure is provided. Such combination of contacts makes assembling of relays easier as there is no need for installation of contacting pairs along the common axis. However, when a point is used, electric field intensity between contacts rises sharply, which is why the contact gap should be increased. To switch voltages of hundreds of volts, greater distances are required. In earlier constructions of large relays this presented no difficulty. In modern small-sized and miniature relays with distances between contacts less than a millimeter, two hemispheres are used instead of flat-pointed contacts.

In systems with pressure of more than 50 g, hemisphere-plane and plane-to-plane contact layers are used. In older large relays, contact pressure was adjusted within some limits by proper tension and compression of the springs, and contact pressure was measured with the help of a special dynamometer (Figure 3.9). Such tools cannot

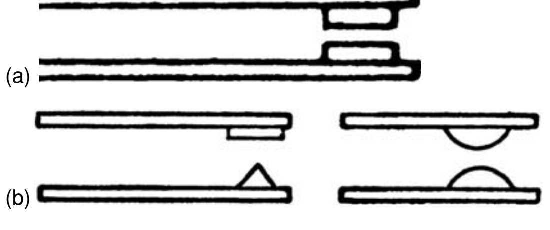


FIGURE 3.7
Forms of contacts of relays.

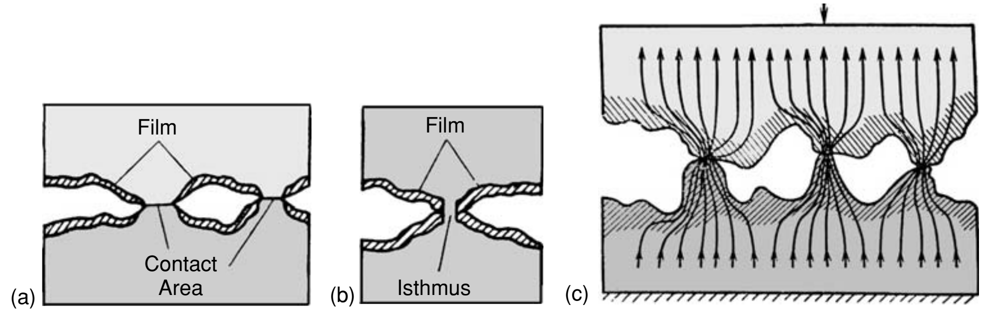


FIGURE 3.8
Surface structure of osculant contacts.

FIGURE 3.9
Dynamometer for measurement of contact pressure.

be applied to modern miniature relays, and therefore such relays cannot be adjusted in the course of operation.

3.5 Self-Cleaning Contacts

Another unconventional way to overcome resistance of films covering contacts is to wipe them when the contacts close. For that it is necessary that the contacts must move with respect to each other.

In some cases mutual micro-displacements of contacts are carried out automatically as they close, as for example in console contacts of relays with an attracted-armature magnetic system (Figure 3.10), where the contacts, which are already touching one another, continue moving. Due to the fact that the console springs of the closing contacts are placed at a certain distance from each other, they move along different radiuses when the contacts touch each other, leading to a certain amount of contact displacement. In other cases, specific, more complex constructions for wiping of oxide films are used for the same purpose.

In power equipment with large and heavy contacts, drive mechanisms enable a certain amount of rolling of the contacts with some mutual slip, causing them to self-clean (Figure 3.11). In such constructions the contacts fixed to a bridge are shifted beforehand with regard to the stationary contacts. At closure they take their place, wiping oxide films as they move as a result of slippage of the bridge along an inclined guide. In more powerful equipment the contacts are rolled during their closure, with a slight degree of slippage of the movable contact with regard to the stationary one (Figure 3.12).

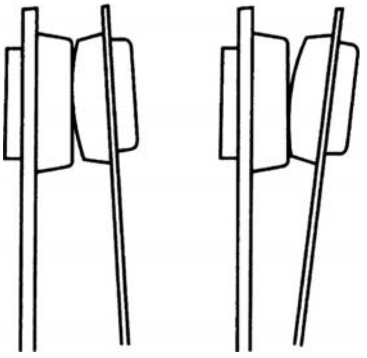


FIGURE 3.10
Mutual contact displacements during their closure, providing destructive effect to oxide films.

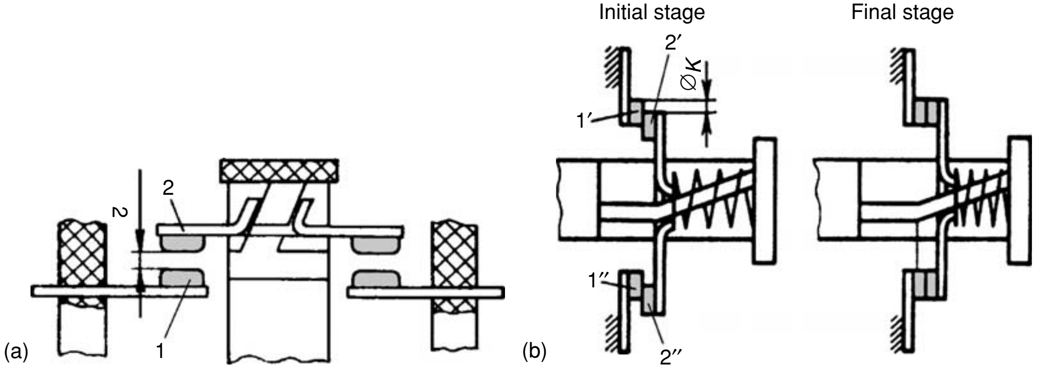


FIGURE 3.11
Construction of a bridge contact enabling the process of mutual contact displacement at closure. 1 — stationary contact; 2 — moving contact.

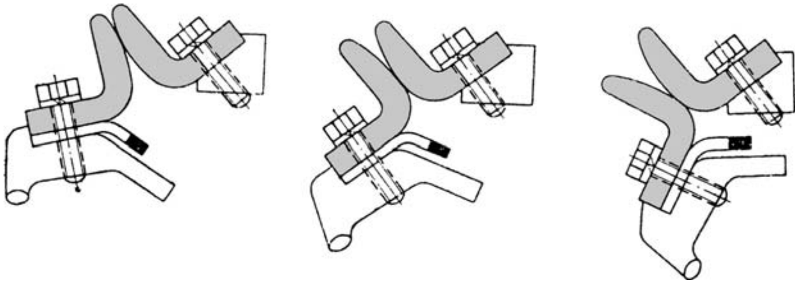


FIGURE 3.12
Contact positions of a more powerful contactor at closure.

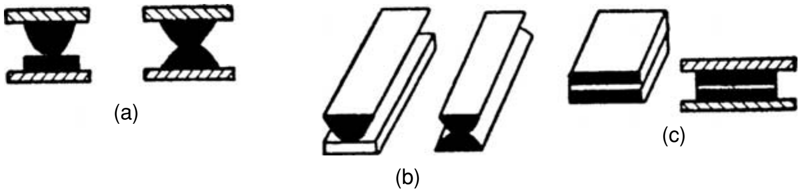


FIGURE 3.13
Various types of contacts used in relays. 1 — point contacts (for currents up to 20–40 A); 2 — line contacts; 3 — plane contacts.

Depending on the type of contacting surfaces, different kinds of contacts are used in different relays: point contacts, plane contacts, and line contacts (Figure 3.13). Each of these contact types is implemented in different construction diagrams of a contact system (Figure 3.14). In sensitive polarized relays (referred to below) a contact system usually looks as it appears in Figure 3.15.

3.6 Self-Adjusting Contacts

In order to enhance the switching capability of the relay, the contact system is made in the form of a bridge (Figure 3.16). Power, partitioned by the contact, is shared by the two serial contact gaps. In this case an open relay of quite a small size (49 × 36 × 41 mm) switches current up to 30 A, voltage up to 600 V, and power up to 1 kW.

Unlike contacts fixed on long and flexible console springs, a bridge contact is a hard component and requires additional elements to provide for reliable compression of the movable contact into the stationary one, for compensation of shock at closure, and also for automatic installation of the bridge in case there are technological variations of sizes, assembling inaccuracies and additional gaps emerging in the course of exploitation of the relay. All of these requirements are in fact fulfilled in the simplest constructions by means of a spring abutting from the central part of the bridge (Figure 3.17).

In some constructions of power relays designed in the 1950s and 1960s, self-installing bridge contacts were made as separate modules of a single-contact (Figure 3.17b) or multi-contact (Figure 3.17c) relay system. Despite the fact that the relays shown in Figure 3.17b and c look quite big and seemingly old-fashioned, General Electric Co., continues to produce them and include them in some types of power equipment it supplies today. The author came across relays of this type, for example, on a new gas-turbine power station still in the running-in process in 2004.

3.7 When Power does not Equal Multiplication by Current and Voltage

If on the miniature relay it is written: 250 V, 5 A it yet does not mean, that this relay is able to switch load 1250 W, that is, 250 V × 5 A ≠ 1250 W. Why? Because 250 V in our sample is the maximal switching voltage and 5 A is the maximal switching current. It has not been

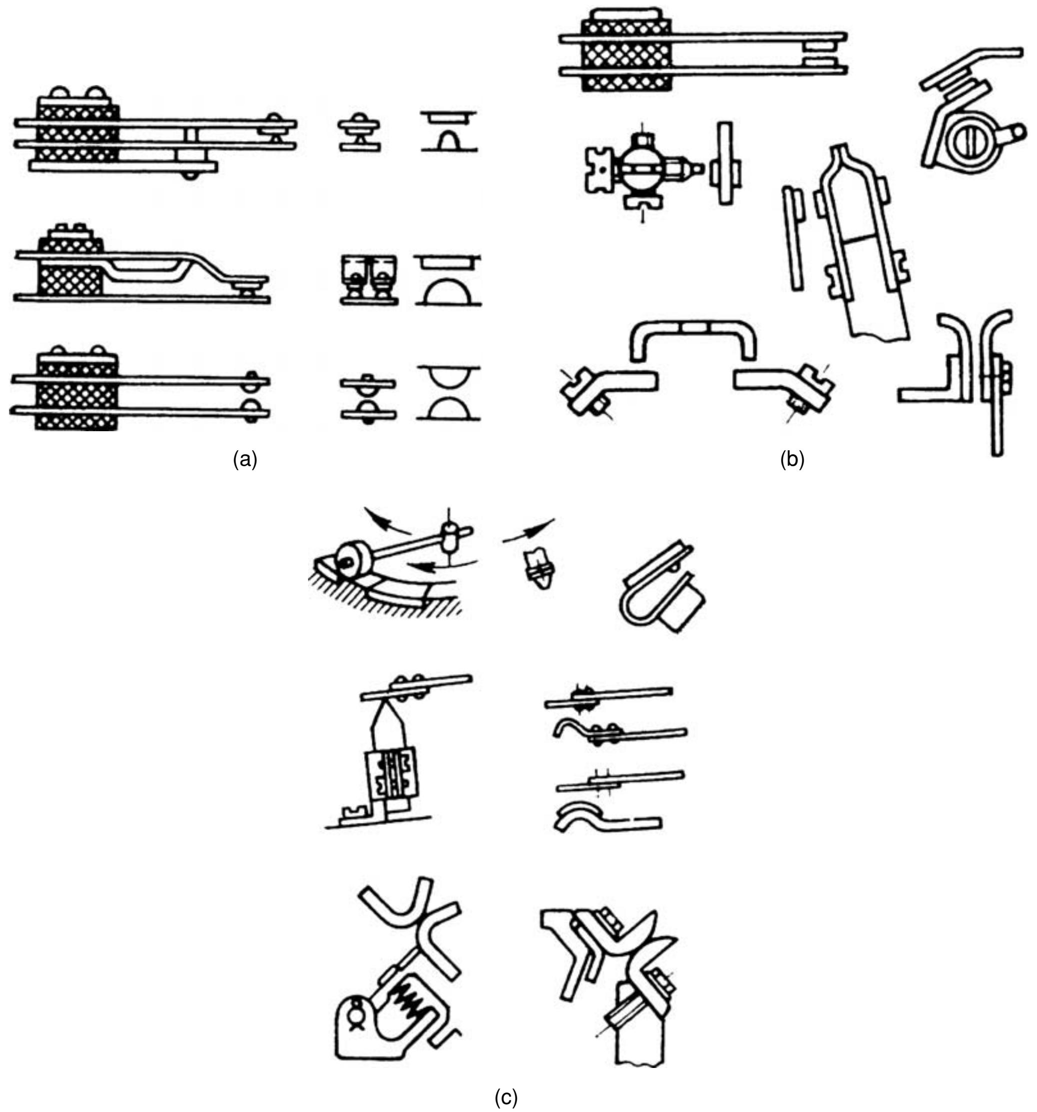


FIGURE 3.14
Different construction diagrams of a contact system with contacts of point (a), plane (b), and line (c) type.

said that both these maximal values can be applied simultaneously. In other words, our relay can switch a voltage of 250 V at current up to 1 or 5 A at voltage of not more than 50 V, that is, the relay has a maximal switching power of 250 W only.

For subminiature relays (which is frequently named as ''power relays''), maximal switching power usually equal multiplication by switching voltage (250 V, for example) and switching current (8 A, for example) signed on relay, but also for these relays it is not so simple.

Power switching apparatus (contactors, starters) must have massive contacts, large in size and heavy in weight, supplied with additional powerful springs to provide the needed contact pressure, and with flexible band wireways through which the current is

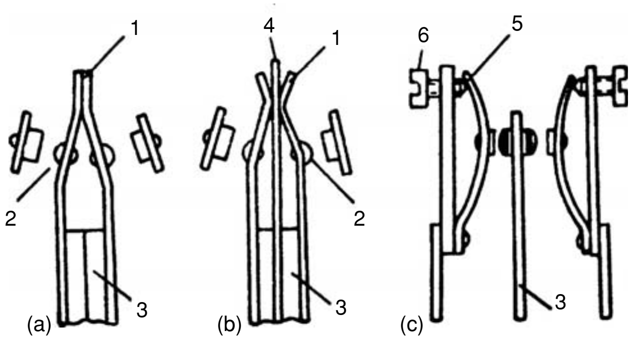


FIGURE 3.15
Contact systems of highly sensitive polarized relays. 1 — current-carrying springs; 2 — contacts; 3 — armature end; 4 — additional spring with silver cover; 5 — unfixed spring ends; 6 — adjusting screw.

fed to the contacts (Figure 3.18). As opposed to this, miniature relays contain very small contacts placed on flexible miniature contact springs (Figure 3.19).

As a rule, subminiature relays which are named power relays, provided with a disproportionately large single contact, can switch quite strong currents (Table 3.1). As has been mentioned above, increase in contact area leads to reduction of contact pressure needed for punching of oxide films. At low voltages on contacts and at low switching currents, this can cause an interruption of the switching process; however, if such relays are not used for switching low voltages and small currents, the oxide films will deteriorate because of thermal impact of arcing on contacts at the time of switching. In addition, massive contacts contribute to better cooling of the arc and to its quick starvation.

Sometimes one can find relays with relatively small dimensions that are really capable of switching high currents (20 to 30 A) at 250 V. One good example is the DI1U-112DMP-type relay, produced by Dongguan Sanyou Electrical Appliances Co. (Figure 3.20). This relay is made as a hybrid device, containing a magnetic system from the miniature relay and a single, normally open, large powerful contact usually used in relays of medium sizes.

When reducing the quantity of contacts to a minimum (that is, down to one) there is sufficient contact pressure even by means of a miniature magnetic system. Naturally, with such a small magnetic system, it is very difficult to provide the large gap necessary between the magnetic core and the armature; therefore, the contact gap in this relay is less (0.3 mm) than with larger relays designed for switching of the same currents. Nevertheless this relay does switch a 20-A current at a voltage of 250 V AC (for resistive load only). Of course, in the switching process a powerful spark between the contacts occurs and the contacts are strongly heated up; however, the author did not find any traces of

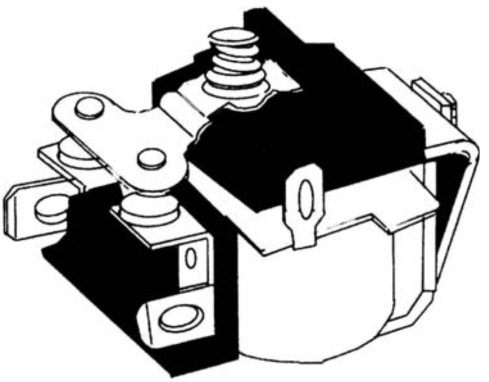


FIGURE 3.16
Open W88UK-type relay with a bridge-type contact, produced by Magnecraft.

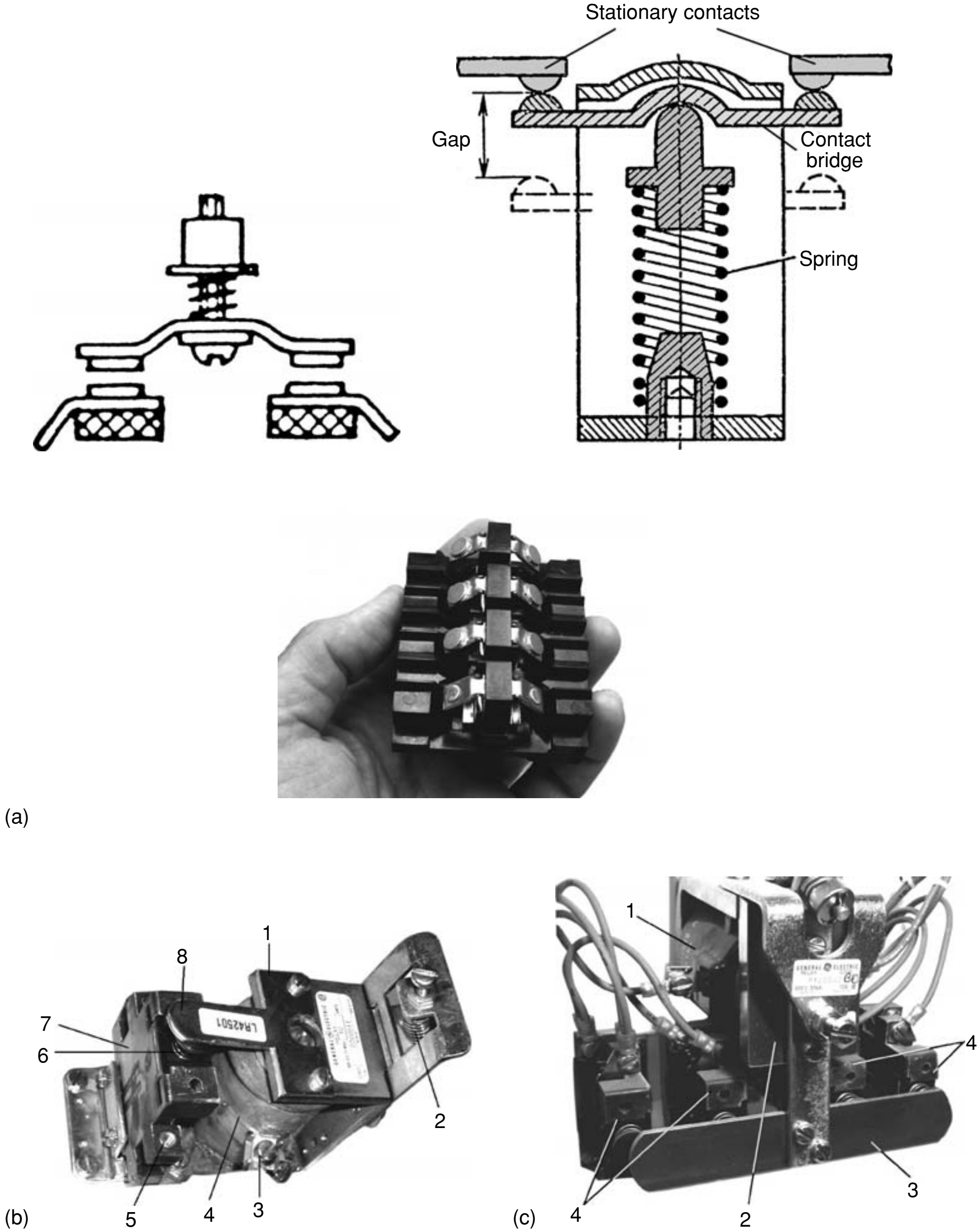


FIGURE 3.17
(a) Self-adjusting bridge contacts. (b) D300B11-type power relay (600 V, 10 A) with one switched bridge contact made as a separate module (General Electric Co.). 1 — armature; 2 and 6 — springs; 3 — coil outlet; 4 — coil; 5 — one of the outlets of the contact module; 7 — contact module with a switched bridge contact; 8 — contact pusher. (c) Contact system of A100BB3-type relay (600 V, 10 A) consisting of four modules with bridge contacts (General Electric Co.). 1 — coil; 2 — armature; 3 — plate transmitting the force from the armature to contact modules; 4 — contact modules.

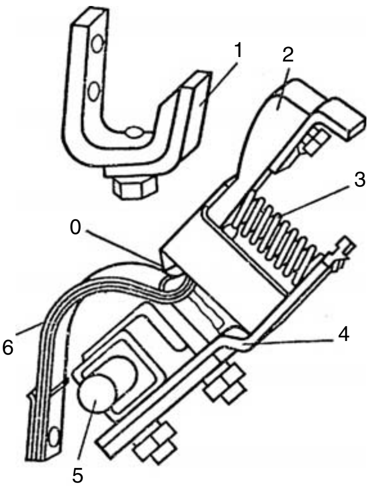


FIGURE 3.18
Construction of a contact system of greater power. 1 — stationary contact; 2 — movable contact; 3 — spring; 4 — contact lever; 5 — contact lever shaft; 6 — flexible band wireways; 0 — rotation axis of the movable contact.

electric erosion on the contact surface after several hundred switching cycles at a current of 22 A.

Switching capabilities of the relay for DC load are approximately ten times worse, than for AC load (Table 3.1). Values specified on the case of the relay usually refer only to AC. Further reduction in switching ability of the relay occurs with inductance in load, even in small ratios (Figure 3.21). Increased inductance of load decreases switching capability of the relay drastically, especially DC. Therefore, all data for switching capabilities of the relays are indicated, usually, only for resistive load.

Additional confusion in the choice of the relay type cause an inrush of current for many kinds of loads (electric motors, transformers, coils of other relays and solenoids, incandescent lamps). All this is inconvenient when it comes to choosing a relay for particular use, and frequently misleads the consumer.

To avoid misunderstanding and to bring different types of relays into sync, special standards (IEC 60947) have been introduced with all types of electric loads divided into so-called ''utilization categories.'' In Table 3.2 there is some data for relay contacts switching auxiliary circuits. As it can be seen, in normal switching mode a relay of an AC-15 (AC-11) category (the most popular one for automation relays) can switch ten times more making current than its stated current and in the mode of infrequent switching 11 times more! For same loads on DC applications (DC-13) switching capacity is in ten times less. This implies that one industrial class relay with switching capacity 2000 VA (200 W)

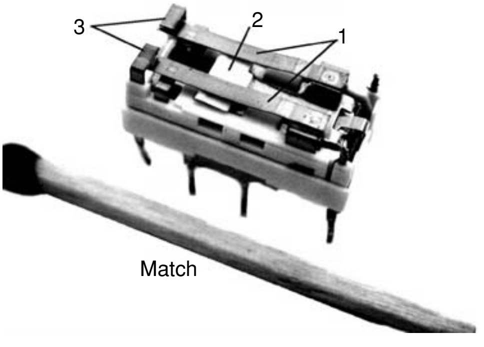


FIGURE 3.19
Miniature relay with weak-current contacts near a match.
1 — contact springs; 2 — pusher; 3 — contacts.

TABLE 3.1
Switching Parameters of Some Types of Subminiature Power Relays

Relay Type (Manufacturer)	Maximal Switching Power (for Resistive Load)		Rated Current and Voltage (for Resistive Load)		
	AC (VA)	DC (W)	AC	DC	For 250 V DC
ST series (Matsusita)	2000	150	8 A; 250 V	5 A; 30 V	0.40 A
JS series (Fujitsu)	2000	192	8 A; 250 V	8 A; 24 V	0.35 A
RT2 (Schrack)	2000	240	8 A; 250 V	8 A; 30 V	0.25 A
RYII (Schrack)	2000	224	8 A; 240 V	8 A; 28 V	0.28 A
G6RN (Omron)	2000	150	8 A; 250 V	5 A; 30 V	–
G2RL-1E (Omron)	3000	288	12 A; 250 V	12 A; 24 V	0.30 A

suitable to AC-11 can switch at once ten lamps on 200 W each on AC, and unable to switch even one such lamp on a DC, because inrush current for incandescent lamps is 6 to 11 times of that of the steady-state current. Unfortunately, miniature and subminiature relays are usually not intended for work under standard utilization categories, therefore, sometimes it is very difficult to choose such relays correctly.

Similar problems arise when one tries to determine areas of working voltages for relays to be used. Originally, miniature relays designed only for use within electronic equipment had less insulation reserve for switching loads than industrial relays. For example, if a voltage of 300 V is indicated as nominal on a miniature relay it is possible to use it also at voltages of 100 and 250 V in low voltage electronic equipment, but this does not mean that the same relay can be used in industrial automation systems with a nominal voltage of 220 V without checking its withstanding voltage. The level of this voltage is determined by the kind of relay: contactor, electromechanical elementary relay, measuring relay, etc. There are many standards for different kinds of relay:

IEEE C37.90-1989. Relays and relay systems associated with electric power apparatus
IEC 60664. Insulation coordination within low voltage systems, including clearances and creepage distance for equipment
IEC 60947-4-1. Low-voltage switchgear and controlgear — Part 4: Contactors and motor-starters — Section 1: Electromechanical contactors and motor-starters

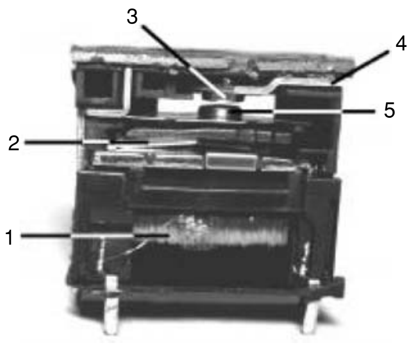


FIGURE 3.20
Relay DI1U-112DMP type without cover (30.2 × 16.2 × 26 mm). 1 — coil; 2 — upper part of armature; 3 — stationary contact; 4 — heat sink; 5 — movable contact.

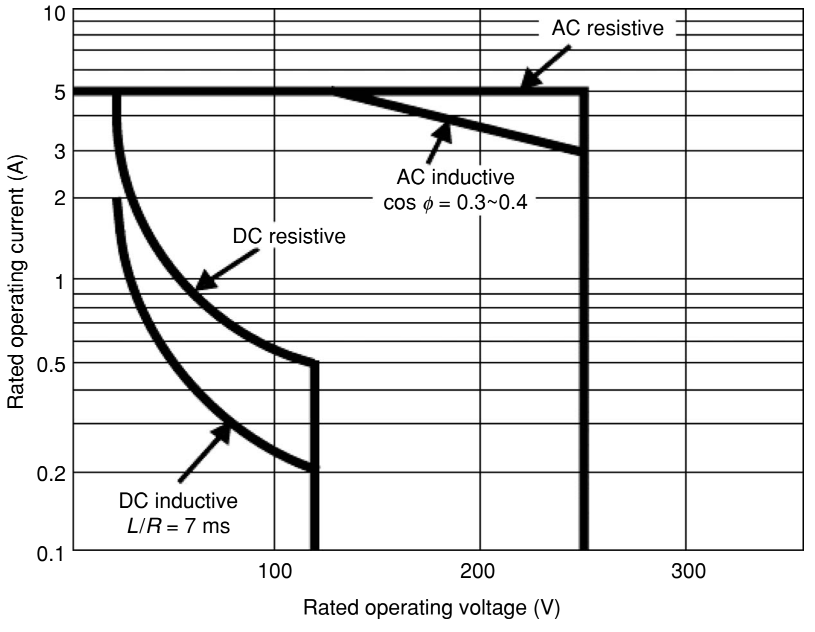


FIGURE 3.21
Typical relationship between switching current, voltage, load type, and electrical life (number of operation cycles) of a miniature relay.

IEC 60947-5-1. Low-voltage switchgear and controlgear. Part 5: Control circuit devices and switching elements. Section 1: Electromechanical control circuit devices

IEC 60947-6-2. Low-voltage switchgear and controlgear — Part 6: Control and protective switching devices

IEC 60255-5. Electrical relays — Part 5: Insulation coordination for measuring relays and protection equipment. Requirements and tests

IEC 61810-1. Electromechanical nonspecified time all or nothing relays — Part 1: General requirements

TABLE 3.2

Switching Capacity of Contacts Depending on the Type of Load for Control Electromagnets, Valves and Solenoid Actuators

Utilization Category IEC 60947–4	Type of Current	Make (Switching ON)			Break (Switching OFF)		
		Current	Voltage	cos φ	Current	Voltage	cos φ
Switching Capacity of Contacts in the Mode of Normal Switching							
AC-15	AC	10 I_N	U_N	0.3	10 I_N	U_N	0.3
DC-13	DC	I_N	U_N	–	I_N	U_N	–
Switching Capacity of Contacts in the Mode of Infrequent Switching							
AC-15	AC	10 I_N	1.1 U_N	0.3	10 I_N	1.1 U_N	0.3
DC-13	DC	1.1 I_N	1.1 U_N	–	1.1 I_N	1.1 U_N	–

I_N and U_N rated values of currents and voltages of electric loads switched by relay contacts.

It is sometimes very difficult to determine relay kind, but in most cases it is possible to use the simple equation for the minimal required value of dielectric withstanding voltage (DWV) on open contact of industrial relays: $U_{DWV} = 2U_N + 1000$. According to this equation for relays with nominal voltage 250 V, the minimal DWV value should not be less then 1500 V. Industrial relays have the DWV usually in the range of 1500 to 2500 V, and miniature relays not more than 1000 V.

3.8 Split, Make-Before-Break, High-Frequency Contacts

Let us continue our survey of contact constructions of relays. In many measuring relays (current and voltage relays) the armature turns at a greater angle. Its moment of rotation is very small, and in order to provide a reliable contacting line, contacts of specific construction are used (Figure 3.22 and Figure 3.23). The angle at which the movable contact touches the stationary one is 45 to 70°. When the surfaces of these contacts touch, the movable contact in the form of a pin (4) continues sliding on the stationary contact (1), drawing the contact spring (2) towards the backstop (3).

In point contact systems and plane contact systems of relays one may come across split contacts instead of the more common twin ones (Figure 3.24). Split (twin) contacts are more reliable than a single one because the switching is carried out simultaneously by both contacts. If there is a problem with switching, one contact will duplicate and back up the other. Another advantage of split contacts are their high resistance to vibration. This can be explained by the lower weight of each contact, fixed to a quasi-individual spring and by the high resonance frequency of this type of contact system. The vibration time of the contacts at closure is also reduced; however, small contacts do have lower thermal capacity and lower thermal resistance to arcing, so as a result of this the rated switching voltage of the relay may be reduced several times.

The construction and functions of the first three types of contacts (Figure 3.25) are quite obvious and require no additional comments.

As far as a ''make-before-break'' contact is concerned, it is a variant of a changeover contact in which the relay is energized first, the normally open contact (NO) closes, and only after that does the normally closed contact (NC) open (Figure 3.26). When the relay is energized the movable spring (2), compressed by the pusher, moves in the direction of the contact spring (1) (up) until closure. When contacts c and d close, the pusher continues to compress the contact spring (2), and the entire contacting mechanism (*c*, *d*, and the contact spring (1)), moves up to break the a–b contact.

To switch high-frequency circuits (of hundreds of kHz) in radio equipment typical relays are of little use because of the high capacitance between contacts. Long current-

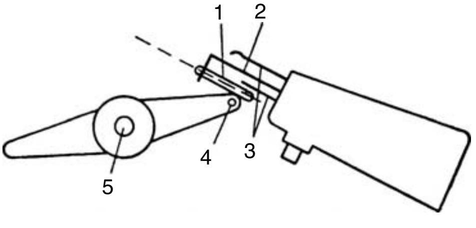


FIGURE 3.22
Diagram of a turntable contact system of a measuring relay with line contact; 1 — stationary contact in the form of a silver cylinder; 2 — contact spring; 3 — fixed stops; 4 — movable (turntable) contact in the form of a pin; 5 — rotating axis.

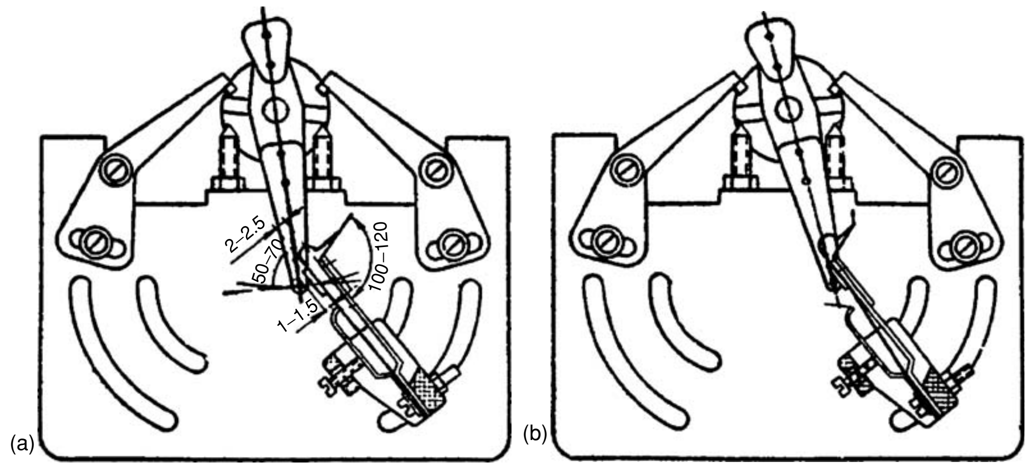


FIGURE 3.23
Construction of a turntable contact system of a measuring relay with a line contact. (a) before closure and (b) after closure.

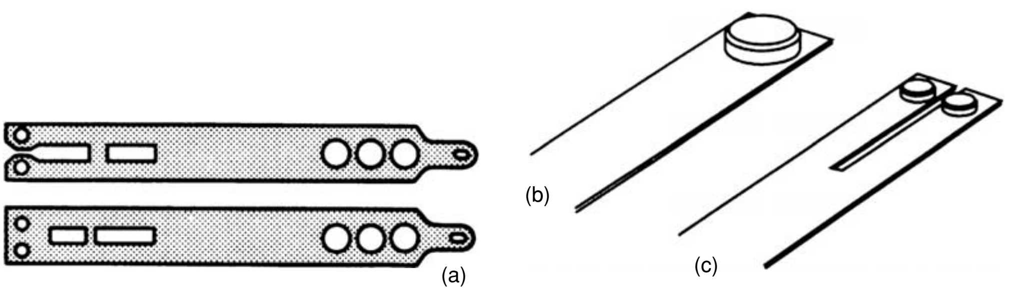
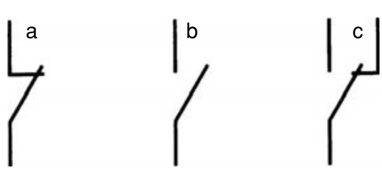


FIGURE 3.24
Single (a), twin (b), and split (c) contacts of relays.

FIGURE 3.25
Schematic of three types of contacts: type a — opening or normally closed contacts (NC), type b — closing or normally open contacts (NO), type c — changeover contact (CO); another type known as ''make-before-break'' contacts are also available. a, b and c — are standard types of contacts.



conducting springs with contacts form capacitance condensers, causing considerable leakage of a high-frequency signal (when contacts are open) and impact on switched circuit.

To reduce capacitance of a contact system, current-conducting springs of stationary contacts are made Γ-shaped and movable contacts are made flat in such a way that the intersection of their projections occurs only at the point where the contact is fixed (Figure 3.27). For switching of even higher frequencies (up to 1 GHz), special coaxial relays with outlets for a coaxial connector with a high-frequency cable are used (Figure 3.28). Stationary contacts (1 and 3) in such a relay are welded on to holders fixed to the inner ends of pins of the two coaxial connectors, insulated with glass.

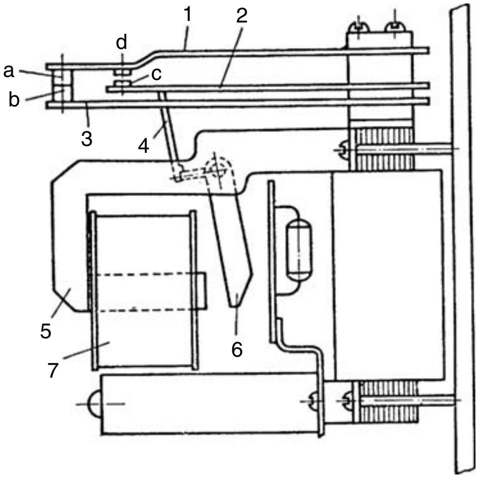


FIGURE 3.26
RP-341-type relay (Russia) with a changeover contact of the make-before-break type. a, b, c, d — contacts; 1, 2, 3 — contact springs, 4 — pusher, 5 — magnetic core; 6 — armature; 7 — coil.

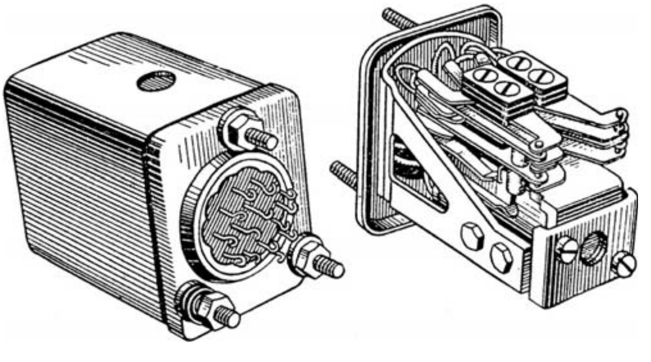


FIGURE 3.27
Hermetically sealed high-frequency relay type RMYG (Russia).

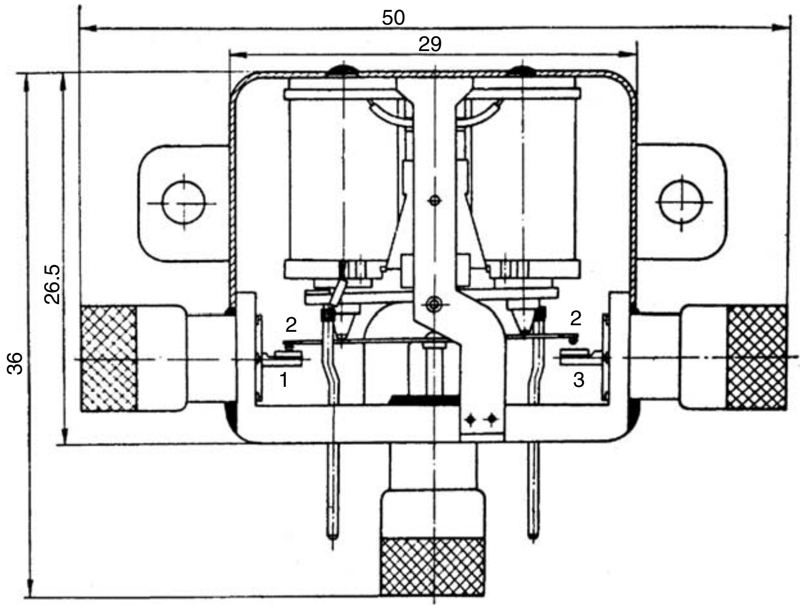


FIGURE 3.28
High-frequency coaxial RPV-5-type relay (Russia) with switching current of 8 A. 1, 3 — stationary contacts, linked with the inner part of the coaxial connector; 2 — movable contacts of the swinging bridge type forming a switching contact.

3.9 Compensation for Shock and Electrodynamic Forces in Contacts

In order to reduce erosion of contacts (failure caused by electric arc) and to enhance their switching capacity, the opening and closing velocity of the contacting pairs must be increased as much as possible, but high velocity may lead to collisions, rebounds, vibration causing new arcs, and other contact damage. In addition, in many cases, oscillations in the switched circuit resulting from contact vibration are inadmissible.

To prevent or at least to weaken such effects, one must choose the appropriate spring rate at the design stage, and produce the stationary current-conducting springs with built-in pretension. To prevent stiffness of the contact system of power relays and contactors, contacts are designed and constructed with a so-called armature overtravel or contact wear allowance (Figure 3.29). Values of the gap between the contacts (contact gap) and the amount of armature overtravel are assigned when the relay is designed. For power relays and contacts there is often a possibility to adjust the contacts during the process of exploitation. This is what many popular cheap relays often contain.

In complex measuring relays costing hundreds of dollars, additional complications of the contact system may not lead to a considerable rise in price, which is why special contact vibration suppressors are used. Contacts absorbing kinetic energy from shock have become especially popular (Figure 3.30). When a movable contact bumps into the element (7), all the energy of motion is transmitted through a flexible membrane to the ball (2), which rebounds, absorbing the energy of the shock and, due to a slight tilt of the tube, and returns to the initial position (as it is shown in the Figure). Adjustment of the initial gap between the movable and stationary contacts is carried out by moving tube

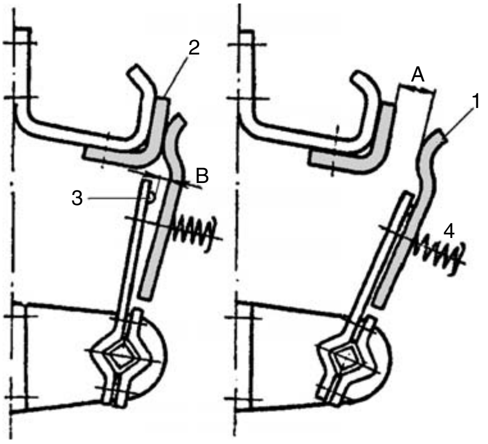


FIGURE 3.29
Contact gap (A) and armature overtravel (B) of power relays. 1 — movable contact; 2 — stationary contact; 3 — stop; 4 — loading spring.

1 in the holder, with the help of an external screw thread. Such contacts have been used for tens of years in different protective relays of the General Electric Co. (Figure 3.31).

At the same time, there still exist absolute hard-type contact systems, which resemble ancient electric arc transmitter relays (see above). They are even harder since they do not even contain damping springs (Figure 3.32). Such construction is possible only with very small gaps between contacts (in this particular relay the gap is 0.09 mm) and, short armature travel when kinetic energy from the shock of movable and stationary contact is so small that it does not lead to rebound of the contacts. On the other hand, it is possible to adjust and fix contacts with such small gaps only if the construction itself is hard enough.

In spite of such a small gap between contacts, it is able to withstand a test voltage of 500 V AC. The sensitivity of this relay is also quite remarkable: operating power, 13 mW; operating current, 2.5 mA. Apart from extremely small gaps, the contact system of such a relay is also remarkable because its NOs and NCs are made of different materials: the former are made of silver, and the latter of tungsten. During frequent switching of such contacts, the tungsten oxide film is impregnated with silver. This considerably lowers transient resistance and increases the reliability of the contact. Generally speaking, different (by size or by material) contacts in the same relay are not that rare.

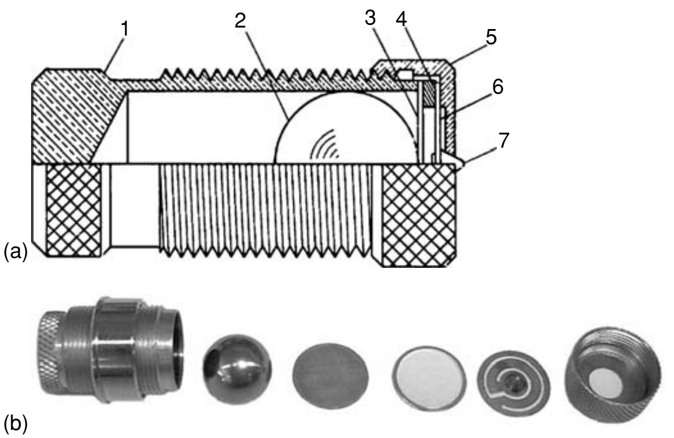


FIGURE 3.30
Stationary contact with compensation of kinetic energy as a result of shock. 1 — case (a hollow tube with external thread); 2 — metal ball; 3 — internal membrane; 4 — washer; 5 — case cover; 6 — second membrane; 7 — element receiving shock from the movable contact.

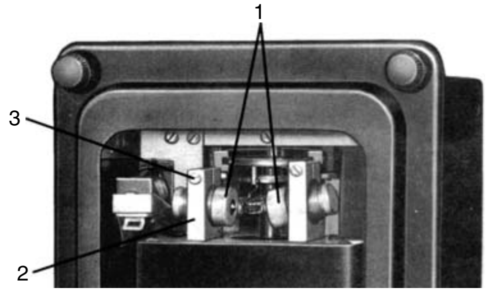


FIGURE 3.31
Protective relay with compensators of kinetic energy from shock of a movable contact, produced by the General Electric Co. 1 — stationary contacts with compensators with a movable contact between; 2 — stationary contact posts; 3 — screw setting position of the stationary contact.

As far as gaps between contacts are concerned, they may vary from 0.05 to 10 mm and more in more powerful and high-voltage equipment. The lesser the gap, the higher the operational speed of mechanical parts of a relay, but the voltage that the contact can switch is low, and its resistance to arcing is even lower. The electric strength of a gap between contacts depends on numerous conditions rather than just on the contact gap alone. In particular it depends on the shape of the contacts, the materials that they are made of, severity of erosion, the strength-to-weight ratio of the gas filling the gap between the contacts, frequency of applied voltage, etc., which is why it is possible to say that a certain gap corresponds to a certain voltage only after having taken into account all of the above conditions.

The closed contact of a relay warms up due to the current passing through it, because the resistance between the closed contacts does not equal zero. In old constructions of relays this level bound the amount of current passing through the contacts, and the temperature of the contacts could not exceed 50 to 70 °C (when the external temperature was +40 °C). In modern small-sized constructions working at their highest efficiency, the temperature of contact heating can reach 100 to 120 °C. In very powerful switching devices with currents up to 2000 A, the temperature of the contacts may reach 200° (for silver contacts). In such cases, sometimes, liquid cooling of contacts is used, thus one can make a simpler contact system, and the overall size of the device smaller. It is obvious that the less transient the resistance of the contacts, the greater the current that can pass through them without fear of exceeding maximum permissible temperatures. It is clear then why designers do their best to increase contact pressure between the contacts after they close. Theoretically, the greater the current passing through the contacts, the greater the pressure between them should be.

However, this is true only in theory. In practice, instead of snuggling up, they repel one another. This happens under electrodynamic forces tending to repel one contact from the

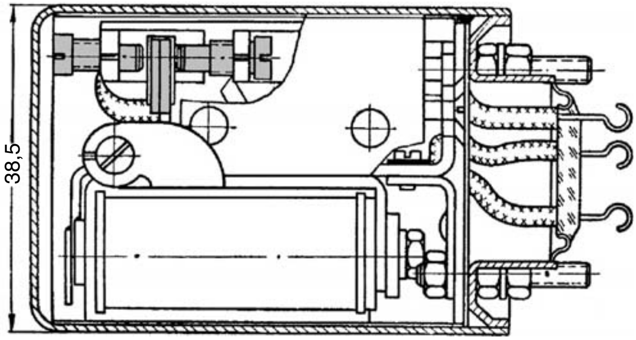


FIGURE 3.32
Construction of a Russian hermetic RDCHG-type relay of heightened sensitivity with an absolute hard-type contact system.

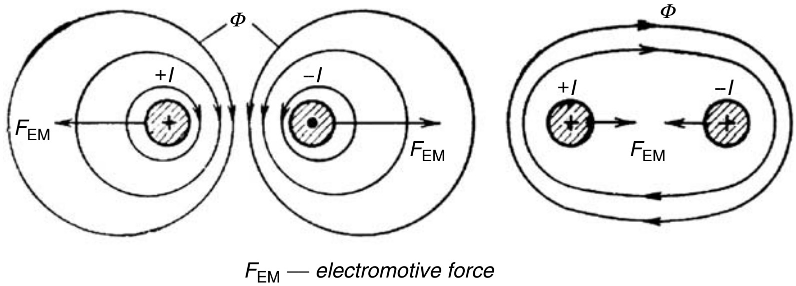


FIGURE 3.33
Direction of electrodynamic forces between conductors. Left: Repulsion of conductors with opposite current direction. Right: Attraction of conductors with the same current direction.

other (Figure 3.33). At nominal working currents these forces are not appreciable but with short-circuit current passing through contacts, can increase so much that closed contacts may be thrown away from each other. What happens when a contact through which a short-circuit current passes and which is not designed for switching off short-circuit currents, is broken? In most cases it leads to welding of contacts or to significant damage of contacts.

To prevent spontaneous opening of closed contacts under electrodynamic forces of short-circuit currents in power switching devices, sometimes special compensators are used (Figure 3.34). In such devices short-circuit current I causes an attractive force F (1–3) between the elements 1 and 3 and a repulsive force F (2–3) between the elements 2 and 3. As a result, the element 3 where a contact is placed is affected by the sum of these two forces, causing additional compression of the contacts. Repulsive force F_2 between elements 1 and 2 creates efforts amplifying the pressing effort P. Joint coupling between elements 1 and 2 is usually shunted with flexible copper ties (Figure 3.35).

Knowledge of contact peculiarities allows us to design a contact system correctly without any specific constructions. For example, in the bridge contact shown in

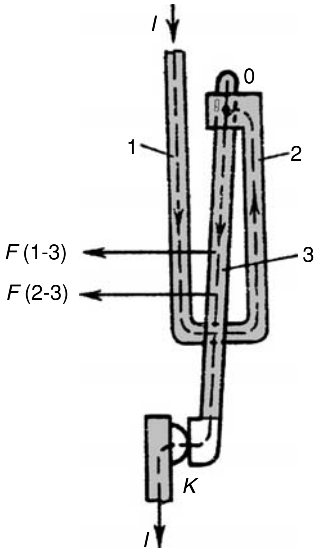


FIGURE 3.34
Compensators of electrodynamic forces.

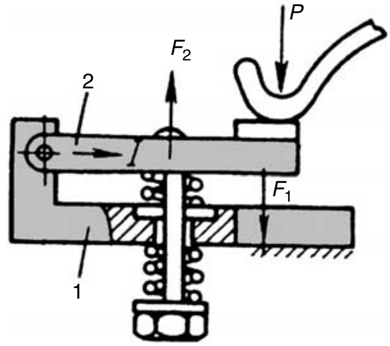


FIGURE 3.35
One of the practical constructions of compensators.

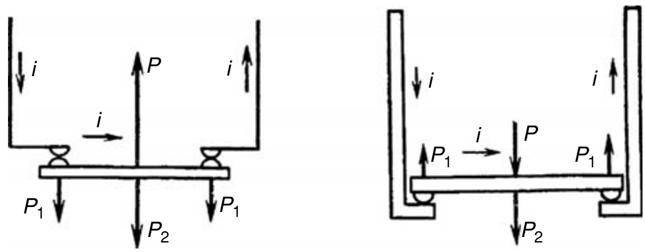


FIGURE 3.36
The effect of a bridge arrangement on the distribution of forces, which are operational on contact.

Figure 3.36 it is enough just to put the bridge form in a lower position relative to the top so that electrodynamic force P_2 can change the direction of its impact on the contacts. In the first case (Figure 3.36, left), this force is subtracted from force P of contact pressure provided by the springs, while in the second case (Figure 3.36, right) this force is added to the force P increased by the springs.

Moreover, due to the additional effort P_2, one can select a pressing spring with a smaller force leading to a diminution of the coil size and to facilitation of the magnetic system.

3.10 Sparking Contacts and their Control

As contacts to which working load voltage is applied close, they draw closer to each other. When the minimum distance (hundredth parts of a millimeter for low-voltage relays) is reached, electric breakdown of the gap between the contacts takes place. Discharge arising from that does not pass to an arc because a movable contact can pass distances of hundredth parts of a millimeter very quickly, and when the contacts open, the discharge disappears. However, the process of closing does not come to an end at this stage. Elastic collision of the contacts is accompanied by rebounding, with repeated closings, followed by additional rebounding and closing. Sparking contacts entail transfer of material from one contact to the other (the so-called electric erosion). As continuous current of certain polarity is switched, a bulge arises on one of the contacts and a crater on the other one (Figure 3.37). The direction of erosion depends on the type of discharge and current value.

However, due to the high speed of contact attraction the period of existence of this discharge is very short (up to the moment the contacts touch each other). When contacts open, contact pressure decreases, transient resistance proportionally rises and the temperature of the points of contact touch goes up considerably. At the moment of opening the contacts may be heated to melting point (if the amount of current in the circuit is great

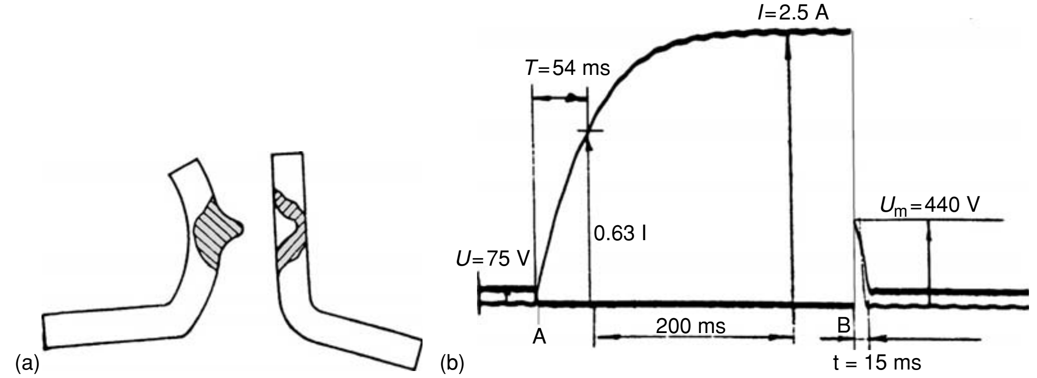


FIGURE 3.37
(a) Bulges and craters on contacts caused by electric spark. (b) Oscillogram of the process of switching ON and OFF of the inductive load with time constant $T = 54$ ms in DC current with nominal voltage $U = 75$ V; A — switch-on point; B — switch-off point.

enough) and when that happens a bridge of melded metal is formed between them. At further separation of contacts that bridge stretches and breaks turning into an arc discharge. Such a discharge will burn until the contacts separate at a distance where further burning of the arc is not possible.

On alternating current and at resistive load arc extinction occurs at the moment when the AC sinusoid passes through zero. If the contacts have separated at a distance where the electric strength of the gap between the contacts exceeds voltage restoring on contacts the switching process comes to the end (since repeated break-down of the gap is impossible). If not, another breakdown of the gap between the contacts will occur.

The basic requirement for normal circuit opening is excess of electric strength restoring during the switching process over restoring voltage. Restoring electric strength of a gap between contacts depends on the speed at which the contacts are separating, on the insulating environment of the gap between contacts (air, vacuum, sulfur-hexafluoride (SF_6), oil, etc.), and on the type of switching element (mechanical contact, semiconductor structure, etc.), with all of the above determined by the construction of switching equipment. Restoring voltage in circuit with resistive load equals the resistance of the power source.

In DC current with reactive load (containing considerable inductance or capacitance) restoring voltage depends mostly on load parameters and the rate of restoring electric strength rise.

At abrupt breakdown of current in a circuit with greater inductance energy accumulated in the form of a magnetic field is released on separating contacts with quite high intensity in the form of impulses of high-voltage exceeding voltage of the power source by 5 to 10 times (Figure 3.37b). In this particular case power source voltage of 75 V amplitude of over-voltage impulse reaches 440 V and may be subject to quite a great duration of this impulse (about 15 ms).

But restoring electric strength may be not enough to withstand such over-voltages and the following arcing process may break the contact gap jump-in changes in arc parameters during arcing may lead to self-oscillating processes in circuits with high inductance. Arcing continues on fully opened contacts until they completely burn out. The author witnessed such complete meltdown of a contact system of a hermetic relay with maximum switched current of 10 A and maximum working voltage of 350 V when coil of a power DC contactor (working as a contact load) with a nominal current in the circuit of this coil of 2 A and a nominal voltage of 100 V was disconnected.

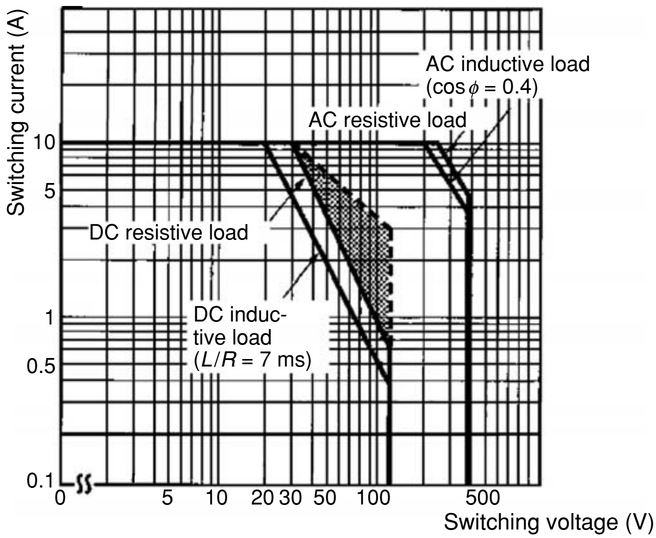


FIGURE 3.38
Typical relation between commutation parameters (voltage, current) and load character for relay contacts.

In AC circuits current passing through the contacts equals zero twice a period. It may seem that at that point the arcing processes on the contacts must cease. Indeed, switching of AC circuit is a simpler mode for contacts than DC switching (Figure 3.38). However, if there is high inductance in the switched circuit current is not in phase with the applied voltage and when the current equals zero, the voltage on the contacts can be quite high, thus maintaining an ionization state of the contact gap. Such conditions may lead to arcing even in AC circuits. Experimental investigations have shown that during switching of currents up to 6 A and voltages up to 380 V an arc goes out at first current passing through zero value in a wide range of contact separating rates (in the experiments rates from 8 up to 280 mm/s were studied). Problems in AC circuits usually arise when one has to deal with currents of a few tens of amperes. In this case specific technological solutions described below should be applied.

Repeated closing and opening leads to electric spark or arcing causing considerable wear of contacts due to fusion and dusting of contact material. Bulges and craters on contacts are dangerous because not only they destroy contacts but also they lead to frequent sealing of contacts caused by jamming of spurs in the craters, and eventually to malfunction of the relay. Contact rebounds can be controlled by special dampers and springs while electric spark must be controlled by circuit means using different protective circuits switched parallel to a contact or a load (Table 3.3 and Figure 3.39).

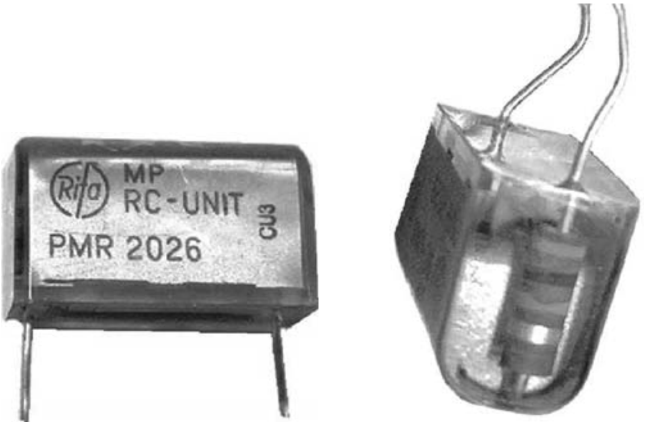
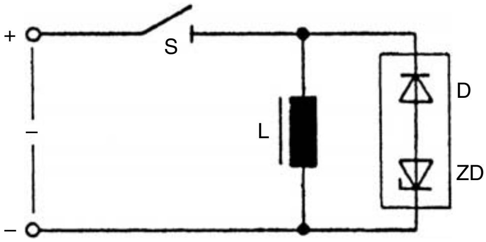
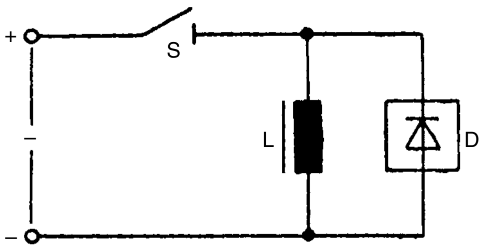
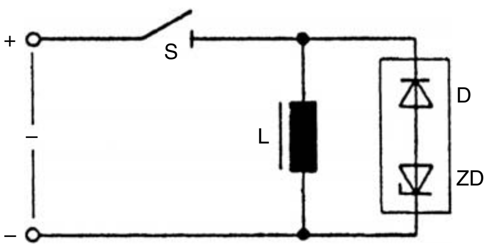
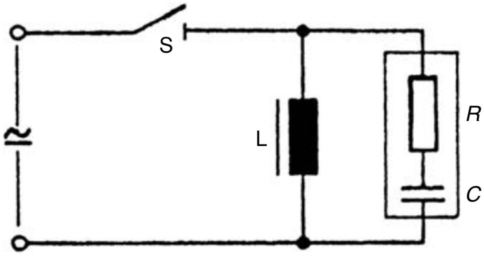


FIGURE 3.39
Protective RC type element produced by the firm RIFA consisting of a 0.25 μF, 630 V DC capacitor and a 100 Ohm resistor.

TABLE 3.3

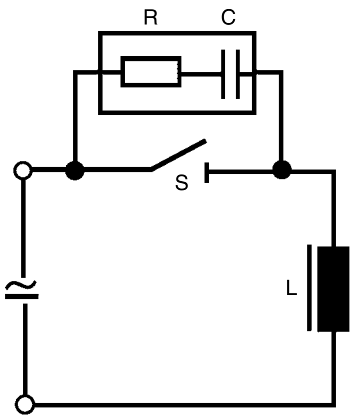
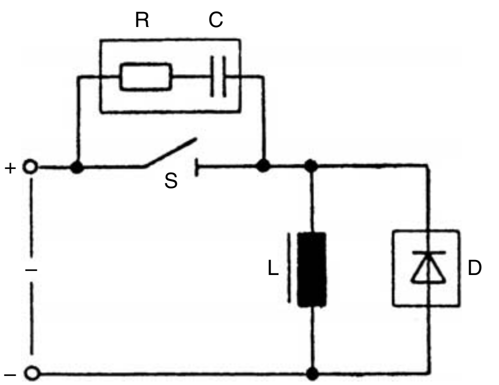
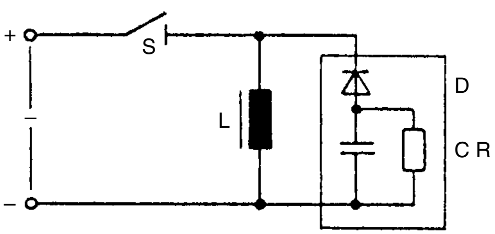
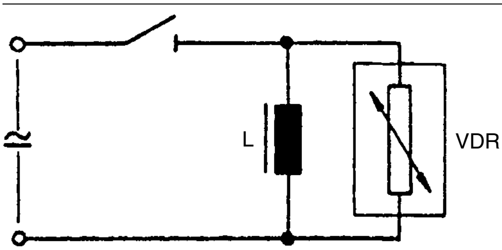
Types and Features of Arc Protective Circuits

Protective Circuits	**Commentary**
	At circuit opening energy accumulated in inductance is discharged through resistance *R* Drawback of the circuit design: increase in current load of a contact
 Diode voltage must be 3 to 5 times as much as circuit voltage, maximum pulse current must not be less than load current	For DC circuits only EMF of load self-induction arising at circuit opening has direction opposite to the source, which is why the diode is blocked in the normal mode and unblocked only at the moment of contact opening and shunt inductance Drawback: increase in time of current drop in inductance. When dealing with a relay winding or a contactor — increase in time of relay drop-out
 Voltage of Zener diode must be not less than voltage of power source, Zener current must not be less than 0.5 to 0.7 of load current	This circuit design, when compared to the previous one, does not have much effect on time of current drop in load because Zener diode is blocked, thus preventing shunting of the load by diode when voltage rating value in circuit decreases Drawback: high cost of a Zener diode for power loads
	Popular type of protective circuits Does not have much influence on time of current drop in inductance. Energy of spark is used for condenser (*C*) charge. Resistance (*R*) restricts discharge of current of charged condenser at repeated contact closing Capacitance chosen is 0.5 to 1.0 μF for each ampere of switched current

(*Continues*)

TABLE 3.3 (*Continued*)

Spark Protective Circuits and its Characteristics

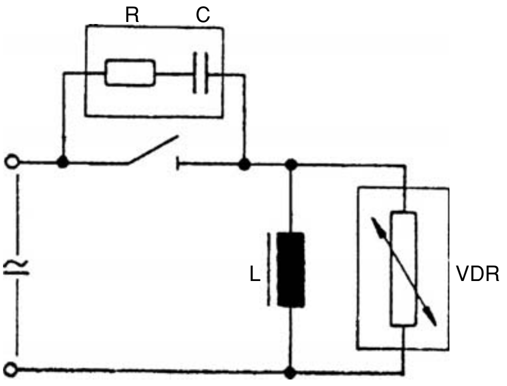
<table>
<tr><th>Protective Circuits</th><th>Commentary</th></tr>
<tr><td>
</td><td>Resistance is 0.5 to 1 Ω for each Volt of working voltage
The condenser should be designed for work in AC circuit with voltage not less than that exceeding rating voltage by 1.5 to 2 times
In the schematic below on AC current there is a leakage of current through RC circuits that can have an influence on the load</td></tr>
<tr><td>
</td><td>For DC circuits only
Compound schematic combining both advantages and disadvantages of the variants mentioned above</td></tr>
<tr><td>
</td><td>For DC circuits only
Very effective circuit design, which practically does not affect current drop in a load. Resistance connected parallel to a condenser does not make it less effective for absorbing of spark energy, and discharges quickly after voltage surge</td></tr>
<tr><td>

Classification voltage of a varistor must not be less than rayed voltage of circuit</td><td>Popular variant
A varistor (VDR) is used. A varistor is a resistor with nonlinear resistance. Being affected by over-voltage its resistance considerably goes down
Effectiveness depends on the proper choice of the varistor (voltage, dissipation energy)
Has insignificant influence on time of current drop in the inductive load</td></tr>
</table>

(*Continues*)

TABLE 3.3 (*Continued*)

Spark Protective Circuits and its Characteristics

Protective Circuits	Commentary
	Combined schematic combining both advantages and disadvantages of the variants described above

Some companies produce protective circuits as separate articles. Companies, manufacturers of relays, produce protective circuits in special cases for easy mounting on their relays (Figure 3.40).

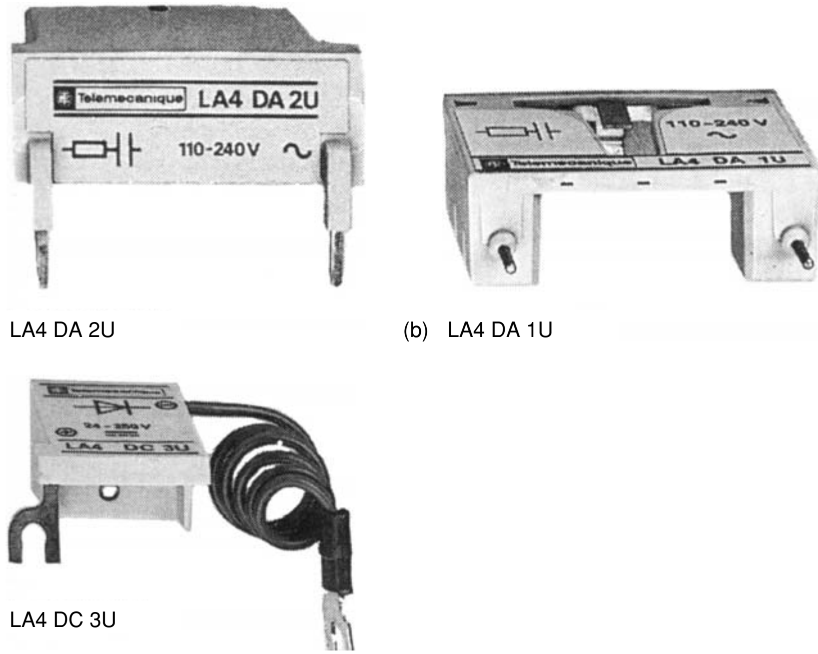
It must be mentioned that gas-discharge processes arising on opening contacts are quite complex and this book is not aimed at a detailed consideration of these processes, which are described in extensive monographs, and although the author does not want to simplify these problems it is still possible to draw a generalization digressing from the complex theory: when current switched by the contacts and the voltage applied to the contacts exceed certain threshold values necessary for maintaining arcing, the electric-spark discharge turns into an arc and the means described above are ineffective for extinguishing it. Conditions for arcing are ambiguous and may depend on many factors (Table 3.4).

Moreover, different researchers have provided considerably different data, which nevertheless because it gives the reader some idea regarding the conditions, we will cite here concerning critical current of arcing (that is current exceeding the arcing point, which

TABLE 3.4

Critical Currents of Arcing for Different Materials of Contacts and Different Voltages on the Contacts

Material of Contacts	Critical Current of Arcing A for Voltage on Contacts, V			
	25	50	110	220
Copper	—	1.3	0.9	0.5
Silver	1.7	1.0	0.6	0.25
Gold	1.7	1.5	0.5	0.5
Platinum	4.0	2.0	1.0	0.5
Nickel	—	1.2	1.0	0.7
Zinc	0.5	0.5	0.5	0.5
Iron	—	1.5	1.0	0.5
Tungsten	12.5	4.0	1.8	1.4
Molybdenum	18.0	3.0	2.0	1.0



(a) LA4 DA 2U (b) LA4 DA 1U

(c) LA4 DC 3U

FIGURE 3.40
Spark proof elements produced by the firm Telemechanique. (a) LA4 DA 2U (b) LA4 DA 1U — RC-type element; (c) LA4 DC 3U — diodes.

causes arcing) for different materials of contacts and different voltages on the contacts. The information is taken from research literature.

Basic means of arc affecting switching devices:

- Expansion of an arc channel by separating contacts
- Arc partition on small sections by metallic plates making the arc cool
- Displacement of arc in the zone between contacts by magnetic field
- Increase in pressure of gaseous atmosphere where there is arcing
- Arc extinction in vacuum
- Arc extinction in insulating liquid or gases.

With small cutoff currents and low voltages permanent magnets are often installed near the contacts in the relays (Figure 3.41). Electric arcs, which are at the same time flexible conductors of current, interact with the magnetic field of the permanent magnets and are forced out by this field from the area of the contacts.

3.11 High-Power Contact Systems

In power AC devices the electric arc is affected by a magnetic field created by working current passing through conducting bars and additional amplified ferromagnetic

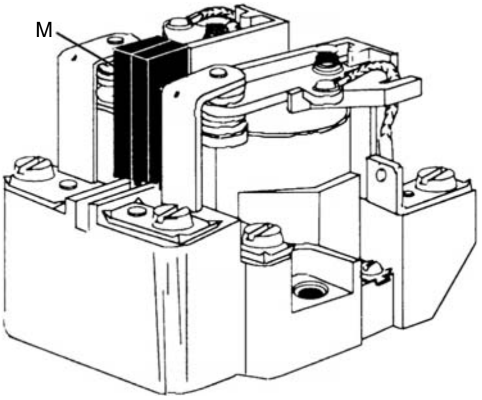


FIGURE 3.41
W199BX-14 type relay with an arc-suppressing magnet (M) designed for switching circuits of continuous current up to 30 A (produced by Magnecraft).

elements (2, Figure 3.42). As can be seen in Figure 3.42, contacts of this device are supplied not only with additional steel inserts but also with deflected metal plates. As we are now discussing an arc-suppressing chamber, it is obvious that these plates are essential for arc extinction. Any arc arising when the contact openings are supplied with such additional plates will move along these plates under electromagnetic forces of interaction between current fields in the plates, with the arc current rate reaching tens of meters per second.

If these plates are fixed at an angle forming horns (Figure 3.43), during arc movement, the arc will stretch. This will result in an increase in resistance and decrease in temperature, bringing about extinction of the arc.

One of the most popular types of arc-suppressing devices is a lattice placed near the contacts (Figure 3.44). This lattice can be made of metal (steel, copper) and of high-temperature insulating material. In the first case, the arc drawn by electromagnetic forces in such a lattice is divided into a number of short arcs with small potential difference (20 to 30 V) between the adjacent plates (anode and cathode). Thus conditions for extinction of these short arcs are created. In addition, in a metal lattice the arc cools down, which is also another significant factor in bringing about its extinction. When ferromagnetic (steel) plates are used, additional forces drawing an arc into a lattice are created. At great currents, due to the high resistance of steel, the plates of the lattice heat up to high temperatures during arcing.

In order to lower temperatures and to reduce electric erosion, the plates are covered with copper. In the second case arc extinction occurs due to its extension (Figure 3.45 (2)). This method of arc extinction by means of an arc-suppression lattice was invented more than a hundred years ago. In Russia it was implemented for the first time by M. Dolivo-Dobrovolsky. Later, more complex devices appeared; for example, in 1927 in Germany, an

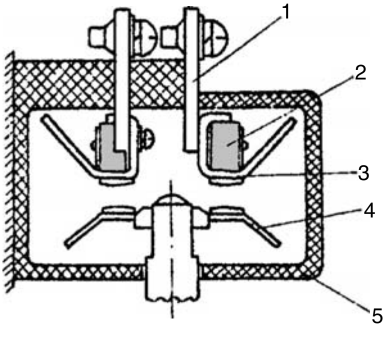


FIGURE 3.42
Arc-suppressing device of an AC contactor with rated currents of 50 to 150 A. 1 — current contact jaw; 2 — steel insert; 3 — stationary contact; 4 — movable bridge contact; 5 — vacuum chamber.

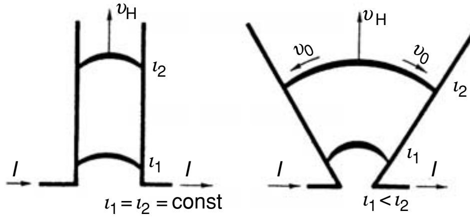


FIGURE 3.43
Arc moving along plates.

arc-suppressing device with an arc rotating in a stack of interjacent flat electrodes was patented (patent 576932). In 1951, this idea was further developed (German patent 928655) and quite successfully implemented (Figure 3.46). In this device the arc descends from horns and turns to a grid. Sub arcs between the flat electrodes rotate in annular channels formed by insulating guides (lattices) under a radial magnetic flux, created by permanent magnets.

There are also arc-suppressing devices based on forced ''blowing up'' of an arc into a slot chamber where the arc cools off and goes out (Figure 3.47). In this device a coil (1) flown over by current creates a magnetic flux (*F*) that with the help of the magnetic core (2) and ferromagnetic plates (3) is brought to an arc. The interaction of the magnetic flux, Φ, and arc current creates an electromagnetic force driving the arc to the slot, where the arc cools off and is deionized.

There were also some attempts to use insulating and metal elements of different shapes, brought in by a spring between the contacts at the moment of their separation (Figure 3.48), and distorting the trajectory of the plasmic flux of the arc.

In actual constructions of power AC relays (contactors) most arc-suppressing devices in use are based on arc-suppressing lattices (Figure 3.49 and Figure 3.50). Arc-suppressing chambers are large in size and quite heavy. This considerably increases characteristics of mass and size of the switching device itself.

Accordingly, power relays produced by some firms (Figure 3.51), really do look amazing. They switch currents of tens and hundreds of amperes and at the same time are quite compact. Why? Let us recall miniature relays with disproportionately great switched current. The same is true when great currents can be switched on by lower voltages

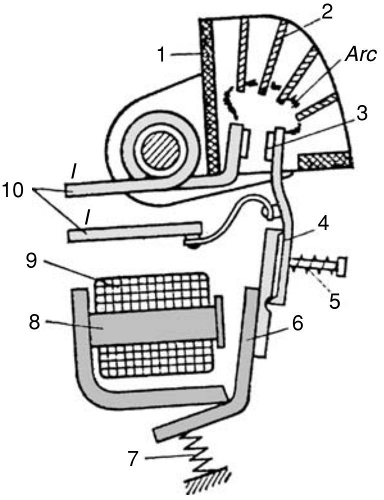


FIGURE 3.44
Principle of an arc-suppressing chamber. 1 — chamber; 3 — main contacts; 2 — lattice; 4 — lever; 5,7, — springs; 6 — armature; 8 — core; 9 — winding; 10 — wireways.

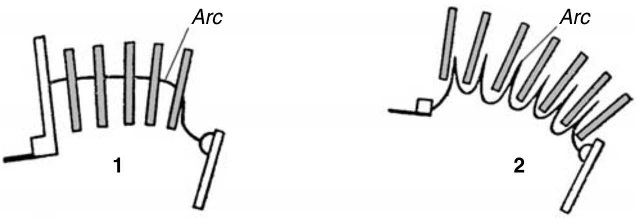


FIGURE 3.45
Principle of arc extinction in a lattice made of metal (1) and of high-temperature insulating material (2).

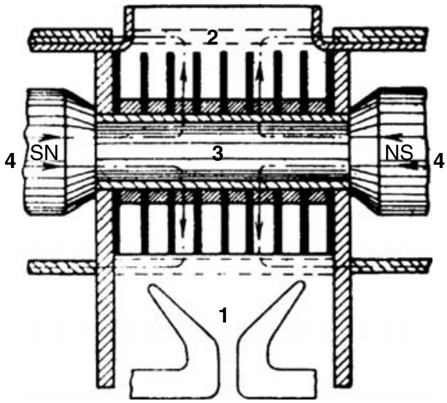


FIGURE 3.46
Arc-suppressing device with a rotating arc (German patent 928655, 1951); 1 — contacts with plates in the form of horns; 2 — lattice formed by round insulating plates; 3 — iron core; 4 — permanent magnets.

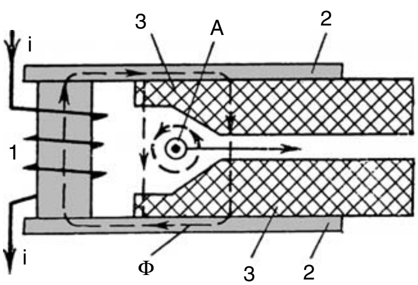


FIGURE 3.47
Slot chamber with magnetic blow-out. 1 — coil; 2 — magnetic core; 3 — ferromagnetic plates; A — arc.

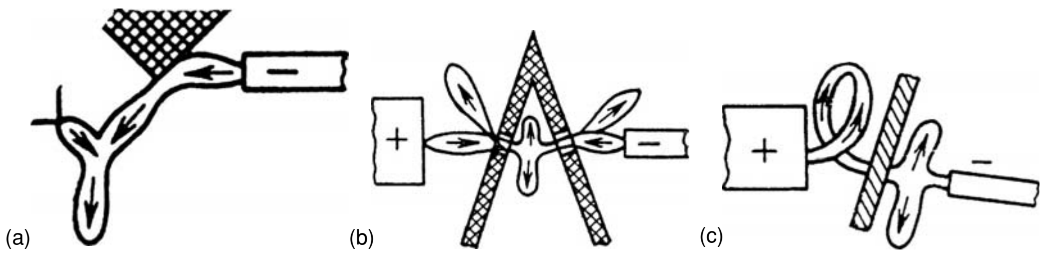


FIGURE 3.48
(a), (b), and (c) Implementation of insulating and metal elements brought in between electrodes to affect the plasmic flux.

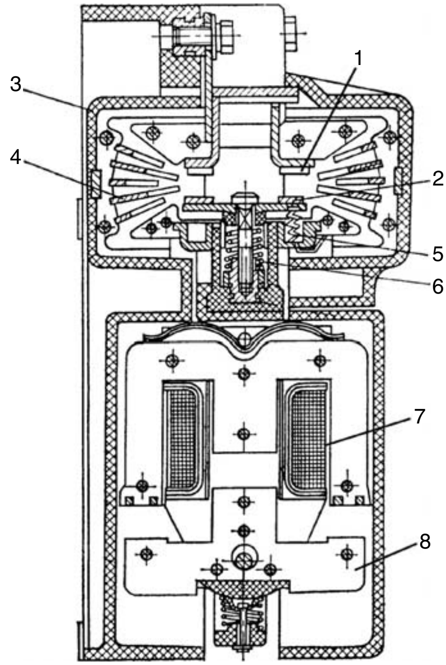


FIGURE 3.49
KTU-2E type power relay (contactor) produced in Russia. Rated current is 63 A (for the AC-4 mode), rated voltage is 1140 V (50 Hz). 1 — stationary contact; 2 — movable bridge contact; 3 — arc-suppressing chamber; 4 — arc-suppressing lattice; 5,6 — springs; 7 — winding; 8 — movable part of the core.

with the help of a simplified contact system. In this case we are speaking about a class of power relays with switched voltages of 12 to 14 and 28 V of continuous current.

The first voltage level is used in cars (Figure 3.51a), and the second is employed in aircraft power systems, tanks, other types of military, and some types of civil equipment (Figure 3.51b and c). Simple construction of a contact system is typical not only of automobile relays with switched current of tens of amperes, but also of military relays with switched currents of hundreds of amperes (Figure 3.52). These systems do not contain any special arc-suppressing elements. It is only natural that in power relays the contacts are more massive and larger in size (as a rule they are made of silver) and contact pressure is harder. These are the main characteristics of such contact systems.

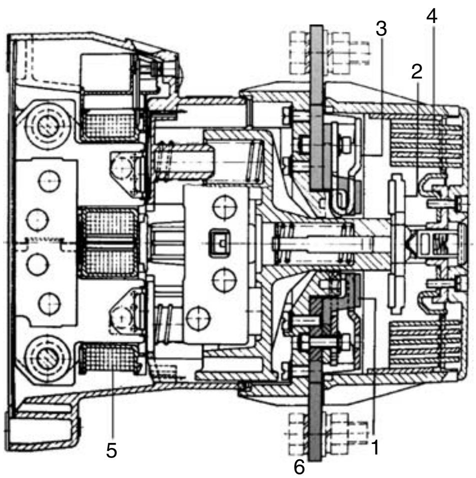


FIGURE 3.50
3TF56-type power relay produced by Siemens. Rated current is 80 A (for the AC-4 mode), rated voltage is 1000 V. 1 — stationary contact; 2 — movable bridge contact; 3 — ferromagnetic plate for blowing up an arc into the lattice; 4 — arc-suppressing lattice; 5 — one of the two coils; 6 — current leads.

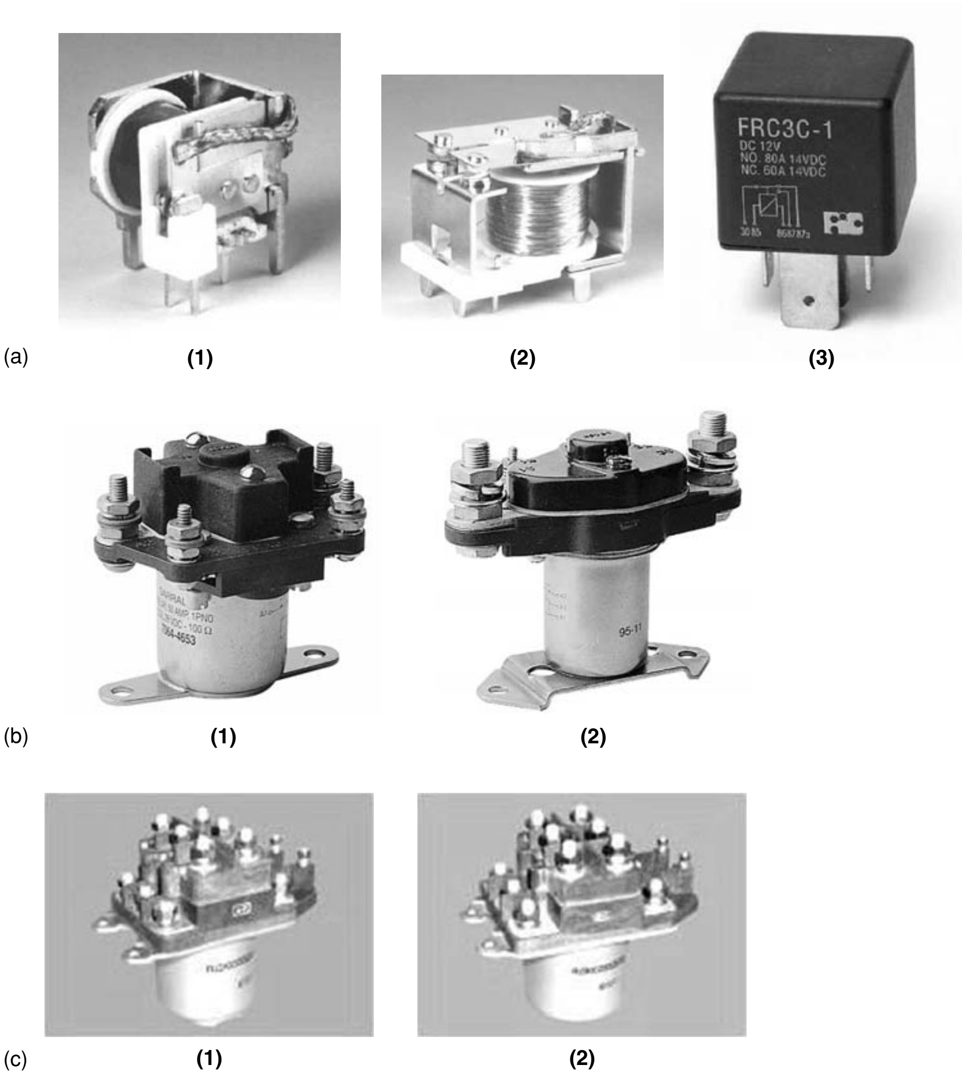


FIGURE 3.51
(a) Miniature relays of car type with simplest contact system, allowing for switch current of tens of amperes. (b) Relay designed according to the military standard for DC voltage of 28 V. Produced by LEACH International. 1 — Relay of 7064-4653 type with switching current of 50 A, size: 70 × 53.4 × 65 mm, weight: 267 g; 2 — relay of 7401-4658 type with switching current of 400 A, size: 139.7 × 62 × 44.3 mm, weight: 1180 g. (c) Power relays designed according to the military standard for DC voltage of 28 V, produced by the Kirov Electric Machine-Building Enterprise ''LEPSE'' (Russia). 1 — Relay of PDKS133DOD type with 100 A switching current, size: 117 × 68 × 119 mm, weight: 1.35 kg; 2 — relay of PDKS 233 DOD with 200 A switching current, size: 147 × 92 × 148 mm. weight: 2.8 kg.

Low voltage on contacts (12 to 28 V) is not enough to maintain the arc with quite great contact gaps. For example, at a voltage of 28 V for switching currents of 1 A the gap between silver contacts should be 0.8 mm, for currents of 5 A — 0.25 mm, for currents of 15 A — 0.6 mm, etc. In addition, massive silver contacts (Figure 3.52) cause intensive cooling of an arc and it goes out quickly as the contacts separate.

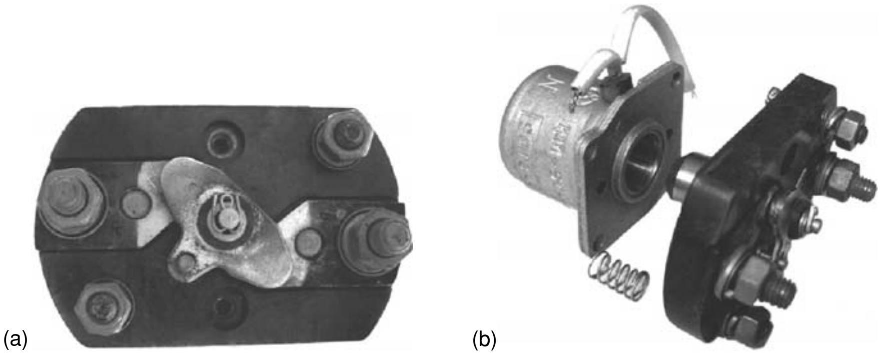


FIGURE 3.52
(a) Contact system (of bridge type) and (b) magnetic system (of solenoid type) of a high-current relay for military equipment for a voltage of 28 V.

In practice it is sometimes necessary to switch not only average and above-average currents but also low currents and voltages (micro-volts and micro-amperes), or for example, in circuits of some electronic devices, measuring sensors. The process of switching then differs considerably from that of switching average and greater than average currents (voltages): there are practically no electro-spark processes destroying oxide films on the contacts. Circuits with such small current and voltage values, which cause no electric erosion of contacts in the process of switching, are called ''dry circuits.'' It is obvious that such contacts switching such low currents and voltages are less reliable than contacts switching normal currents and voltages. To enhance reliability of contacting, usually materials with minimum chemical activity, oxidability, and small thermal-EMF etc., are used. Experimental research of different contact material has shown that contacts from platinum and palladium have the worst characteristics. While reasons for failures of such contacts have been studied, a new method of removal of dirt from the contact surface has been suggested. A preheated contact is pressed on a clean sheet of transparent plastic. After cooling of the contact and its extraction from plastic all unnecessary films appearing during contact operation remained in the hole formed in the plastic, while the contact remained absolutely clean.

The imprint of contact dirt was examined with the help of micro-chemical analysis. Thus the source of contact contamination was determined: quite unexpectedly it turned out to be amorphous organic brown powder. Further research proved that no arc or spark will cause this powder to appear. It is formed by slippage with friction of contacts from metals of the platinum group (platinum, palladium, rhodium, iridium, osmium, ruthenium) and also from molybdenum, tantalum and chrome, when there is organic vapor in the air. When this polymeric powder is formed during friction activation, it is called ''friction polymer.'' When switching with arcing takes place, organic films and powders are quickly destroyed. That is why this effect is produced only during ''dry circuit'' switching.

Such powder does not appear on silver contacts, but silver is not used for the switching of ''dry circuits'' as they contain sulfur films, which are not prone to destruction during switching of such circuits. Such circuits are well switched by contacts of pure gold. But pure gold is not so hard and in the course of exploitation contacts are often grinded to each other. As there are no oxide films on gold, due to certain contact pressure inter-diffusion of gold atoms of contact surfaces may cause cold welding of the contacts, which is why 8% of silver is usually added to increase the hardness of the contacts. Use of split contacts (see above) also increases reliability of a relay.

Even circuits with a weak spark (currents of more than 10 mA with voltages more than 0.1 V) cannot be switched even once by contacts designed for switching of "dry circuits." That is why for checking such relays one must use not only incandescent lamps, but also light-emitting diodes.

In construction of a contact (containing a contact spring and a multi-layer contact attached to this spring) different metals and alloys are used. For switching of low voltages one should take into account that a pair of contacts from different metals in conditions of elevated humidity forms an electrochemical element (galvanic couple) with an e.m.f. of 0.05 to 0.25 V. In addition, the thermo-electromotive of a pair of contacts (1 μV/°) is also quite great. For example, the thermo-electromotive of contacts of an RES-22-type relay (Russia) is 100 μV and of an RES-10-type relay (Russia) is even 250 μV. To avoid distortion of a switched signal the thermo-electromotive value should not exceed more than a few percentage points of working voltage. That is why for RES-22- and RES-10-type relay minimum switching voltages are 1.2 and 5 mV, respectively.

Another problem is commensurability of switched current with current leakage through relay insulation, especially in conditions of elevated humidity. To remove the impact of current leakage on switched current, current leakage should not exceed than a few percentage points of switched current. For example, to switch current of 0.01 μA with a voltage of 1 V insulation resistance should be not less than 2 GΩ.

This is difficult to implement in open relays, which is why relays for micro-signal switching are usually hermetic. However, this does not solve all the problems, since with low levels of switched signals contacts are affected by a microscopical amount of organic and water vapors released from the winding as it is heated. That is why in most reliable relays double encapsulation is used, with the contacts placed in a separate hermetic shell inside a common hermetic shell. Some other technical solutions may also be applied, for instance removal of winding extruded by plastic from a hermetic shell where only the contacts remain (see "Reprocon" relay below, designed by the author).

3.12 Mercury Displacement Relays

Liquid metal contacts also play quite an important role in the history of the development of contact systems. Liquid metal contacts are contacts in which current is switched not by hard metallic contact surface but with the help of liquid metal. Since the only metal that remains liquid at low temperatures is mercury, that is the metal used

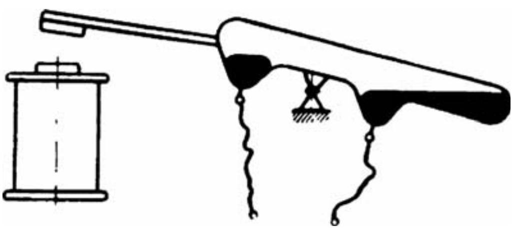


FIGURE 3.53
Principle of construction of a relay with a mercury contact.

in contacts of electric relays, which is why liquid metal contacts are also called mercury contacts.

Why is a mercury contact better than hard metal one? Because when arcing occurs during switching, the contact material does not evaporate irretrievably leaving a crater on the surface; it condenses on the walls of a shell (which usually contains a mercury contact) and drains back into a reservoir. In addition, mercury contacts have quite low and stable transient contact resistance, and do not require contact pressure with great currents.

Vibration of contacts wetted by mercury does not lead to load circuit breakdown and contact welding. Mercury contacts are effective both with increased gas pressures in the shell and in a vacuum. As the good conductive qualities of mercury were known to the first physicists, at the very beginning of the development of electrical engineering, they started using such contacts in relays as well, a long time ago (Figure 3.53). In such relays when power is applied to a coil, the armature is attracted to a core carrying an ampoule with mercury. The ampoule spins about its axis and the mercury flows from the right of the ampoule into the left closing the contacts soldered into the walls of the ampoule. This was the basic principle of construction of industrial relays in the 20 and 30s of the previous century (Figure 3.54).

In these mercury contacts, the mercury is moved (with closing and opening contacts) through displacement by means of a plunger immersed into the mercury (Figure 3.55). In this power relay with a mercury contact system hollow ferromagnetic floats (3) drift in the mercury until the control winding is switched on. When the operating coil is switched on, the floats drawn by the magnetic field of the coil sink into the mercury. The mercury level in both compartments of the body increases and upon reaching the hole (4) in the dielectric barrier, both portions of mercury merge, closing the circuit of the outlet contacts. As the coil is switched off, the floats emerge, the mercury-level increases, and the outlet circuit is opened.

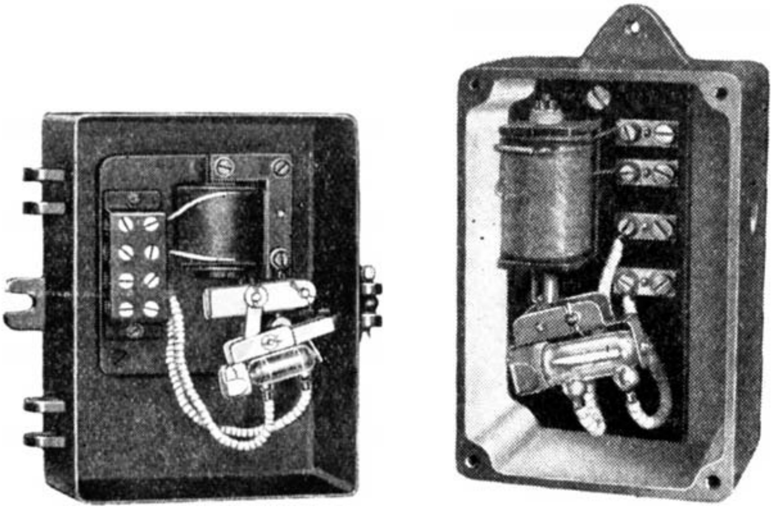


FIGURE 3.54
An industrial relays with turning mercury contacts. Switching current up to 6 A with voltage of 250 V (General Electric, 1935).

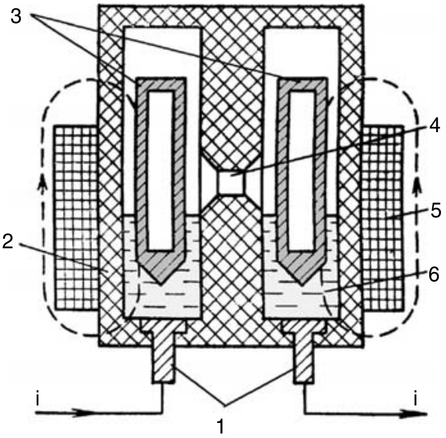


FIGURE 3.55
Power relay with a mercury contact system. 1 — outlet electrodes for attaching of external circuit; 2 — insulating case; 3 — hollow ferromagnetic floats; 4 — hole in barrier between two compartments of the body; 5 — control coil; 6 — mercury. Outside view of contact node.

A similar principle works in power mercury displacement relays with switched currents of 30 to 100 A, produced by a surprisingly large number of firms, but there are still some differences in the construction. The principle of operation of all types industrial mercury displacement relays can be understood by visualizing a nonmagnetic stainless steel tube containing a pool of mercury upon which floats a metallic plunger (Figure 3.56). An electrode is suspended some distance above the surface of the mercury. When the coil power is off, the mercury level is below the electrode tip. No current path exists between the insulated center electrode and the mercury pool. When coil power is applied the plunger is drawn down into the mercury pool by the pull of the magnetic field and the plunger centers itself within the coil. This action raises the mercury level until the mercury covers the end of the electrode and thus completes the current path.

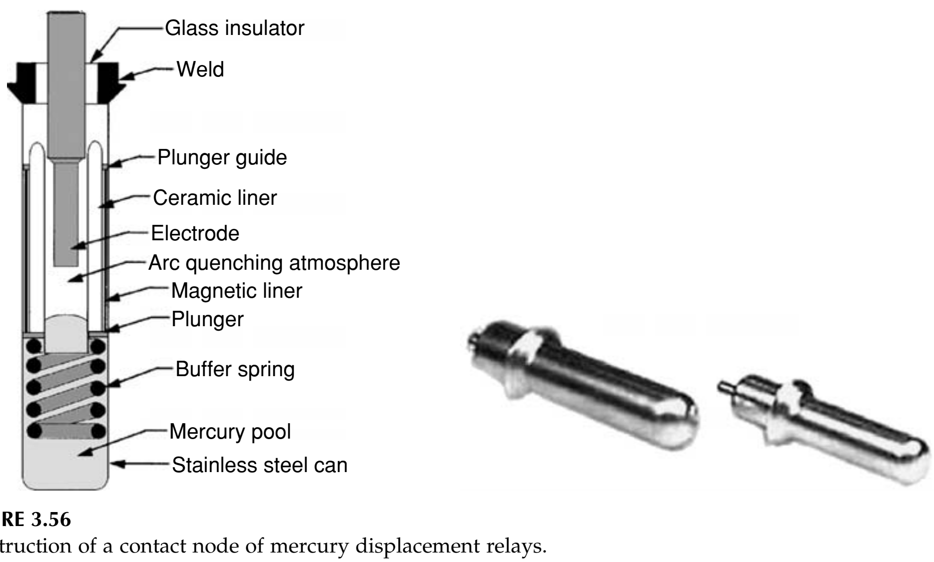
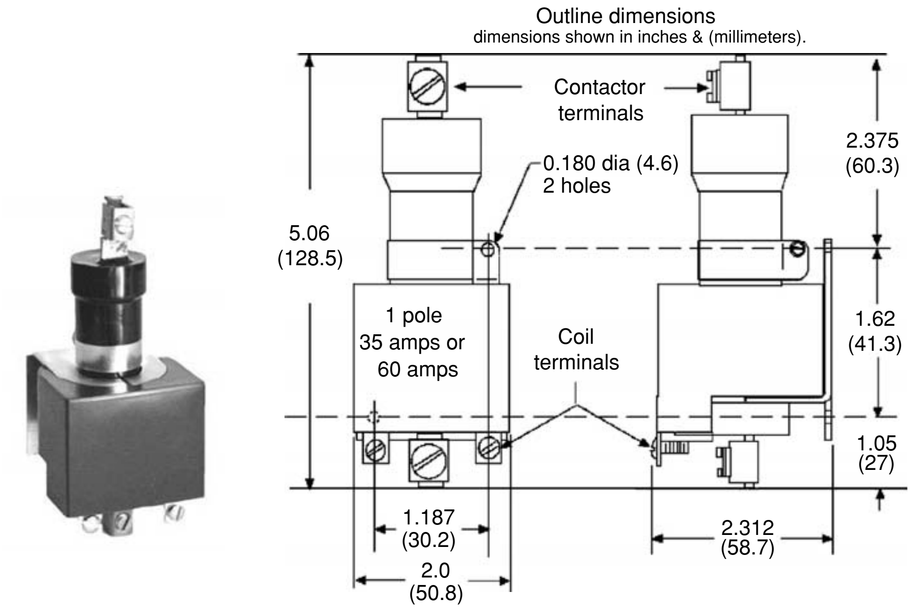


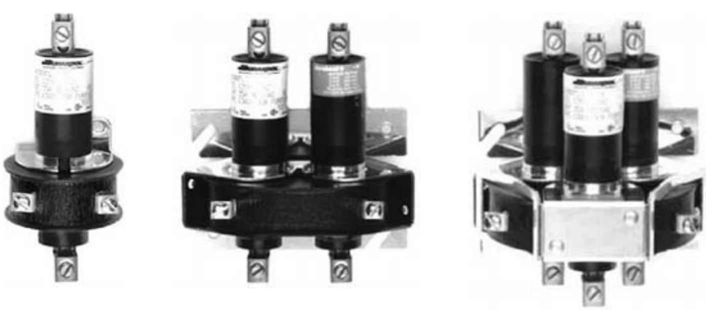
FIGURE 3.56
Construction of a contact node of mercury displacement relays.

When the coil power is turned off, the buoyancy force of the mercury causes the plunger assembly to again rise to the starting position. This drops the level of the mercury and breaks the current path through the center electrode and the mercury pool. A disadvantage of this type of control is that the relay must be mounted upright. The nonmagnetic stainless steel can (contact tube) is filled with pressurized gas to minimize arc erosion.

Every contact system is hermetically sealed in a steel tube to provide maximum life, protection to the user from arcing, and from the hazards of switching heavy loads with exposed contacts. Liquid mercury means a new contact surface after every operation. The mercury is self-renewing; it cannot pit, weld, disintegrate or oxidize. The internal resist-



(a)



(b)

FIGURE 3.57
(a) External design and size of 1 pole mercury displacement relay WM60A (Magnecraft and Struthers-Dunn); (b) external design of 1 to 3 pole mercury displacement relays BFL35 for currents of 30 to 100A produced by International Sensors and Controls Co. (USA).

(*Continues*)

(c)

FIGURE 3.57 (*Continued*)
(c) external design of 1 to 3 pole mercury displacement relays HG series for currents of 30 to 100A produced by Watlow (USA).

ances of the contact surfaces typically measure only a few milliohms and are ideal for switching large loads safely.

Due to significant advantages in comparison with common relays with hard contacts, mercury displacement relays for currents of 30 to 100 A are widely used in industry and produced by a large number of companies. However, they are all based on the same principle and look quite alike (Figure 3.57).

4

External Design of Relays

4.1 Environmental Impact on Relays

In practical service conditions, relays are affected by negative environmental factors, which can considerably change their characteristics. Changes in the temperature of the environment may cause changes in the linear dimension of a core, an armature, a case, and other significant elements of a relay. As a result, distortion of movable parts and even jamming may occur. Changes in the resistance of relay windings and the modulus of elasticity of a restorable spring can lead to considerable changes in relay pickup (operate) and dropout (release).

As the temperature increases from $+20$ to $+100^{\circ}$, the insulation resistance of a relay decreases practically by ten times. Strange as it might seem, even increased air humidity can lead to changes in pickup and release currents of a relay. Oxide films and corrosion in joints of the movable parts of a relay may cause pickup current multiplication of 10 to 15%. Temperature fluctuations varying from 0 to -20-60° may result in malfunctions of a relay caused by freezing of contacts. As air-pressure goes down, its electric strength considerably decreases, in accordance with Paschen's curve (Figure 4.1). As it can be seen from the curve, minimum electric air strength is about 320 V/mm at a pressure of 4 to 5 mm Hg, corresponding to 42 km height. This fact must be taken into account for relays designed for aircraft and rockets.

When relays are used in movable units or stationary equipment affected by vibration, they are prone to external mechanical vibration loads of different frequencies and amplitude. Under vibration the pickup current of a relay usually decreases by 5 to 25% because of recurrent reduction of the magnetic circuit gap, easier relay operation at the moment, and also because of a decrease in the constant of friction between movable and stationary elements. In addition, the pressing strength of the closed contacts may also change occasionally. A weakening of this effort may lead to contact welding. If this frequency of external oscillations is in accordance with the frequency of natural oscillations, resonance may occur, causing a sharp increase in the amplitude of oscillations, bringing about opening of closed contacts or closing of open contacts, breaking winding outlets, and eventually causing mechanical collapse of the relay. Relay specifications usually indicate frequency band and amplitude (acceleration) range, at which no spontaneous closing or opening of the contacts will occur, and at which the pressing effort (strength) remains great enough for a continuation of reliable work.

Apart from vibration, a relay installed on movable units is also prone to linear acceleration. Most relays are affected by strong acceleration during aircraft take-off, in-flight maneuvers of military aircraft, and missile take-off. In these cases if special precautions are not taken, relays may be picked-up spontaneously. Relay with so-called ''balanced

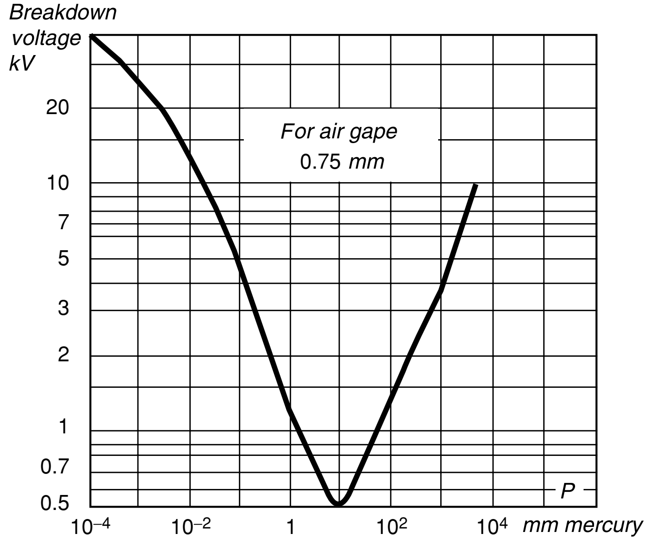


FIGURE 4.1
Paschen's curves for air.

armature'' (see above) have the highest resistance to linear accelerations. This type of relay is the most widespread today. Some years ago in some cases relays with an attracted-armature magnetic system (see Section 2.3.1) were used in operations with linear accelerations. Such relays were designed in such a way that spontaneous energizing in the direction of acceleration could be avoided.

Relays are also very sensitive to current-conducting dust or gases causing metallic corrosion. For example, unprotected relays installed in automation systems of big poultry-yards or stock farms will go out of action quickly due to the corrosive impact of ammonia.

4.2 Wood and Cardboard: First Protection Shield For Relays

Of course the necessity of relay protection was not realized at once. It took decades to form a system of knowledge about negative impacts on relays and means of protection. However, due to intuitive realization of the fact that relays are sensitive and precision devices that can be easily damaged, the first relays were also supplied with some elements of protection.

At first, these were simple frames (Figure 4.2), and then later wooden boxes (Figure 4.3). Simple cardboard boxes were used as shipping containers (Figure 4.4). Wooden boxes for relays had been used for a long time (at that time wooden constructions were widely used in engineering). For example, in the 1935 directory of the biggest English electrotechnical company, General Electric Co. (later GEC Measurements, now Alstom), there are quite a lot of relays in wooden cases for different purposes (Figure 4.5).

By the end of the 19th century, some companies began producing relays in round metal cases with wooden heelpieces (Figure 4.6), supplied with convenient clamps for switching of external circuits. Later on, durable metallic cases were also widely used for other types of relays, in particular for relays used in military equipment (Figure 4.7).

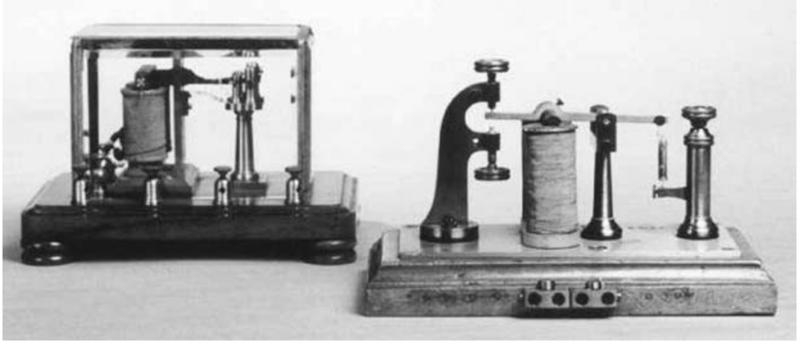


FIGURE 4.2
First half-covered relay (on the left).

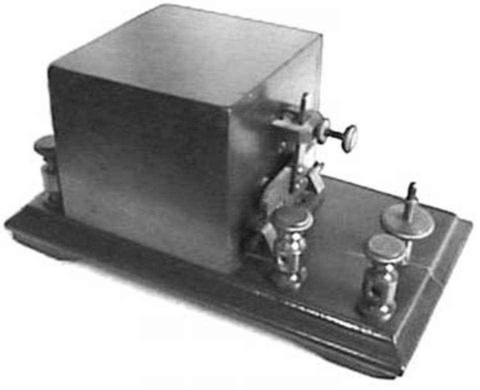


FIGURE 4.3
One of the first covered relays.

As production of plastic became widespread in the middle of the 20th century, protection shields for relays gained their modern design (Figure 4.8). According to the modern classification there are open relays and dust-proof and sealed relays. Due to the quite strong environmental impact on relays, open relays are very rarely used now. In constructions of the second type, either plastic cases snapping shut at the heelpiece of the relay, or expanded aluminum cases, are most often used (Figure 4.9). There are a few types of plastic cases (Figure 4.10 and Figure 4.11), that provide different levels of protection.

To protect the winding from mechanical damage and humidity it is often impregnated with epoxide resin.

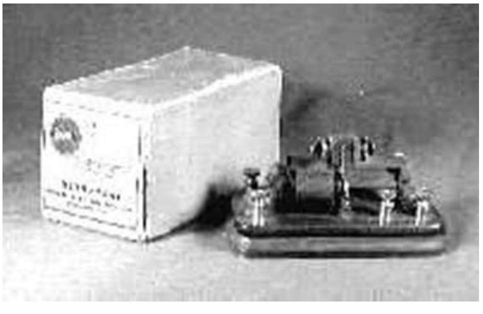


FIGURE 4.4
Cases for packing of early relays.

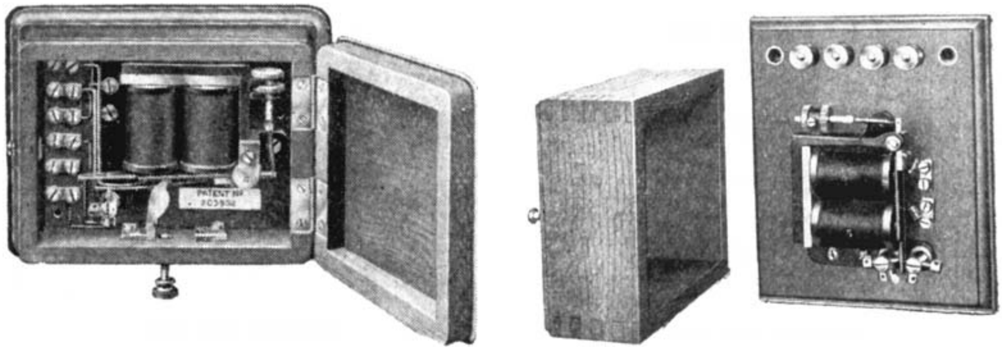


FIGURE 4.5
Relays for automation systems in wooden cases produced by General Electric Co. (From the G.E.C. Catalog of Electrical Installation material, 1935.)

FIGURE 4.6
Telegraph relays of the 19th century in round metal cases.

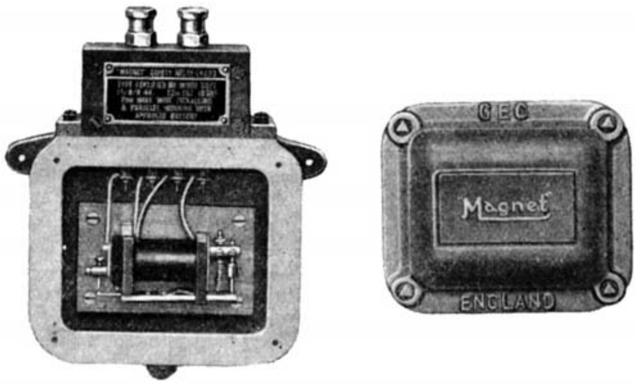


FIGURE 4.7
Relay in heavy metallic case for military equipment produced by General Electric Co. on request of the Mine Department in the 1930s. (From the G.E.C. Catalog of Electrical Installation material, 1935.)

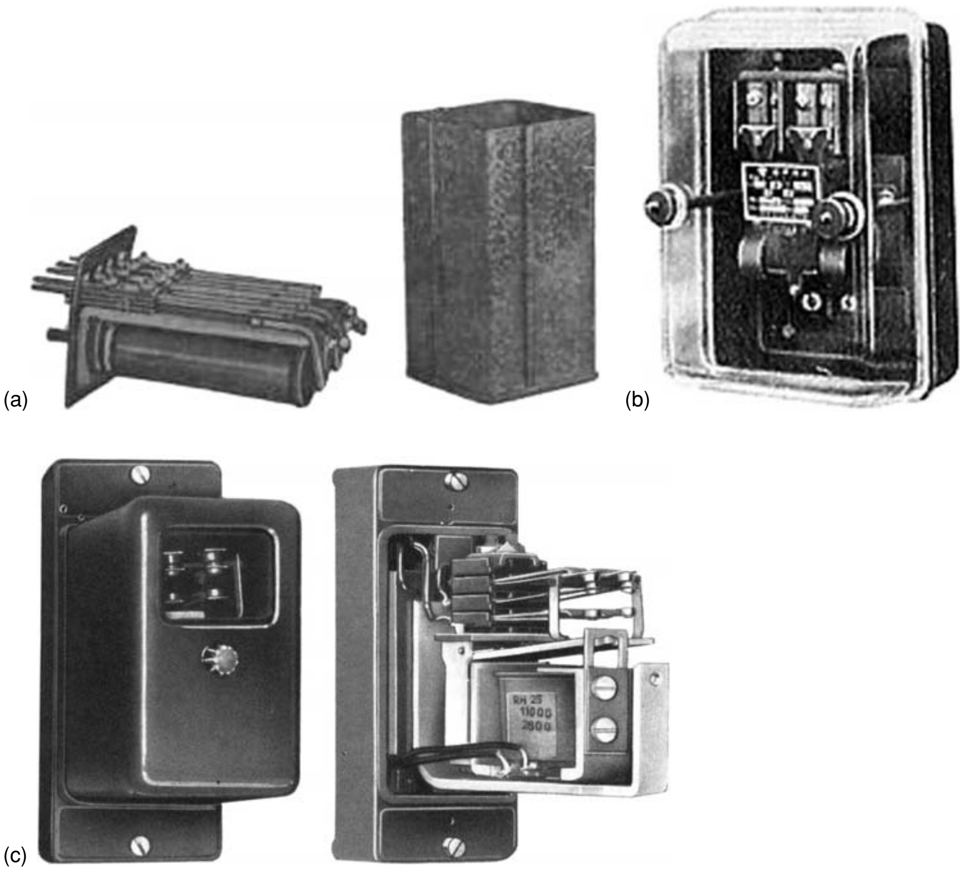


FIGURE 4.8
Relays with plastic protection shields produced in the middle of the 20th century. (a) Ericson relay; (b) Omron relay; (c) Siemens relay of RH-25 type (Russian relay of MKU-48 type has a similar design).

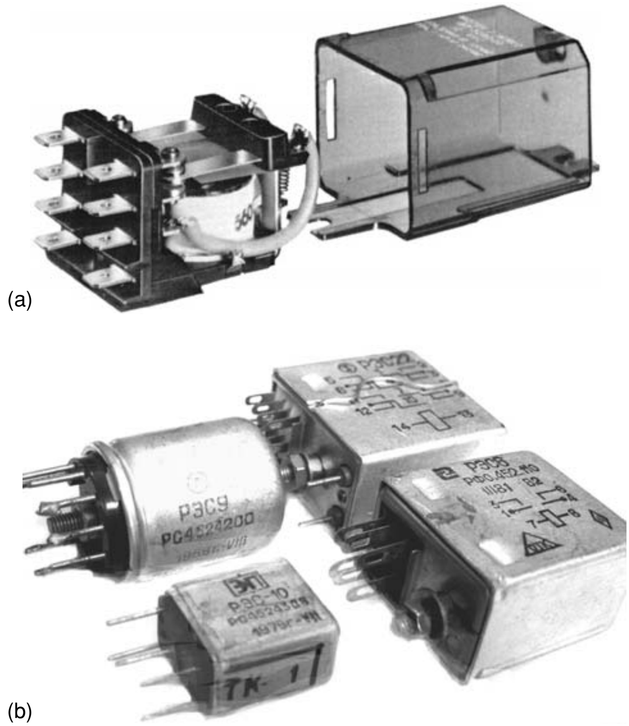


FIGURE 4.9
Modern dust-proof relays in (a) plastic and (b) aluminum cases.

4.3 Is a Sealed Relay Always Better than an Open One?

On the face of it, all dust-proof relays may seem to be less prone to environmental impact than open ones, but paradoxical as it might seem this is not true.

At increased humidity of the environment, moisture gradually penetrates the relay through the uptight joint of the heelpiece and protective case, and remains for a long period of time because of the lack of ventilation. Also, when there are fluctuations of temperature and air-pressure, humid air may be sucked into the relay. After switching ON and warming of winding, moisture may be condensed on contacts and can sometimes lead to water bridges between the opening contacts. Moisture, together with the difference of potential on the contacts, may cause more intensive processes of decomposition of the contact material. Long-term moisture leads to a sharp decrease in insulation resistance and a further lowering of temperatures — even to icing over of contacts and windings.

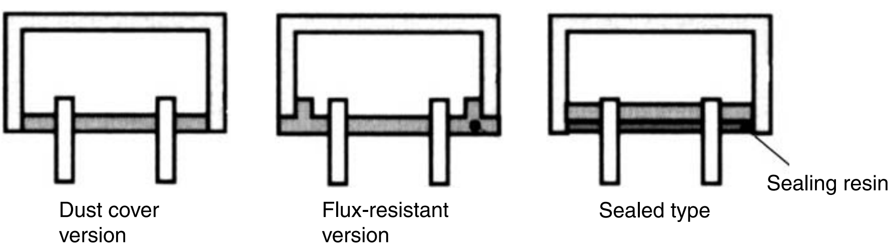


FIGURE 4.10
Schemes of plastic cases of different types.

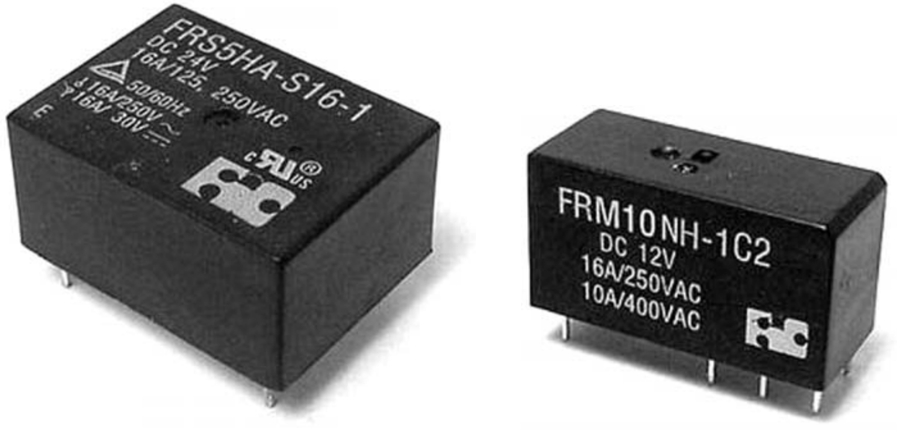


FIGURE 4.11
Relays in plastic cases sealed by epoxide resin (sealed-type relays).

For these reasons dust-proof relays are frequently more prone to high humidity impact than open ones; nevertheless, such relays are still better protected from dust and external mechanical effects.

To enhance reliability of dust-proof relays under high humidity conditions, some models are produced with vent doors in cases of approximately 1 cm^2 in area, covered on the inside with a few layers of poultry netting (8 to 10 thousand of meshes per square centimeter). Such netting protects the relay against dust, but allows air circulation inside the relay.

Sealed relays with welded metal cases have a more perfect design allowing protection of all internal elements of the relay from environmental impact (Figure 4.12). However, special materials and technologies are required to produce them mostly, because even small amounts of substances which usually do not affect open relay operation can have a strong negative impact if found in small stoppered cases of sealed relays. As metal vapors or flux arise during soldering or welding of contacts, or sealing of the case, such substances

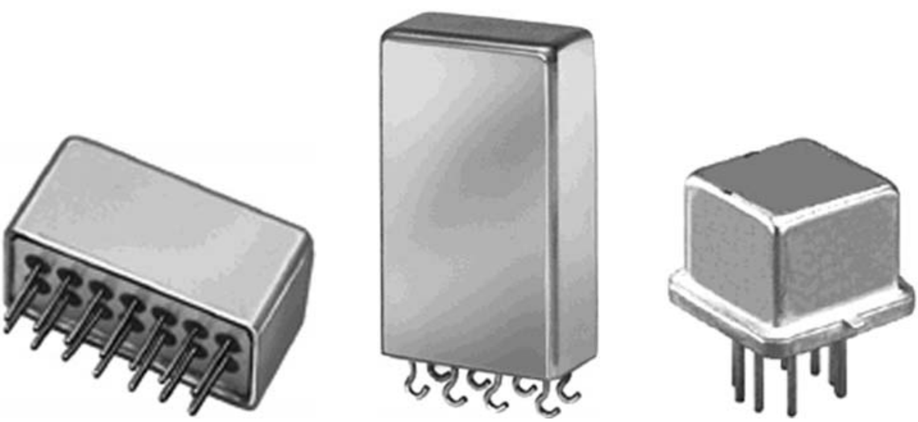


FIGURE 4.12
Relays sealed into metal cases.

can penetrate or pass under the relay shell as it is being produced. Hazardous substances can also be released in the course of relay operation when elements such as plastic coil bobbin or enameled wire are heated, because of which special materials are required for sealed relays, and production must be carried out in absolute cleanliness. This is similar to the process required for production of vacuum electronic devices. In some cases, double sealing is required to avoid gas contamination from the winding: the winding is hermetically insulated from the contact system inside an external sealed case. Before sealing-in, the relay is degassed in a vacuum thermostat under pressure of not more than 10^{-4} mm Hg and a temperature of about 170 °C, and is filled with a dehydrated mixture of nitrogen (90%) and helium (10%). Vacuum-tight sealing of relay outlets is carried out by lead-out pins made from Kovar® (Kovar® is a registered trademark of Carpenter Technology Corporation). Kovar alloy is a vacuum melted, iron–nickel–cobalt low expansion alloy whose chemical composition is controlled within narrow limits to assure precise uniform thermal expansion properties. Outlets, insulated with glass insulators, soldered inside relay with argon-arc welding or in a hydrogen environment (Figure 4.13).

You may think that such relays are perfectly protected against moisture and Paschen's curves, but in fact it is not so. Of course there will be no more problems with internal elements, but how are we to deal with external elements such as outlets, for example?

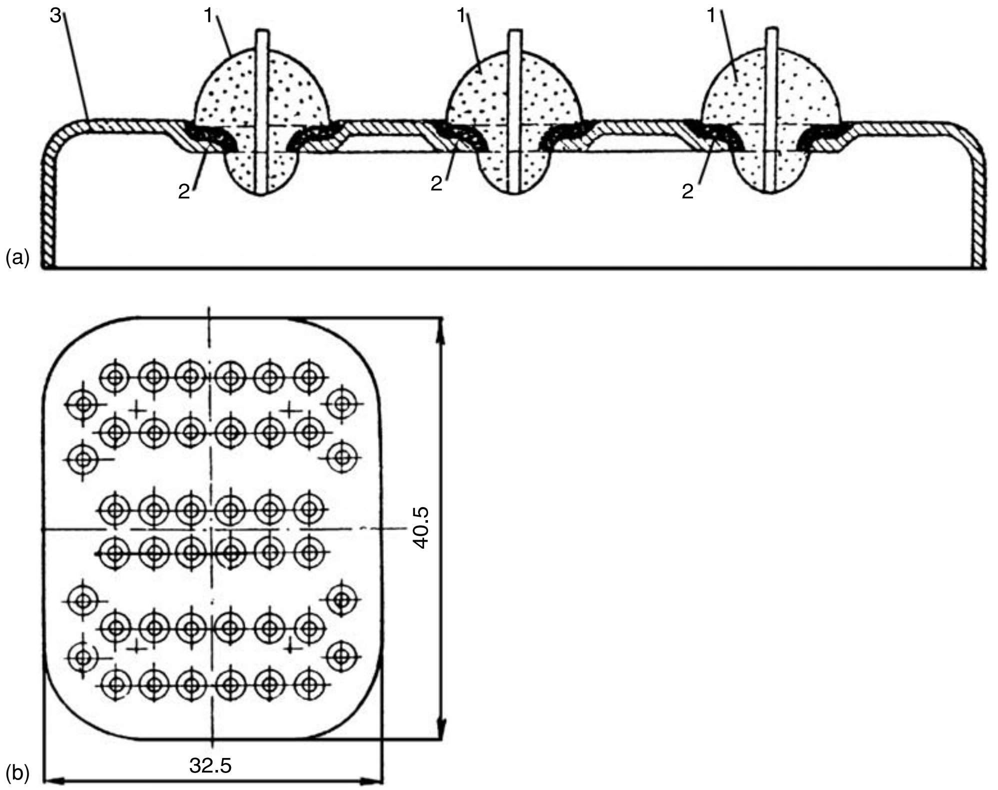


FIGURE 4.13
(a) Sealed relay outlets. 1 — glass insulators, 2 — layer of silver baking into glass; 3 — metal heelpiece. (b) Heelpiece of a DP-12 relay with 12 switching contact groups.

4.4 Outlets, Terminal Sockets and ''Containers'' for Relays

Multi-contact relays have a number of such elements (Figure 4.14). Since the heelpiece area is quite small, glass insulators are also very small in size (about 3 mm in diameter with about 1 mm of surface leakage path).

Here problems begin to arise. If under normal air-pressure such glass insulators can withstand AC voltage with an active value of more than 2000 V (which is more than enough for miniature sealed relays), at 15 km height (when air-pressure is about 70 mm Hg) breaking-down voltage reduces to 700 V and at 42 km height already to 200 V. Moreover, at working voltage subnormal discharge may arise between the contacts.

External contamination of a relay with dust, and increased humidity may lead to an increase in leakage current on the glass insulator surface, even under normal air-pressure. So safe protection of just the internal elements is not enough for reliable relay operation. It is also essential to protect the outlets. Usually such protection is carried out in the equipment itself after the relay has been installed. In case of point-to-point wiring, the heelpiece of the relay is covered with foamed sealant or silicon. If a relay is installed on a printed circuit board, the whole board and the relay together are covered with several layers of high quality waterproof varnish.

Modern relays can have outlets of different types. Sealed relays have direct outlets for soldering into a printed circuit board or hooks for point-to-point wiring (Figure 4.14). As has been mentioned above, outlets of sealed relays are made of a special alloy called Kovar in order to obtain a coefficient of expansion similar to that of glass, but this material is not the best conductor of electric current, which is why the outlets are sometimes made bimetallic to increase their carrying capacity with the internal copper core pressed into an external tube made of Kovar.

The diversity of outlets for industrial relays is even greater. It used to be quite easy to install such relays in equipment (in control cabinets, for instance) when they were large in size and had their own terminal sockets for connection of external wire (Figure 4.15). The solution was to provide small relays with pin-like (or flat) outlets (Figure 4.16). They were designed to be inserted into terminal sockets (Figure 4.17), and supplied with screw clamps for connection of external wire. Many of them look like sockets of old radio valves and similar size spectrum — heelpiece with eight-pinned radio valves (Figure 4.17) — used for relay outlets. Such terminal sockets can be called an interface-providing joint of

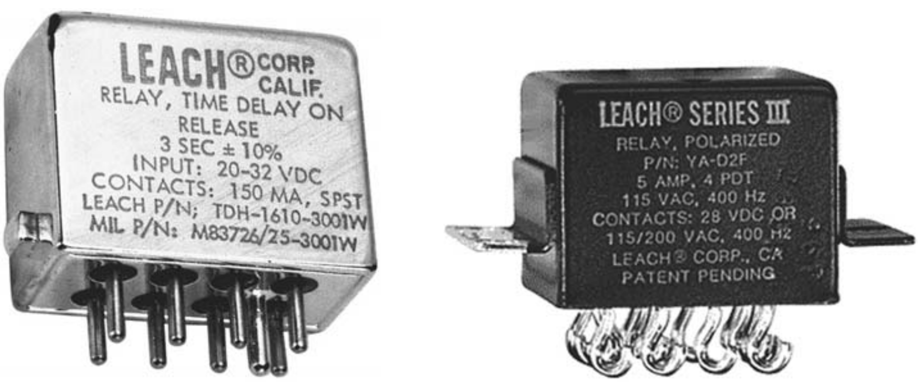


FIGURE 4.14
Various types of outlets of sealed relays.

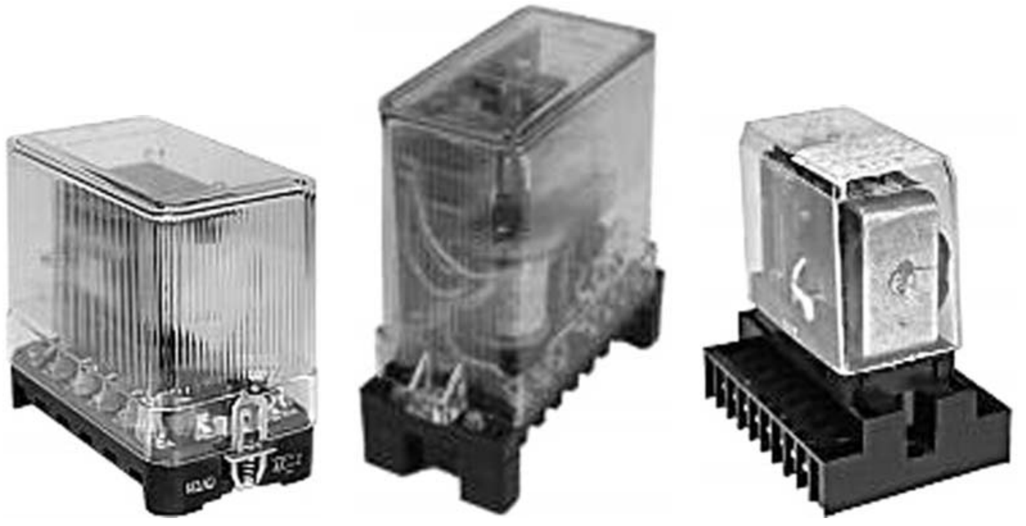


FIGURE 4.15
A large industrial relays with its own sockets, with screw clamps for connection of external wire.

small relays to external circuits. These sockets may be two and even three-steps in height, thus saving space in the cabinet if the relay has many contacts. Due to such terminal sockets relays can be assembled and dismantled easily, quickly, and conveniently (Figure 4.18), and sockets can be also easily installed on a standard DIN Rail (Figure 4.19). Due to a great number of spring-loaded pins in a terminal socket a relay

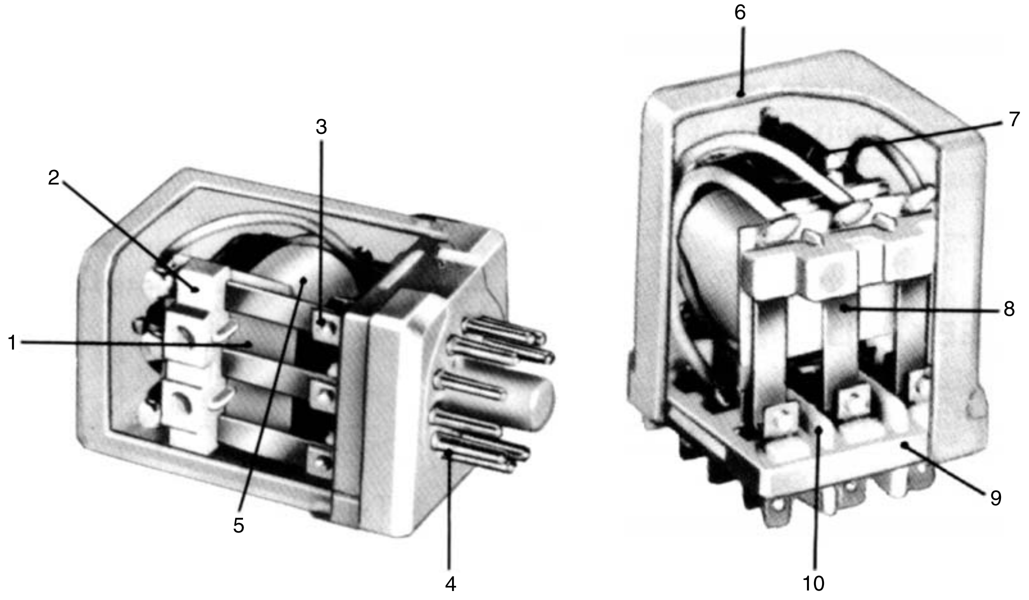


FIGURE 4.16
Industrial relay with pin-like outlets (terminals). 1 — insulation sheet; 2 — movable contact; 3 — fixed contact; 4 — terminals; 5 — coil; 6 — transparent dust-proof case; 7 — releasing spring; 8 — movable contact spring; 9 — base; 10 — insulating barrier.

FIGURE 4.17
Terminal sockets for industrial relays.

is well held in a vertical and horizontal position, however, it is not recommended to install relays vertically downwards on such terminal sockets, because long-term vibration can cause the falling out of a relay from a terminal socket.

Many firms produce terminal sockets supplied with a special lock holding a relay in any position in space (Figure 4.20). Sockets of this type allow assembly of relays in electric cabinets with very dense mountings, with the help of a DIN Rail.

The designers of Phoenix Contact created a whole world of original constructions based on the use of terminal sockets holding relays on standard DIN Rails in electric cabinets (Figure 4.21). In particular they designed original ''containers'' where ready-for-service relays produced by other firms were placed (Figure 4.22). Pin-like outlets of a container allow direct installation of relays on standard terminal-socket connectors used for connections of wire in electric cabinets.

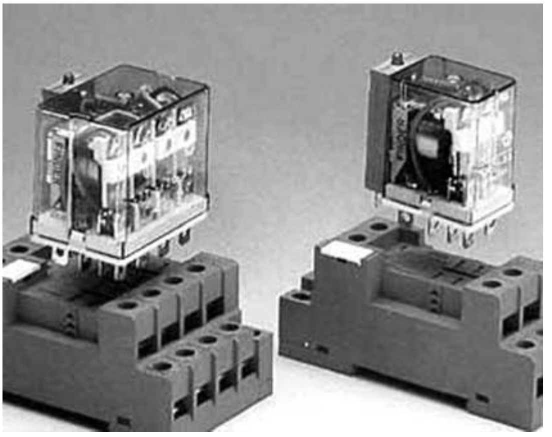


FIGURE 4.18
Installation of a relay on terminal sockets.

The Phoenix Contact Company uses some other original principles of positioning of a relay on standard DIN Rail (Figure 4.23).

Despite the modern tendency to produce miniature relays, some companies still manufacture equipment exceeding modern industrial miniature relays in size. Such equipment is similar (by size, by contact, and by magnetic systems) to relays produced at the beginning of the 20th century. World leaders in the electric-power industry, such as concern ABB, produce such relays, designed for use in electrical power systems.

Production of such large electromagnetic relays is connected with a tendency to unify sizes for protective relays used in the electric-power industry. Protective relays are complex devices containing elaborate magnetic and electronic systems and are quite large in size. Perhaps large electromagnetic relays are better arranged with protective relays in relay protection cabinets, however, in some industrial automation systems there are so many auxiliary relays that several cabinets are required to install and to mount them all (Figure 4.24). In this case it is the consumer who is to pay with his working areas for producers' adherence to their own standards.

Of course such relays do have modern designs (Figure 4.25) and features such as original construction of outlets. By external design as well as by construction, it appears to be a multi-contact connector (Figure 4.26).

The General Electric Company has been producing protective relays in big and heavy metal cases with detachable glass doors for many years. For example, differential relays of PVD, BDD type or others, have size of $380 \times 168 \times 160$ mm and a weight of 8 to 10 kg

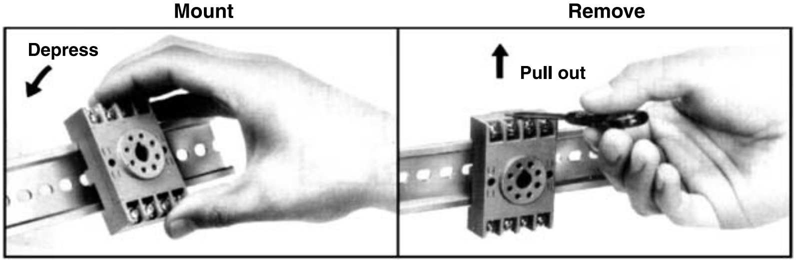


FIGURE 4.19
Installation of a terminal socket on a standard DIN Rail.

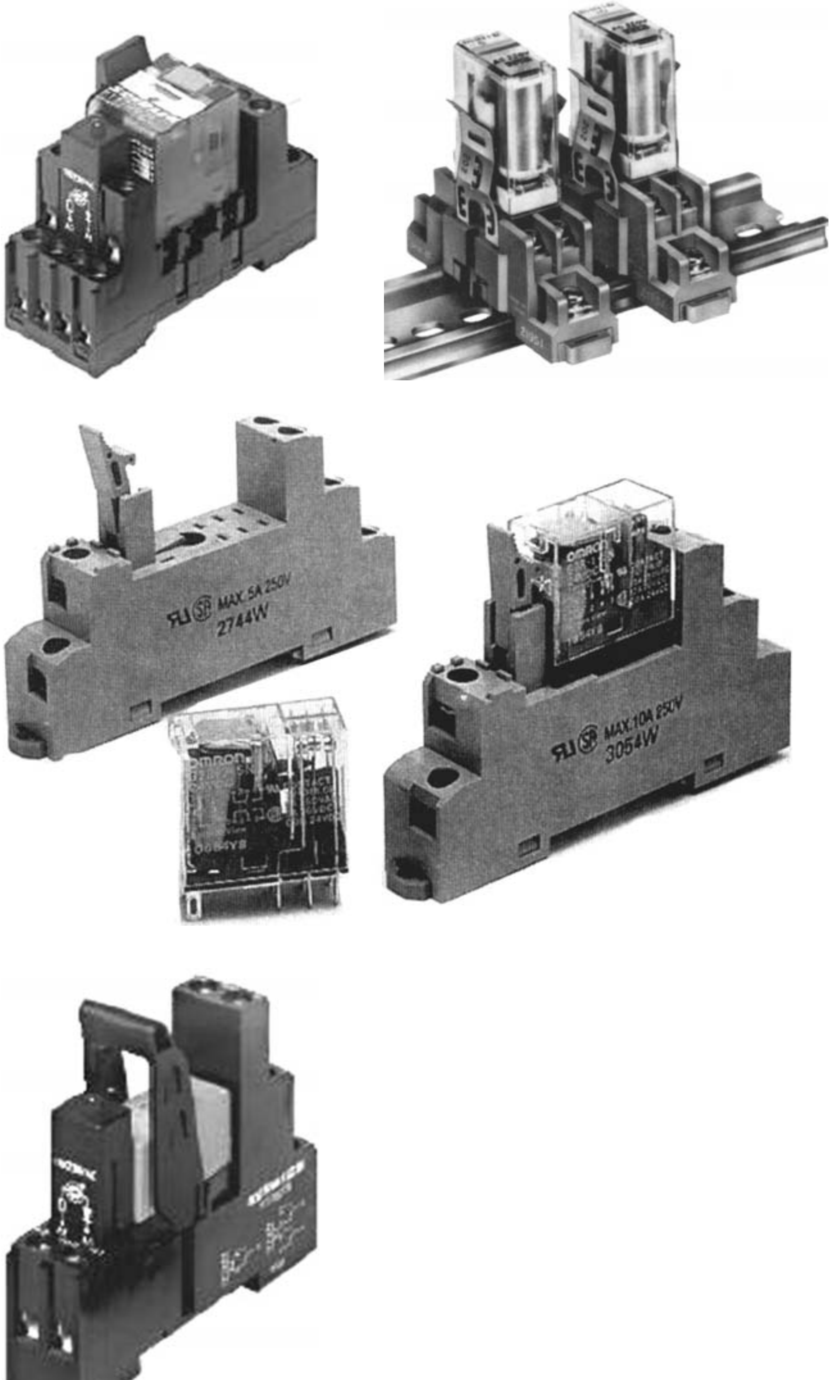


FIGURE 4.20
Rail mount terminal sockets are supplied with a special lock (produced by Omron, Shcrack, Idec).

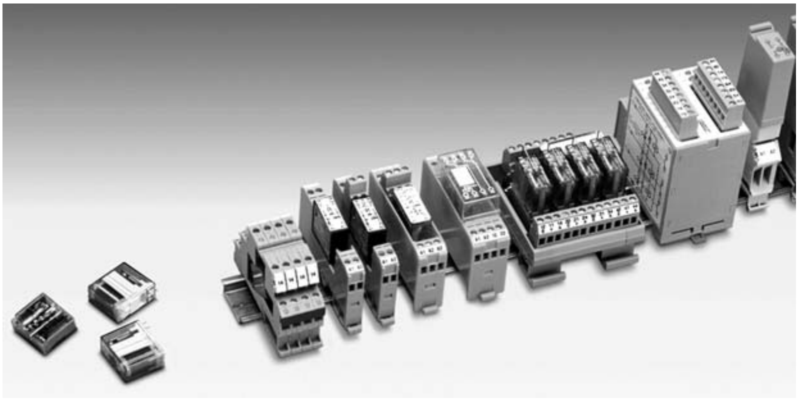


FIGURE 4.21
Terminal sockets produced by Phoenix Contact GmbH & Co KG for mounting of different types of relays on standard rails in electric cabinets. (Picture Courtesy Phoenix Contact GmbH & Co., 2004.)

(Figure 4.27). In spite of the fact that modern relays contain electric and microprocessor-based systems, cases remain the same. This probably happens because such cases are popular around the world since they provide safe protection of the relays against external stress, dust, and magnetic fields. Special plug-in connectors (plug-ins) can be attached to them, allowing connection of external devices to test the relay without having to dismantle it from the circuit. Simple electromagnetic relays have also been produced in similar standard cases (Figure 4.28).

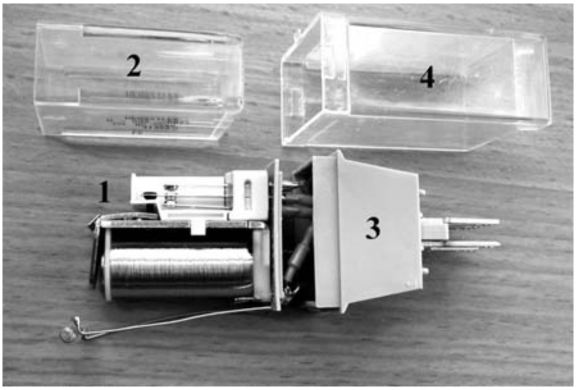
According to different types of mountings (Figure 4.29), modern industrial miniature relays may have different outlets (Figure 4.30). It is obvious that small low-power relays designed for installation on a printed circuit board will have relatively thin straight (or curved, for surface mounting) outlets placed at a standard distance to each other. More powerful relays are supplied with larger outlets designed for soldering of external wire, insertion of them into a terminal socket, or switching of the conductors with the help of a special connector, the so-called ''faston'' (Figure 4.31).

How are we to deal with a power relay that is to be installed on a printed circuit board?

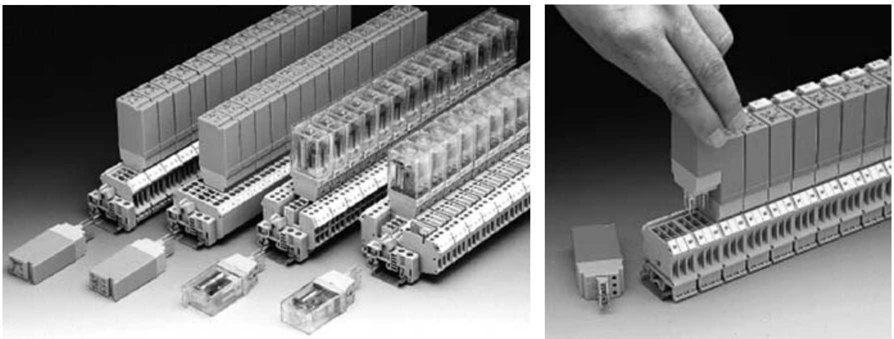
For this purpose firms have designed and constructed relays with TMP-type outlets containing both thin straight outlets of winding for printed circuit wiring (below) and powerful contact outlets for switching massive external conductors with the help of fastons (above — Figure 4.32).

More powerful relays are supplied with screw clamps for external connection of massive wire. As a rule, in order to save space needed for mounting of the relay these clamps are placed on the top of the relay case (Figure 4.33). There is a connection between modern tendencies of development of electromagnetic relays with an increase of switching capacities, on the on hand, and with the process of micro-miniaturization on the other hand (Figure 4.34).

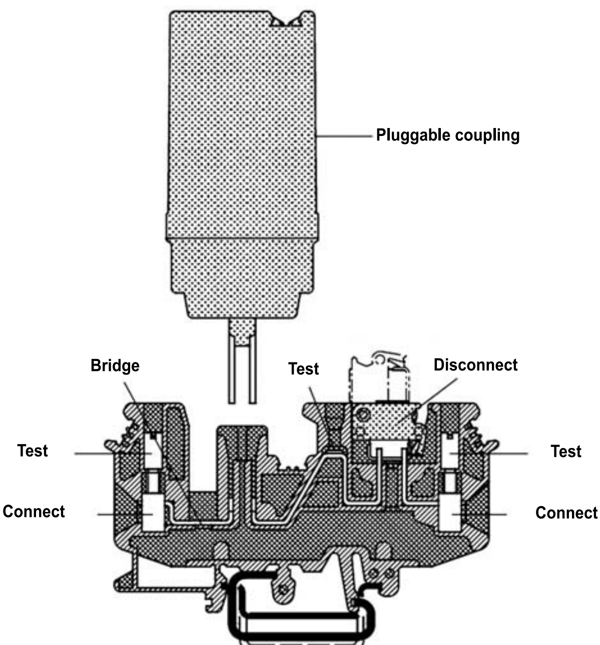
It took many engineering efforts to develop constructions of cases, fastening elements and outlets, but for micro-miniature relays — a masterpiece of engineering — designers did not have to reinvent these elements: micro-miniature relays were placed into standard cases of transistors or chips (Figure 4.34), which were simply soldered into a printed circuit board without any additional fastening elements.



(a)

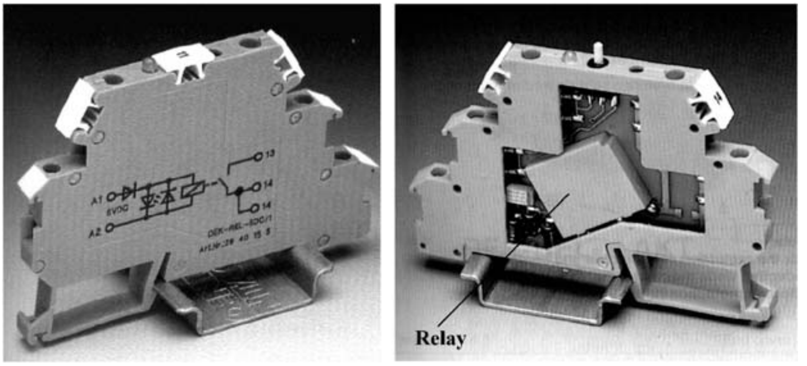


(b)



(c)

FIGURE 4.22
(a) Construction of a container with a relay installed inside. Produced by Phoenix Contact GmbH & Co KG. 1 — ready-assembled electric relay; 2 — plastic case of the relay; 3 — container with pin-like outlets produced by Phoenix Contact; 4 — plastic case of the container. (b) Installation of containers with electromagnetic relays on mounting terminal sockets (Phoenix Contact). (c) Construction of a cell of a mounting terminal socket produced by Phoenix Contact. (Picture Courtesy Phoenix Contact GmbH & Co., 2005.)

(a)


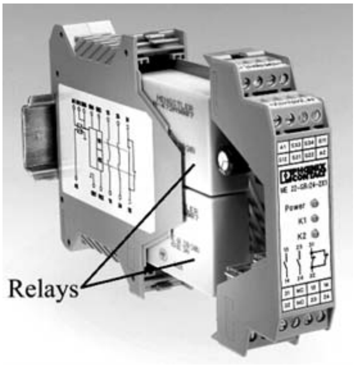
(b)


FIGURE 4.23
(a) Mounting of a ready-assembled miniature relay supplied with a plastic case on a standard DIN Rail (Phoenix Contact). (b) Another method of mounting an industrial relay in a special collapsible plastic case designed for installation on a standard DIN Rail (Picture Courtesy Phoenix Contact GmbH & Co., 2006.)

FIGURE 4.24
Cabinets with auxiliary electromagnetic relays, produced by ABB, installed in one of the industrial enterprises.

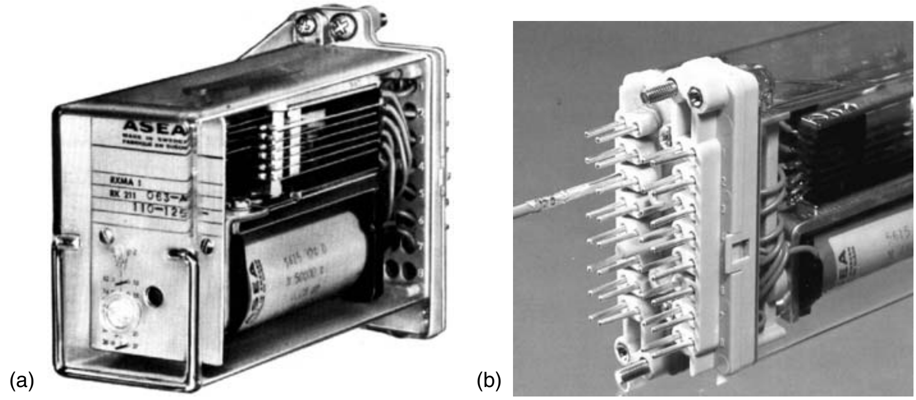


FIGURE 4.25
(a) Modern electro-magnetic relay of RXMA-1 type used in cabinets of relay protection as an auxiliary relay (produced by ABB). (b) Terminal socket of RXMA-1 relay. (From ASEA Relays, Buyers Guide B03-00011E.)

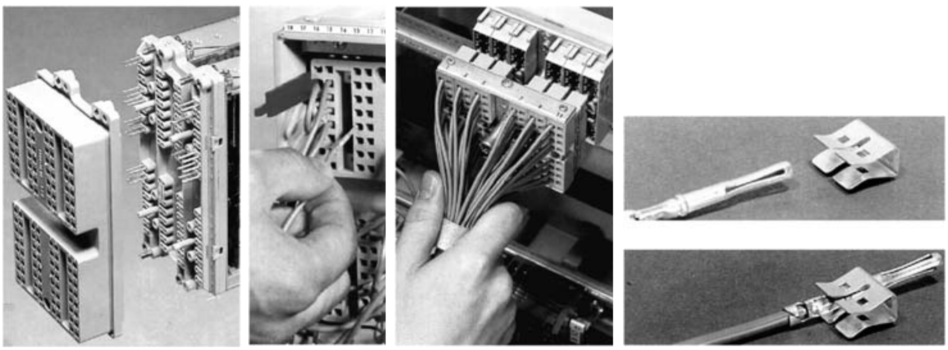


FIGURE 4.26
Peculiarities of mounting and elements of construction of a relay socket produced by ABB. (From ASEA Relays, Buyers Guide B03-00011E.)

FIGURE 4.27
Relays of differential protection produced by General Electric

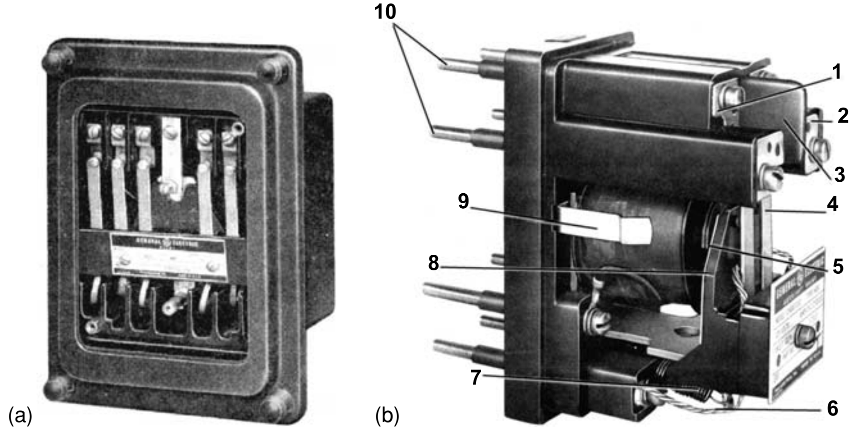


FIGURE 4.28
Electromagnetic auxiliary relays produced by General Electric: (a) — a multi-contact relay in a standard case. (b)— a relay with two switching contacts extracted from a case; 1 — normally open contact; 2 — normally closed contact; 3 — voltage barrier; 4 — spring leaves for moving contacts; 5 — pole piece; 6 — flexible lead; 7 — control spring; 8 — hinged armature; 9 — cover spring clip; 10 — connection studs. (From GE. catalog With permission.)

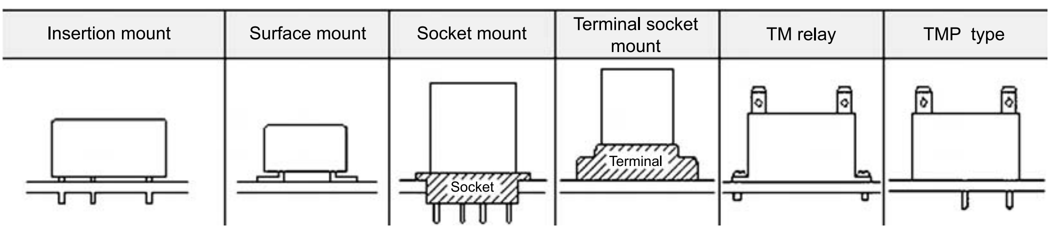


FIGURE 4.29
Means of mounting of modern relays.

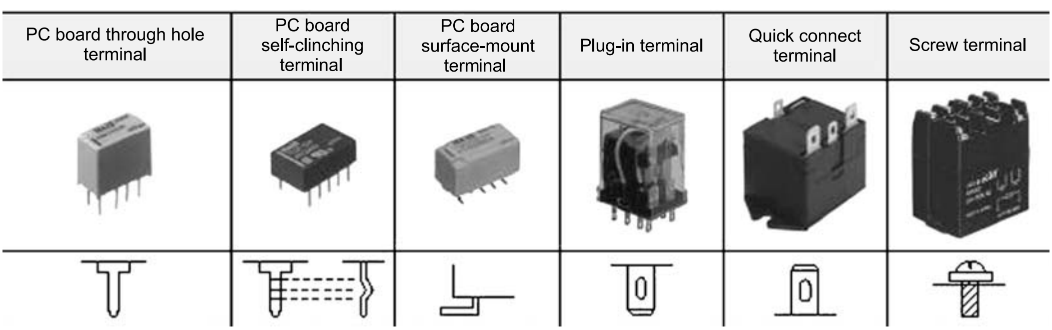


FIGURE 4.30
Types of outlets of modern relays.

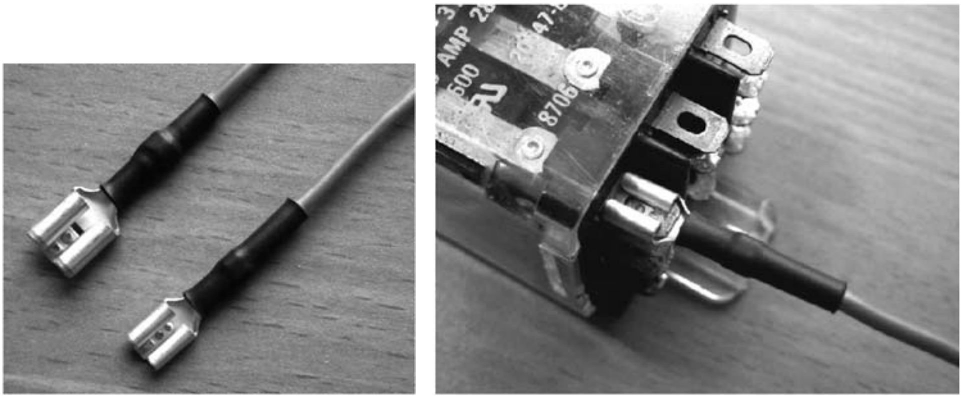


FIGURE 4.31
Faston-type connectors and their use for relay connection

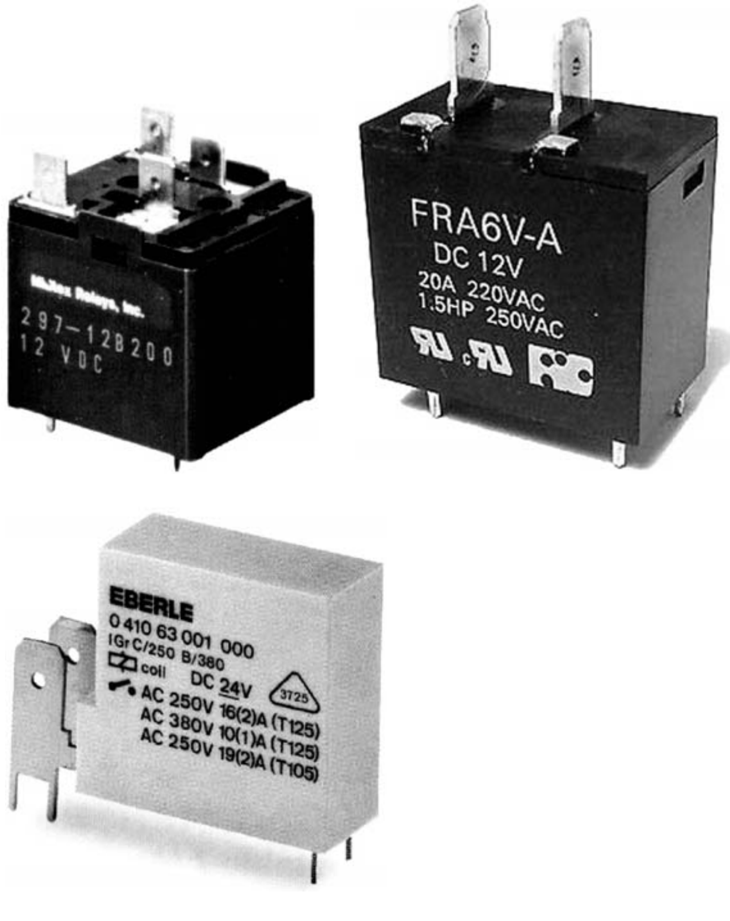


FIGURE 4.32
Relays with hybrid outlets.

FIGURE 4.33
Power relay for switching of high currents with screw clamps for external mountings.

4.5 Indicators of Operation and Test Buttons

Apart from the described peculiarities of constructions of cases and relay outlets, recently additional elements have been placed in cases of industrial relays, making their exploitation more convenient. These include, first of all, light-emitting elements displaying the ''on'' state of the relay (either miniature baseless neon lamps or light-emitting diodes [LED] are usually used as light-emitting elements). These elements are connected through current-limiting resistance parallel to the winding of the relay (LEDs are sometimes connected in series), usually placed under a transparent case of the relay.

RS-series modules (Figure 4.35a) are compact, space-saving relay terminal modules containing six so-called ''card relays'' — small flat relays with one normally open contact each. All relays contain built-in coil surge-suppression diodes and operation indicators (LEDs) that simplify circuit design and maintenance. The module is easily-mounted on a 35 mm DIN rail.

The firm Shcrack produces indicator elements with LED in the form of separate modules, which can be attached to a relay by placing it next to the relay into a terminal socket (Figure 4.35b). As similar modules the firm produces additional diodes designed for lowering of switching over-voltages, with a relay controlled by a DC coil.

Another additional element is a so-called test button (Figure 4.36) This, in fact, is the same as a plastic pusher, one end of which sticks out through a hole in the relay case, with the other end touching the armature of the relay. As one presses the pusher with the relay in a deenergized state, the armature moves as if affected by the magnetic field of the coil, and switches the contact. This relay is very convenient for setting up of automation devices and for fault tracing in circuits.

4.6 Relays Which Do Not Look Like Relays At All

Power relays for 16 to 25 As currents are more often supplied with an additional unit of contacts, which can be easily attached to the upper part of a relay with a help of plastic catches (Figure 4.37). In this case a plastic pusher of additional unit of contacts meshes with the pusher of the main relay providing synchronous reliable operation of all contacts. A basic relay of this type usually has room for up to four convertible contact units

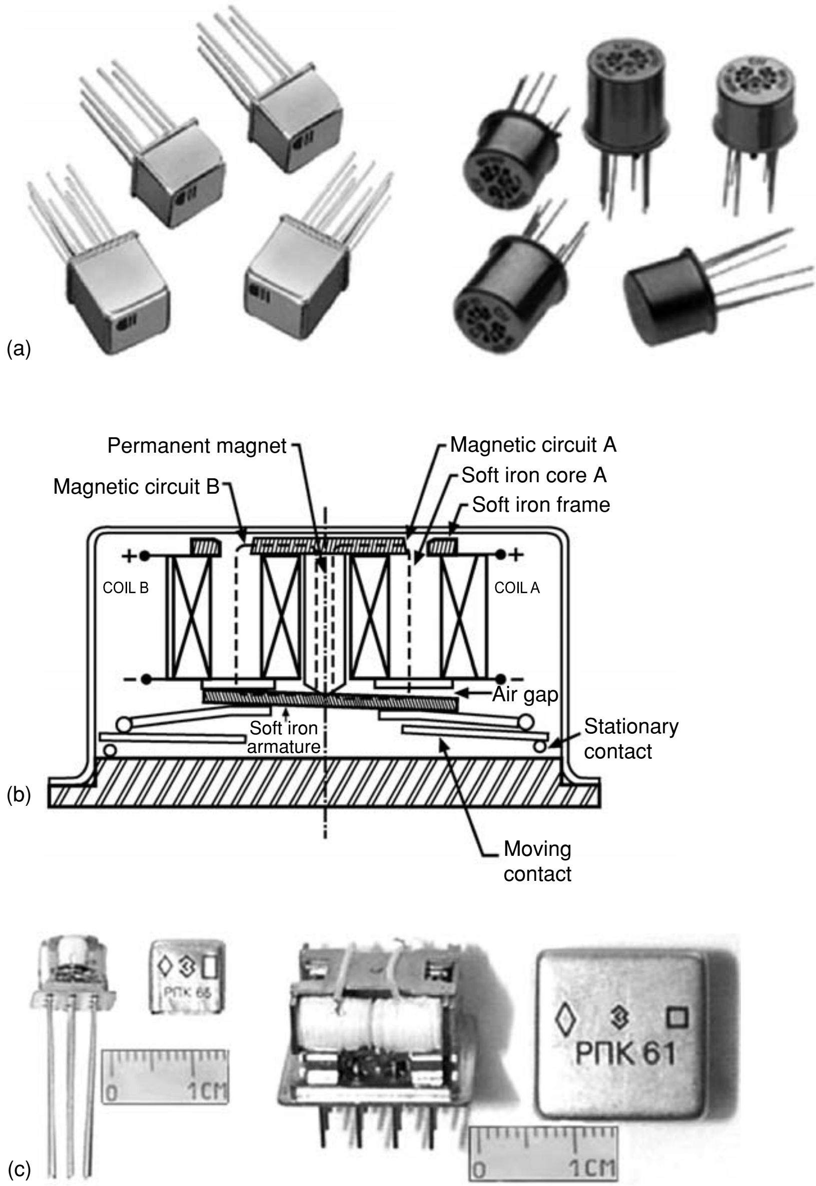


FIGURE 4.34
(a) Micro-miniature relays in standard cases used for transistors and integral circuits (IC), produced by many companies: Teledyne Technologies, CII, Nuova HI-G Italia, Guardian Controls, and others. (b) Construction of micro-miniature relays, produced by Teledyne. (c) External design and construction of new micro-miniature relays, developed by the Russian company ''Severnaya Zarya.''

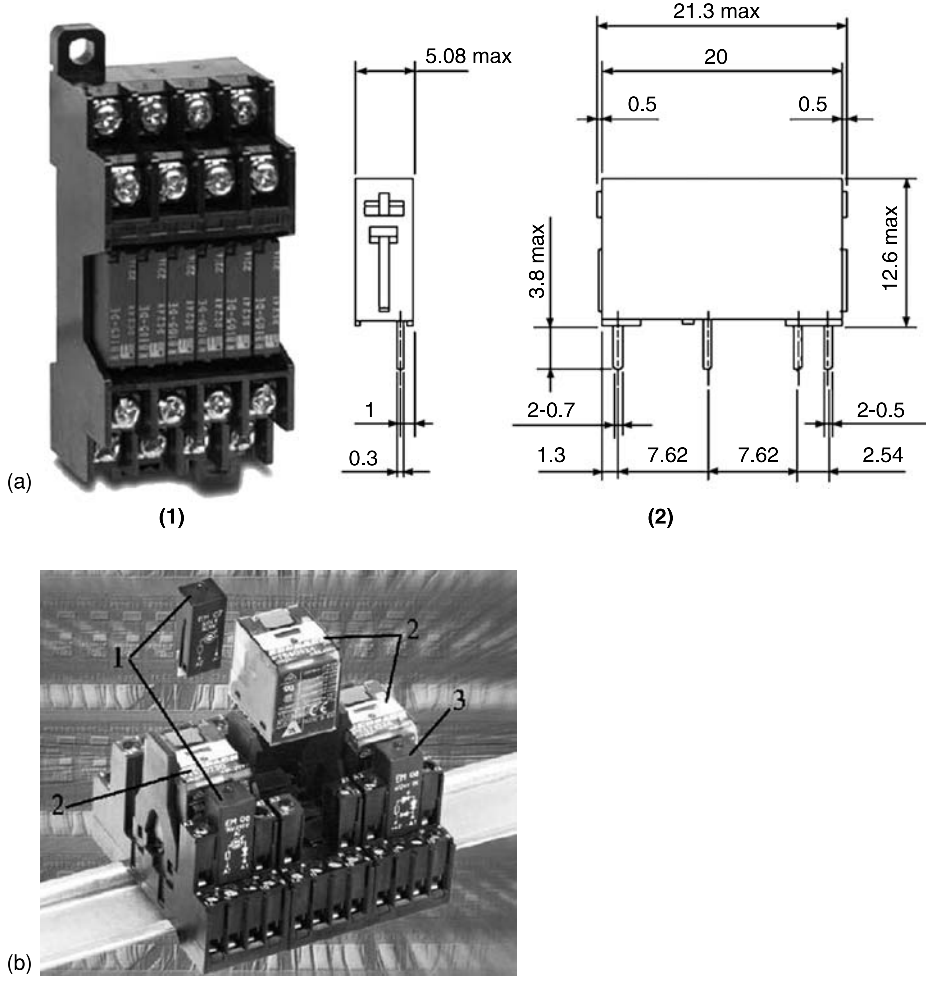


FIGURE 4.35
(a) Module of RS-series card relays and dimensions of separate relay with built-in coil surge-suppression diodes and operation indicators (AutomationDirect Ltd). (b) Modular unit of the firm Shcrack. 1 — indicator units with LED; 2 — relay; 3 — unit with diodes.

(cartridges). It can be expanded to 6 or 8 poles by installing an added deck. A 10 or 12 pole relay can be built by adding a second deck.

The American company Olympic Controls Corp. produced a special so-called T-Bar multi-contact relay (Figure 4.38). T-Bar multi-contact relays are designed for use in controlled environments, such as test areas, computer control rooms, broadcast studios and network management centers. The heart of T-Bar components is the 12 pole-switching wafers. Relay assemblies are available in switching configurations of 4, 8, 12, 24, 36, 48 and 60 form ''A'' contacts (normally open) and 52 form ''C'' contacts (changeover). The 900 series, designed for dry circuits of a maximum 1 A switching for use in data, thermocouple and instrumentation circuits, and the 800 series, used for control interlock and for indicator circuits.

Many companies produce power relays consisting of a main unit which can be used separately, and a set of many auxiliary units and elements attaching to the main unit

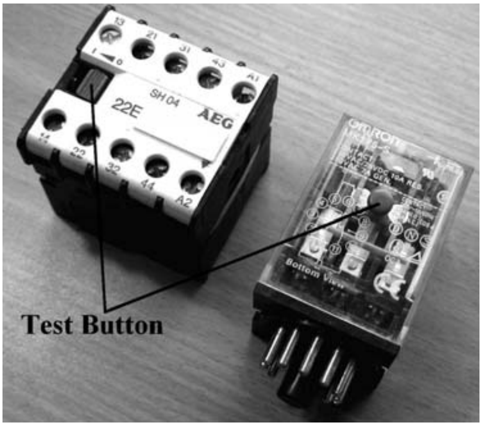
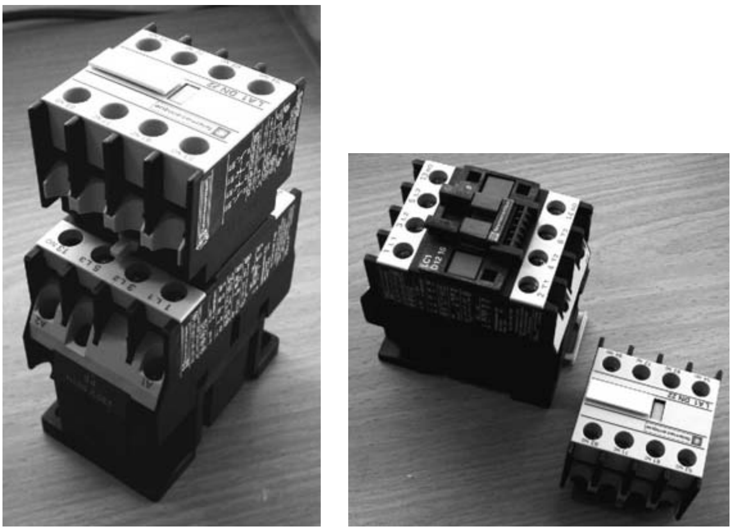


FIGURE 4.36
Relays with test buttons.

(a)


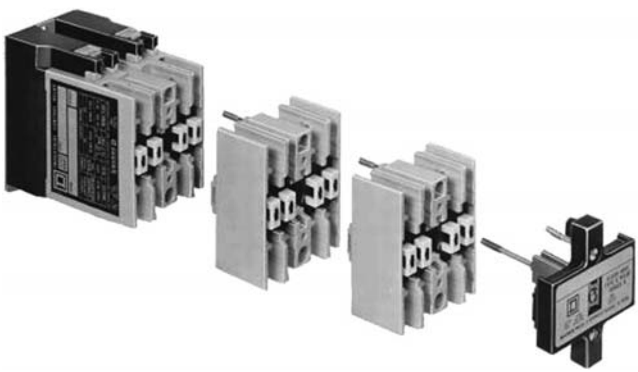
(b)


FIGURE 4.37
Power relays modular construction with attached units of additional contacts. (a — Telemechanique; b — Square-D).

FIGURE 4.38
T-Bar type multi-contact relays, produced by Olympic Controls Corp. (U.S.A.). (From Olympic Control Corp., Online Internet Catalogue, 2004)

(indicator unit, diode unit, additional contacts, time delay unit, overload protection unit, and others) on all sides and considerably broadening the capabilities of the device. Such power relays, designed for reversing start-up of electric motors, are often produced as twin-units supplied with mechanical and electronic blocking prevention from the synchronous switching of both relays, and are supplied with all of the necessary bonds (Figure 4.39).

Especially amazing are the so-called explosion-proof electromagnetic contactors and relays. No, these devices have nothing to do with military equipment. They are used in coal mines. All devices of this type are placed in massive steel cases with hermetic hatches, which can withstand explosion both inside and outside of the shell. They look really original (Figure 4.40). This kind of product (Figure 4.41) is suitable for mining wells with their explosive mixed gas and coal dirt, and for direct starts, stops, and turnovers in the three phase squirrel cage different step electrical motor with AC 50 Hz, rated voltage up to 660 V, rated current up to 120 A.

Relays designed for switching of strong signals of high frequency also look quite unusual (Figure 4.42). The major applications of such relays are:

- High power transmitter switching
- Radar pulse forming networks
- Phased array antenna systems

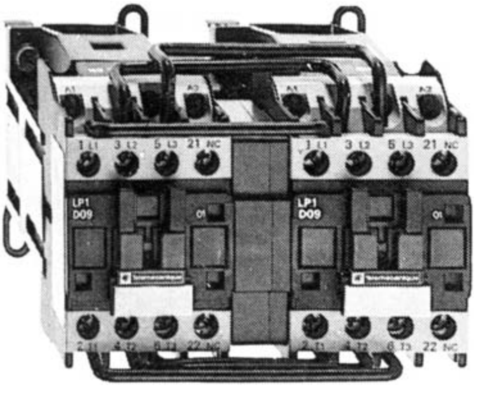


FIGURE 4.39
A twin (so-called ''reversing'') contactor produced by Telemechanique.

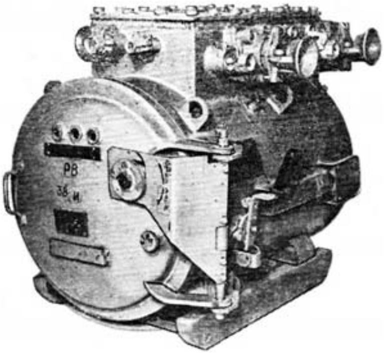


FIGURE 4.40
Explosion-proof electromagnetic contactor of PB-1140 type for 250 A current and 1140 V voltage (Russia). Size: 870 × 850 × 980 mm; weight: 410 kg

- UHF/VHF communications systems
- Magnetic resonance imaging systems

Such relays have high power handling capabilities in a small package. The ability to often handle up to 3 to 5 kW (up to 90 kW for some models of Jennings relays, Figure 4.43) at frequencies of up to 30 MHz is achieved with vacuum-enclosed contacts, minimizing noise and losses. Such rugged switches are capable of ''hot'' switching kilowatts of 30 MHz with optional special tungsten–molybdenum contacts to avoid pitting when switched with RF power applied. Even with heavy-duty construction, hot-switching will reduce the typical operational life of 1,000,000 cycles significantly — to approximately 10,000 cycles.

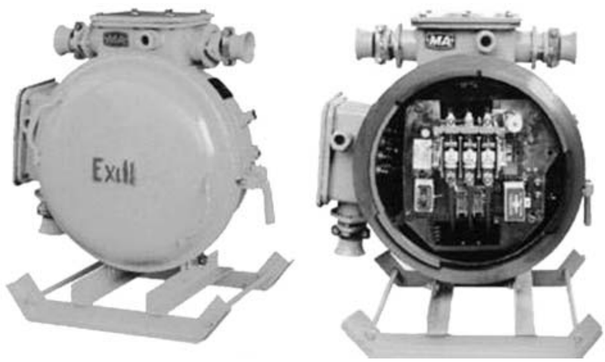


FIGURE 4.41
120ND series mining explosion-proof vacuum changeover electromagnetic starter for 120 A current and 660 V voltage (Yueqing Bada Vacuum Electric Appliances Switches Factory, China).

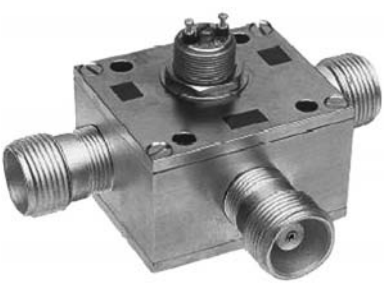


FIGURE 4.42
Powerful high-frequency relay of 310 series (DowKey Microwave).

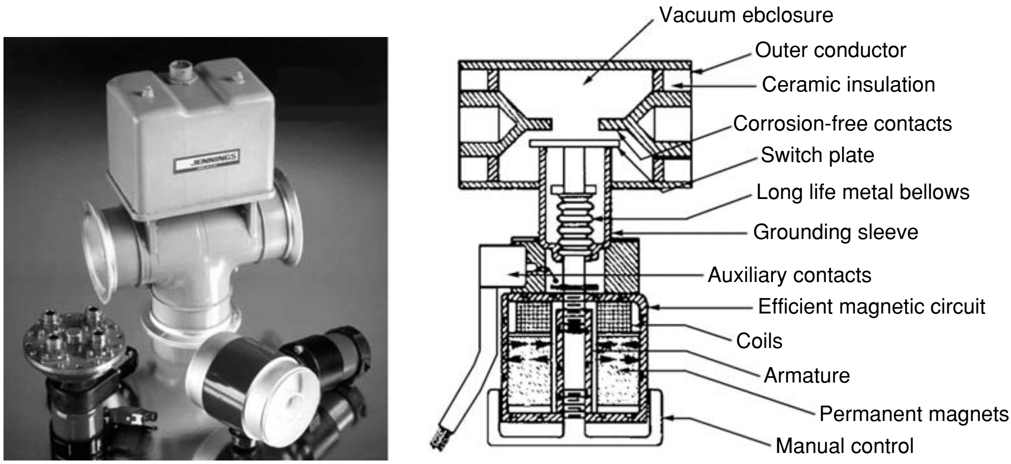


FIGURE 4.43
High Frequency Vacuum Coaxial Relays, produced by Jennings Technology (U.S.A.). (From High Voltage Vaccuum and Gas-Filled Relays, Josyln-Jennings Corp. Catalog. REL-103, 1993.)

TABLE 4.1
Main Parameters of DowKey 310 Series Relay

Frequency (MHz)	VSWR (max)	Isolation dB (min)	Ins. Loss dB (max)	RF Power Watts (CW)
30	1.05	35	0.07	3000
50	1.06	30	0.08	2300
100	1.08	25	0.09	2000
400	1.10	17	0.1	850

Switching capacity of such relays is characterized by a number of specific parameters (''standing wave ratio,'' ''crosstalk attenuation,'' etc.) denoting distortion and waste in the radio-frequency circuit in the closed state, and by a capability to insulate radio-frequency circuits in the open state. We will not go into details of terminology for high and ultrahigh frequencies as this issue lies outside the scope of this book. Here we will give an example of technical specifications for a DowKey 310 Series relay (Table 4.1).