Hans Sauer

MODERN RELAY TECHNOLOGY

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Hans Sauer

Second edition

410 Illustrations
50 Tables
240 Relay types with approx.
6000 Characteristics

Dr. Alfred Huethig Verlag, Heidelberg

The greatest care has been taken in the preparation of text, tables and diagrams, but no liability will be accepted for errors or any subsequent consequences.

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Foreword

This is the second edition of MODERN RELAY TECHNOLOGY, with major revision and many new sections. The original edition first appeared in 1975 in German and was of major use to specialist electro-mechanical relay users worldwide. This new edition gives a summary of the latest state of relay and switching technology including the most modern electro mechanical relays electronically controlled, future applications and new advanced topics are also discussed.
Modern relay technology is synonymous with the name of the author of this book Dipl.-Ing. Hans Sauer, who, due to his pioneering work and worldwide patented inventions has brought modern relay technology to a state of development which only 20 years ago was considered impossible.
Hans Sauer has managed to combine existing and new parameters which are fundamental to the concept of relays such that these parameters are optimized one to the other. The resulting modern relay technology is significantly more reliable, needs less power, has longer life, a wider switching range and an increased efficiency. Because of his developments, there is now in existence equipment and instrumentation which, without the use of modern relays would not have been possible. Hans Sauer has devoted his working life to relays and his efforts have been recognized by many major awards and prizes.
It has been widely acknowledged that Hans Sauer, with his activities as inventor, businessman and partner of Matsushita Electric Works Ltd., and Aromat Corporation, has still found time and has had the interest to pass on his extensive knowledge about electro-magnetic relays to a wide cross section of people. This has helped widen the knowledge of many specialists in major ways.
This book will prove to be an extensive source of information for engineers and students alike. It is unfortunate that many of the latter still learn too little about electro-mechanical relays at university. This is something which the Technical University of Munich has rectified and now studies in electro-mechanical relays are undertaken there.
In the interest of technical development it is sincerely hoped that this book achieves as wide a circulation as possible.

Munich March 1986

Prof. Dr.-Ing. Joseph Eichmeier
Professor of Technical Electronics of
the Technical University, Munich

Contents

SDS RELAIS show the way to future relay technology

The founding of a new company takes place only after much, and varied deliberation. Later these early ideas become integrated in the philosophy of the organization. Hans Sauer worked on relay development for twelve years with large German and American companies until it became obvious to him that modern relays could be developed and marketed in a way different to that practiced by already established companies. This recognition led to the founding of the SDS company in 1962.
In conjunction with Matsushita Electric Works (MEW) as co-operation partner the process of developing modern relays using new technology began. These modern relays, inspite of drastic miniaturization are much more reliable, more efficient, are of lower cost with greater switching capability than are relays which use the conventional, well known technology.
Tables 2 and 3 show in part these unique developments which today are covered by over 200 patents worldwide. Official recognition of their international co-operation and technical achievements have been made to both K. Kobayashi and H. Sauer by the Japanese and German authorities.
The associated companies of MEW Japan, SDS Europe and Aromat USA currently produce approximately 13 million modern relays and approximately 5 million conventional relays per month. The remarkably rapid introduction of modern relay technology has also confirmed the logic behind the unique marketing philosophy which can be summed up as follows:

Close co-operation with users and customers

The conventional multilevel sales system and high-cost field sales personnel have been replaced at SDS by direct and fast direct access by and to customers. Many improvements and new developments on both sides have come about by having a direct connection to the development laboratory. Fully detailed data sheets with prices and additional specialist publications mean that irksome costly routine sales visits are in general not required. In the majorty of cases a clear telephone conversation is enough.

Information and advice is impartial and honest and based on problem solving

All the SDS companies are motivated to recommend the most suitable relay for a given application taking technical and commercial constraints into consideration — even when the most suitable relay is made by a competitor. The relay tables in chapter 4 of this book to which all major relay manufactures were asked to contribute shows the efforts to which SDS will go to ensure it gives objective and neutral information in the interests of all relay users.

Sensible pricing policy

The SDS relay programme covers virtually every sphere of application with a relatively small number of basic types of relay. This allows a rationalized manufacturing programme in large quantities. As a result the quality level is high, but is not achieved at the expense of relay cost.

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born 4. 6. 1923
Founder and owner of SDS

Dr.-Ing. e. h. Ludwig Boelkow
born 30. 6. 1912
Founder of MBB

Kaoru Kobayashi
born 25. 9. 1918
President of MEW

The management board: The well proven younger generation

Sepp Antonitsch
born 14. 3. 1942
Developments and patents

Dr. Ulrich Moessner
born 27. 3. 1945
Management and co-operation

Wolf Steinbichler
born 6. 10. 1941
Sales

Managers of SDS subsidiaries and associated companies

Rudolf Polster
born 10. 3. 1934
SDS, Austria

Hans Widmer
born 12. 7. 1924
SDS, Switzerland

Jacques Lafrance
born 28. 4. 1947
SDS, France

James G. Naples
born 11. 2. 1947
Managing Director
SDS-Relais Ltd

Helmut Kleebauer
born 8. 3. 1939
MSR, D-Pfaffenhofen

Peter Moureau
born 21. 8. 1942
SDS Scandinavia

Randy Doi
born 6. 6. 1934
AROMAT, USA

Dr. Bruno Jachemet
born 5. 2. 1942
SDS, Italy

Contact points for information, sales, service and stock

SDS RELAIS

SDS-Relais Ltd.
17 Potters Lane
Kiln Farm
Milton Keynes
MK11 3HF
Tel. (0908) 567725
Tlx. 826685
FAX (0908) 569097

SDS relays are developed in co-operation with Matsushita, Japan and Aromat, USA and manufactured in three factories. Security of supply is ensured via Matsushita in Asia, Aromat in USA and SDS in Europe.

Due to patent restrictions SDS modern relays are available in Europe only from SDS, whilst in USA they are available from Aromat and in Asia from Matsushita.

Australia
R.V.B. Limited
144 Hall Street
Spotswood, Victoria 3015
Tel. 3912411

Austria
SDS-RELAIS Ges.m.b.H
Stojanstrasse 12
A-2344 Maria Enzersdorf
Tel. (02236) 26846/26847
Tlx. 613222930
Ttx. 3222930

Belgium
N. V. TELEREX S. A.
Bisschoppenhoflaan 255
B-2100 Deurne
Tel. (03) 3833350
Tlx. 33511

Comecon
ACS Ges.m.b.H
Tuerkenstrasse 9
A-1092 Wien
Tel. (0222) 341608/341600
Tlx. 114228

Denmark
Dansk Komponent Import ApS
Jaegersborg Allè 16
DK-2920 Charlottenlund
Tel. (01) 640099
Tlx. 15474

Finland
OY FLINKENBERG & CO AB
Bulevardi 28
SF-00121 Helsinki 12
Tel. (90) 647311
Tlx. 124533
FAX (90) 604758

France
SDS Relais France S.A.R.L.
10 rue des Petits Ruisseaux
F-91370 VERRIERES LE BUISSON
Tel. (1) 69209898
Tlx. 691387f
FAX (1) 69203897

Germany
SDS-Relais AG
Fichtenstrasse 3-5
D-8024 Deisenhofen
Tel. (089) 6104-0
Tlx. 529253
FAX (089) 6104-59
from Oct. 1986:
Tel. (089) 613004-0
FAX (089) 613004-59

Holland
TELEREX Nederland B. V.
Konijnenberg 88
NL-4825 BE Breda
Tel. (076) 879212
Tlx. 74408

Israel
Alexander Schneider Ltd.
44 Petach Tikva Rd.
Tel Aviv 61180
Tel. (03) 372089
Tlx. 33613

Italy
SDS-RELAIS-ITALIA s.r.l.
Via Abruzzo, 7
I-37138 Verona
Tel. (045) 573122/573565
Tlx. 481189

South Africa
Reunert Components PTY Ltd.
32 Andries Street, Wynberg
P. O. Box 599
Bergvlei 2012 R.S.A.
Tel. 7869124/29
Tlx. 424335

Spain
SELCO Sociedad de Electrónica
y Componentes S. A.
Paseo de la Habana, 190
E-28036 Madrid
Tel. (91) 4054213
Tlx. 45458

Sweden
SDS Scandinavia AB
Box 34063
S-11265 Stockholm
Tel. (08) 132225
Tlx. 15363
FAX (08) 133191

Switzerland
SAUER-SDS-RELAIS AG
Am Wasser 24
CH-8049 Zürich
Tel. (01) 443944
Tlx. 822971
FAX (01) 427003

Turkey
Burc Elektronik
Ve Makina San. ve Tic
Bankaci Sok. 15/2
K. Esat — Ankara
Tel. (041) 250300/250302
Tlx. 43430

Conception of and introduction to the second edition

After the publication of the first edition of MODERN RELAY TECHNOLOGY in 1975 there began a process of reconsideration which showed relay technology in a different light. At that time the technical features of the few modern relays then available were compared with those of existing technology relays. Recognition was not immediately obvious that a new relay generation had been established during this time.

There are now three relay generations in existence. This has major significance depending on the application which is to be solved.

It had been difficult to select the appropriate relay from the many first generation relay types for a given application. Now that there are three relay generations available there are even more possibilities. Thus it is important to clearly establish the differences. For this reason, section 1 discusses "Relay evolution", the facts, the reasons and the effects.

In section 2, the most important expressions and definitions are given alphabetically. Words given in italics are also explained.

Section 3 has application examples and offers advice which should be understood when selecting a relay.

In the relay tables of section 4 and from table 46 (section 3.3) the characteristics of the major relay and solid state switching types are compared. All major relay manufacturers (or their representatives) in Austria, France, Germany, Italy, Japan, Switzerland, United Kingdom, and the USA were requested to supply information and characteristics of those relay types which will be available up until the year 1995. The relay tables have been set out with spare positions so as to be able to indicate relays which are not yet on the market but which will become available in the future.

It has been shown that it is neither practical nor useful to discuss the theory of all specific relay problems in detail. Therefore extensive measurements have been performed. For the compilation of the comparison table 36 alone it took five engineers from Matsushita [1] ten months work. Incited by this work, many cooperative relay users added their contributions.

Many relay users have co-operated in the production of this relay lexicon. The editor expresses his thanks to all contributing companies and individuals:

Dipl.-Ing. S. Antonitsch, SDS-Relais AG, D
Dipl.-Ing. W. Arnold, C.P Clare, D
Engineering Division of Aromat Corporation, USA
Marketing Division of Aromat Corporation, USA
Sales Division of Aromat Corporation, USA
Dr.-Ing. M. Bleicher, D
Dipl.-Ing. B. Dietrich, SDS-Relais AG, D
Prof. Dr.-Ing. J. Eichmeier, TU Muenchen, D
W. Herrmann, Neumann Elektronik, D
G. Hoermansdoerfer, Prakla Seismos, D
Dipl.-Ing. W. Holland, Rohde & Schwarz, D
Ing. M. Huenteler, Schleicher Relais-Werke, D
Dipl.-Ing. Dr. B. Jachemet, SDS-Relais-Italia, I
Prof. Dr. A. Keil †, Inovan, D
Ing. H. Kleebauer, MS-Relais, D
Dipl.-Ing. H. Kunath, D
Dipl.-Ing. J. Lafrance, SDS Relais France, F
Dr.-Ing. F. Martin †, AEG-Telefunken, D
Miss I. Mauch, SDS-Relais AG, D
Dipl.-Ing. Dr. U. Moessner, SDS-Relais AG, D
J.G. Naples BSC, SDS-Relais Ltd., GB
Dipl.-Ing. P Nilius, SDS-Relais AG, D
Dipl.-Ing. J. Oberndorfer, SDS-Relais AG, D
PEC Division, Matsushita Electric Works Ltd., J
Dipl.-Ing. H.-J. Plaumann, VALVO, D
Obering. R. Polster, SDS-Relais Ges.m.b.H, A
R & D Laboratory, Matsushita Electric Works Ltd., J
Dipl.-Phys. H. Ritter, SDS-Relais AG, D
Ing. O. Sauer, SDS-Relais AG, D
Dr.-Ing. H. Schleicher, Schleicher Relais-Werke, D
Dipl.-Ing. (ETH) K. Sommer, Hasler AG, CH
Dipl.-Ing. W. Steinbichler, SDS-Relais AG, D
Dipl.-Ing. P Stephan, D
Dipl.-Ing. W. Sterff, Transtechnik, D
Ing. W. Tondasch, SDS-Relais AG, D
Dr.-Ing. W. Traechslin, Landis & Gyr, CH
Dipl.-Ing. H. Ulbricht, Wandel & Goltermann, D
Dr. rer. nat. E. Weber, SDS-Relais AG, D
Dipl.-Ing. (HTL) H. Widmer, Sauer-SDS-Relais AG, CH

1 RELAY-EVOLUTION

from the first to the third relay generation

1.1 Historical development and future prospects

Based on the 1824 ideas of J. Henry, Samuel Morse first made his "Morse Code" machine work in 1837. The relay was born. However, at that stage-coach time anyone who made reference to a "relay" or a "relay station" was thinking more in terms of a change of horses, or the place where coaching horses were kept.

Today there are approximately 25 billion relays in use within electrical devices and equipment, performing regulatory, supervisory and control functions. In the *primary circuit* (*coil*), applied signals (from millisecond long to continuous duration), can be amplified by up to approximately 10^5 or reduced by up to 10^{10} times in the secondary circuit (contacts). These signals can be delayed by milliseconds or up to many hours and can be branched over several contact sets. Thus, relays fulfil (amongst many others) the following functions:

- Multiplicity of switching functions.
- Separation of electronic control and power loads (galvanic separation).
- Signal amplification as well as increasing the number of switching paths.
- Separation of DC and AC circuits (i.e. switching an AC current path via a DC control signal or vice versa).
- Delay of, shaping of, or changing an applied signal (fig. 114).
- Combining information.

Today these functions can be solved using methods of greatly differing *efficency.* However, the larger the jump made in innovated technology the more difficult it becomes to persuade the market of its real worth and the benefits the new development can offer over products using the existing technology. Thus in the 1970^s, there were articles written [2] about the new technology which challenged the new developments as being highly dubious [3].

Such impediments, which have had to be overcome by many innovations [4], have in this case, had a beneficial effect. Here it was argued by the detractors that (incorrectly) there would be a corresponding increase in manufacturing costs and reduction in *quality* associated with relay miniaturization [3], which led to the conclusion [5] that not all opinions on traditional relays are valid for modern relay technology. However on the contrary, due to the major developments made in relay technology it has been shown clearly that today there exist three distinct relay generations.

First generation

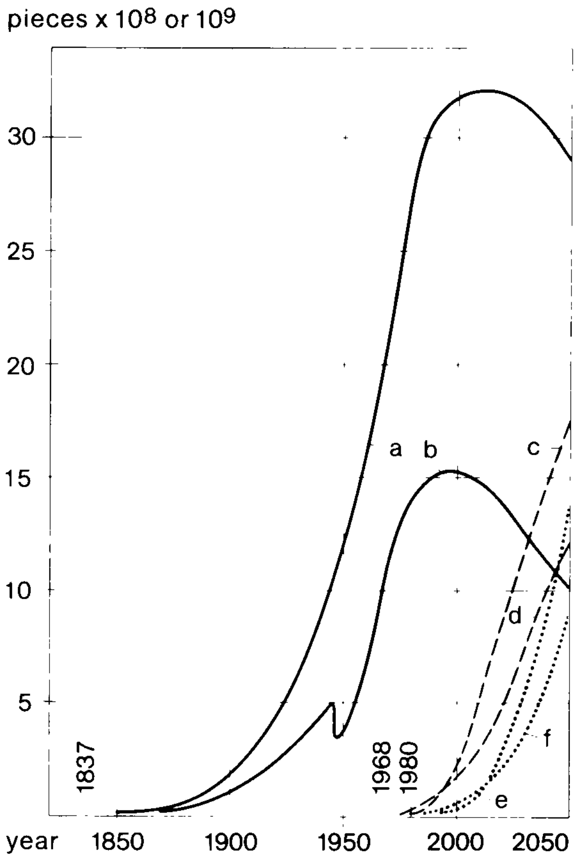
Relays of conventional construction [3] (see comparison table 3) and which due to their high operating power consumption can not be miniaturized in an effective way.

Second generation

Miniaturized *monostable, bistable* (latching) or *tristable* electro mechanical *relays* of very high *efficiency* which consume little or no power yet offer high *contact force* (table 3, fig. 14).

Third generation

A combination of a modern second generation relay with an integrated solid state switching circuit whereby a further increase (approximately 500 times) in *efficiency* is achieved and new application possibilities made possible [6, 7] *IC-relay* (table 3).



— a relays of the 1st generation since 1837, worldwide x 10^9 pieces

— b relays of the 1st generation since 1837, West Germany, Austria and Switzerland x 10^8 pieces

-- c relays of the 2nd generation since 1968, worldwide x 10^9 pieces

-- d relays of the 2nd generation since 1968, West Germany, Austria and Switzerland x 10^8 pieces

.... e relays of the 3rd generation since 1980, worldwide x 10^9 pieces

.... f relays of the 3rd generation since 1980, West Germany, Austria and Switzerland x 10^8 pieces

Fig. 1: Estimated numbers of relays from first, second and third generations

Examination of sales figures (confirmed by demand, manufacturing capacity, *economic value* and technical accomplishment) best illustrates the growth and significance of these three relay generations. If the appropriate data of the past is known, then it is possible to predict future developments [8] as shown in fig. 1.

The faster growth of second and third generation relays in German speaking central Europe as compared with the rest of the world may be explained by the fact that the first edition of the Relay Lexicon was only available in the German and Japanese languages. Figure 1 takes into account the influence this new edition will have as it has been published in several languages.

1.2 Stages of development to the second and third relay generation

Experience shows that relays of the second and third generation are only applied when their characteristics and the benefits they offer are well understood by the user. This understanding is not always easy since, in such relays, electric, magnetic, mechanical, kinematic, thermal, chemical, technological, and now even electronic characteristics can have mutually interactive influences on the relay. At first sight the *characteristics* indicate how well all of these factors have been optimized one to another (e.g. *selfheating* effect, contact reliability, operational *life, switching load range*).

Extension of the relay function

According to a theory of Hansen [9] about the utilization of integral* functions, the *economic value* of a relay is exponentially related to the number of individual characteristics it possesses.

Traditional technology relays have five **part functions:**

1. Conversion of an electrical current into a magnetic flux.
2. Conversion of a magnetic flux into a mechanical force.
3. Transfer of mechanical force to the contact operation points.
4. Storage of mechanical energy to give contact opening after removal of the *energization* voltage.
5. Conduction of the electrical current via the contacts.

With modern relays there are additional **part functions:**

6. Significant superposition of permanent and electromagnetic flux in the *air gap* (compare fig. 9) [10]
7. Storage of magnetic energy to produce pressure at the contacts (compare fig. 9 to 14) [11].
8. Compensation of temperature influence to achieve constant *pull-in voltage* [12].
9. Avoidance of contamination layer build up on the *contacts* [13].
10. Limitation of operating power consumption to only the pick up time (→ C-switching circuit), [14].
11. Storage of electrical energy to open the contacts after removal of the excitation voltage (→ C-switching circuit), [14].
12. Combination of several programmable functions (*IC-relays*), [15].

When compared with conventional *reed relays* having five integrated part functions, the DRC-relay having ten part functions displays an *efficiency* of 8333 times more (table 3), thus confirming Hansen's theory [9].

Of particular significance when considering part functions is not only the cost reduction possibilities which they offer but also the major improvements in quality which they have brought about.

Contact improvements

There is an enormous difference in quality achieved depending on whether the contact current flows through *contacts* as shown in figure 2 or figure 3 (part function 5).

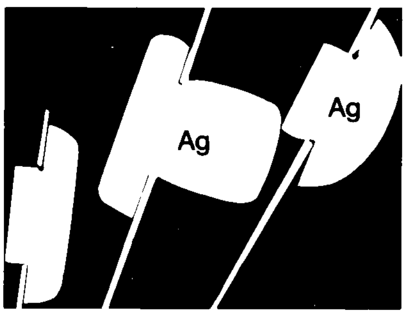


Fig. 2: Section through a traditional simple riveted point formed contact

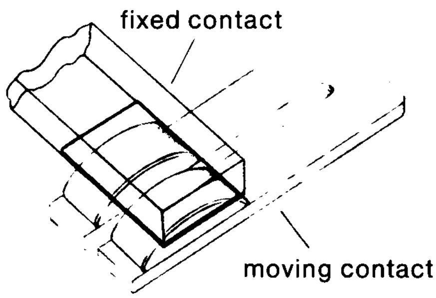


Fig. 3: Linear bifurcated contact [16]

Whilst the point form contact shown in fig. 2 is suitable only for switching loads in the range 1 to 30 VA, the bifurcated lever contact shown in figs. 3 and 4 is suitable for an approximately billion times larger reliable *switching load range* of 10^{-10} to 1000 VA (table 3). In addition there is a five times greater resistance to contact welding, improved bounce char-

* "Integral" here is not to be confused with its mathematical meaning.

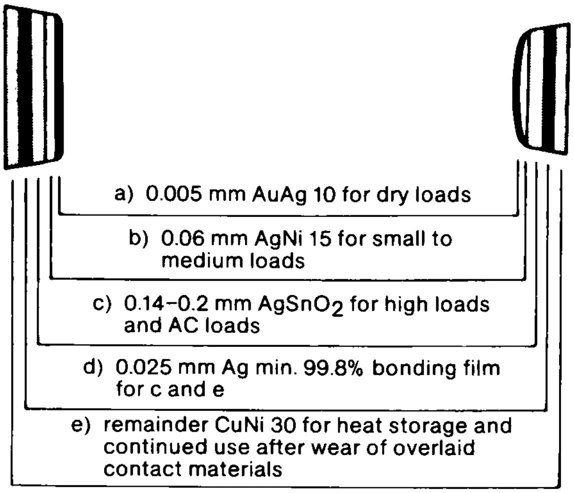


Fig. 4: Section through a five layered contact shown in fig. 3 [16]

acteristics and much larger operational *life* when compared to the five times larger volume of the simple riveted contact shown in fig. 2. Simply by designing the most appropriate contact form [16] the result achieved (with much lower use of precious metal) gave rise to major quality features of significance to relay technology (table 40).

Optimization of magnetic circuit

The conversion of a magnetic flux into a force (part function 2) can be achieved imperfectly (fig. 5), well (figs. 6 and 8), or optimally (fig. 9) with resulting major differences in the quality achieved.

The much used system shown in fig. 5 cannot be fully optimized mainly since between the *yoke* Y and *armature arm* A′ there is a magnetic force, working against the pulling force F (generated in the *air gap* a).

The system shown in fig. 6 uses the magnetic force between the *core* C, *armature* A and both yoke ends Y, Y′ in the pulling direction so that with a closed *armature* the pulling force F is more than twice that as in the system shown in fig. 5 (refer to force distance diagram fig. 7). With increasing air gap width the difference be-

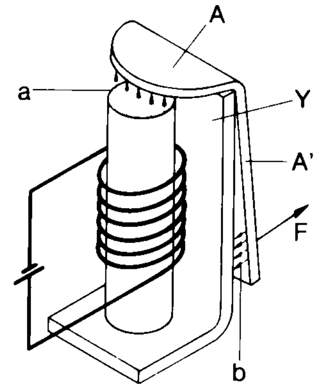


Fig. 5: Traditional magnet system with a simple effective air gap "a" and a single pulling-force-reduction air gap b

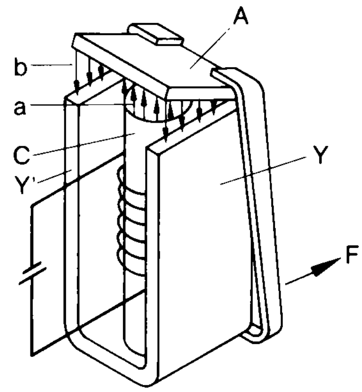


Fig. 6: Magnet systems with two air gaps "a" and "b" permit pulling forces to act in same direction [17]

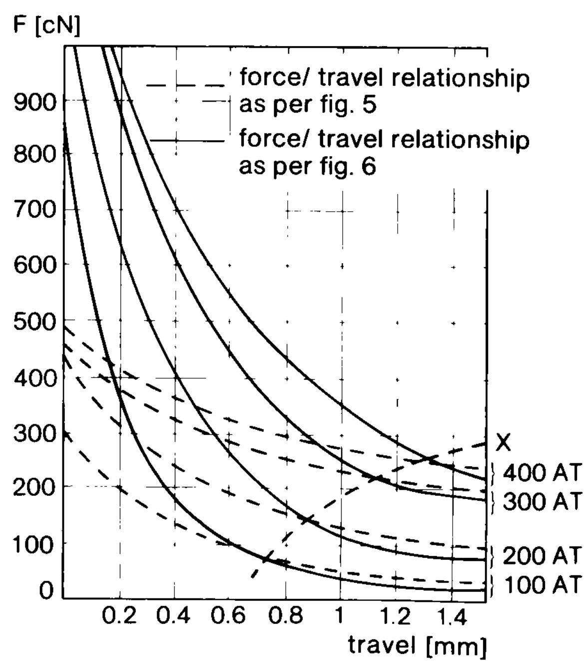


Fig. 7: Force/travel diagram of magnet systems as shown in fig. 5 and 6 (approx. volume 18 cm^3) [72]

comes less. The curve X in fig. 7 shows the force/travel relationship for the same pulling force on both systems. Even more effective are systems having their armatures pivoted in the center of the coil — where there is no stray magnetic flux loss (fig. 8).
Therefore, the magnetic flux Φ_E has a double effect over the two *air gaps* (or armature travel s, s') and thus the cross section of the *armature* can be smaller than that of the coil core.

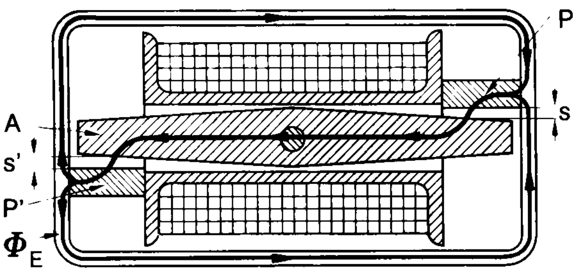


Fig. 8: Section through a magnet system having an armature A pivoted symmetrically in the center of the coil between two opposite poles P, P'

Technology and advantages of polarized magnet systems

Polarized *magnet systems* are significantly more effective than unpolarized systems in so far as the permanent magnetic fluxes Φ_M, Φ'_M, Φ''_M can be superimposed on the electromagnetic flux Φ_E (fig. 9), [10].

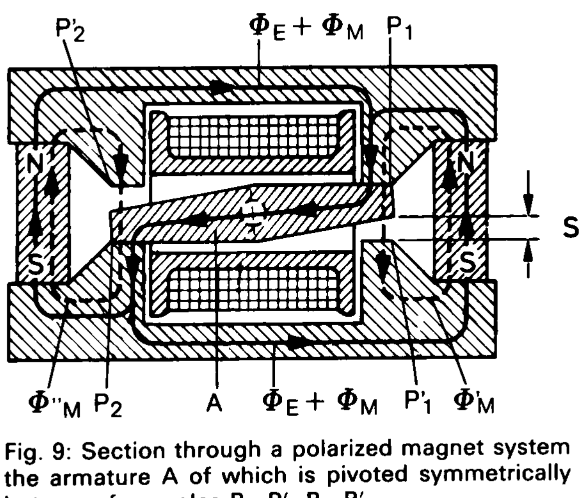


Fig. 9: Section through a polarized magnet system the armature A of which is pivoted symmetrically between four poles P_1, P'_1, P_2, P'_2

The system as shown in fig. 9 is bistable. Monostable operation can be achieved if the opposite pole surfaces of P_1, P'_1, and P_2, P'_2 are of different polarity and if the permanent magnet(s) are arranged asymmetrically [19].

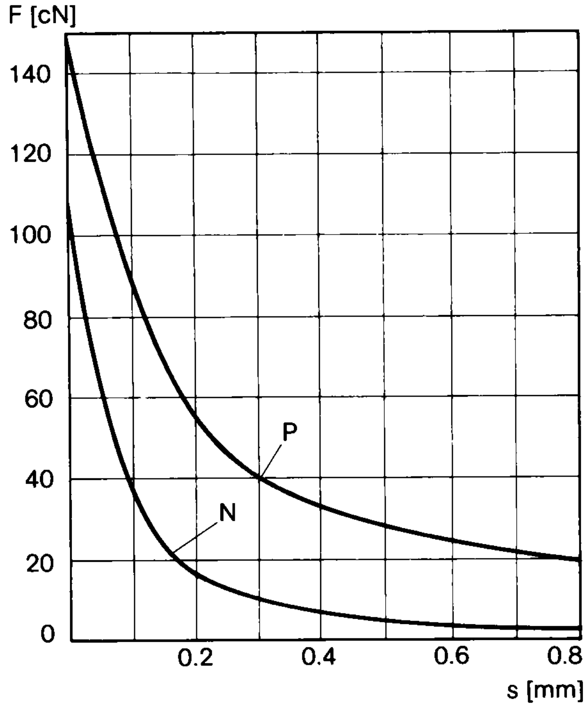


Fig. 10: Force/travel relationship of an unpolarized (neutral) magnet system N as shown in fig. 8 and a monostable polarized magnet system P as shown in fig. 9, each with operating power consumption of 100 mW and having the same volume of enclosure (2.8 cm³)

Fig. 10 compares the pull in force of the polarized monostable relay shown in fig. 9 (curve P) with the neutral system (N) shown in fig. 8 each with a power consumption of 100 mW. This comparison shows that polarized systems have a significantly higher pulling force for the same power consumption. Alternatively, in spite of reduced power consumption and significantly smaller volume, polarized systems offer a considerable increase in *contact force* than do unpolarized systems.
How much this has improved the *characteristics* of relays can be seen from table 2 where comparable unpolarized and *polarized relays* have been compared.

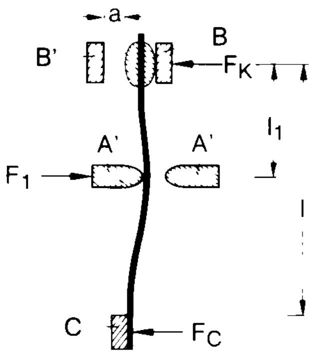


Fig. 11: Operated single-contact spring

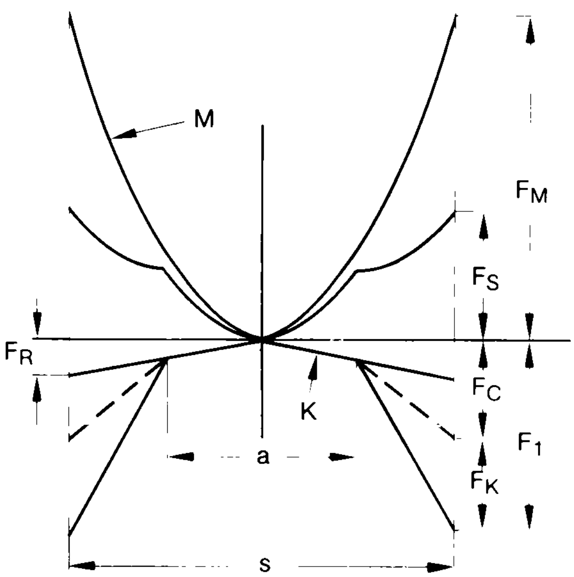


Fig. 12: Force/travel diagram of the magnet system shown in fig. 8 with contact spring(s) as shown in fig. 11

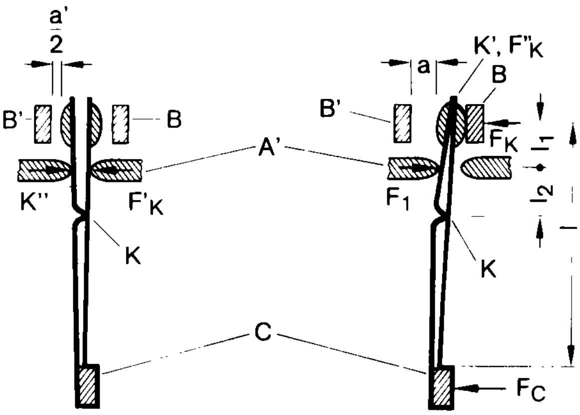


Fig. 13: Dual contact spring in center and end positions (FLOC) [11]

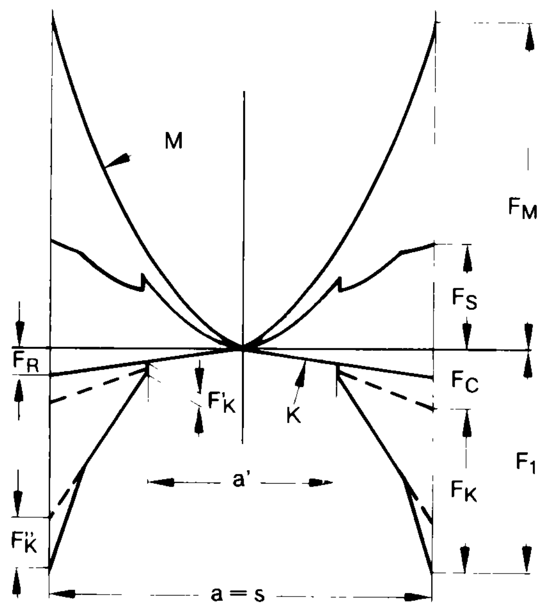


Fig. 14: Force/travel diagram of the magnet system shown in fig. 9 with contact spring(s) as shown in fig. 13

A'	Armature (A) operating cam (fig. 9)
B, B'	Fixed contacts
C	Moving contact mount
F_C	Force on moving contact mount
F_K	Contact force
F'_K	Spring pre tension due to contact
F''_K	Additional contact force due to disturbance of the spring ends
F_M	Permanent magnetic pulling force
F_R	External force due to contact

F_S	Position force of armature $= F_M - F_1$
F_1	$= F_K + F_C$
a	Contact gap
a'	Contact gap during operating
l	Contact spring length
l_1	Spring length for contact opening
l_2	Additional spring length for contact operation
K, K', K''	Contact points of contact springs
s	Armature travel (fig. 9)

Moreover permanent magnetic energy may be stored as contact operating force, this (part function No. 7) storage is achieved reasonably well (figs. 11 and 12) or optimally (fig. 13, 14) with greatly differing results (table 1).

If the *magnet system* shown in fig. 9 is equipped with *contact springs* shown in fig. 11 or 13, then the force/travel relationship shown in fig. 12 or 14 is achieved. M shows the force/travel curve of the de-energised permanent magnet system and K the opposing curve of contact spring forces.

In contrast to the single contact spring shown in fig. 11, the normally closed FLOC (flexure lift off contact) shown in fig. 13 is opened (may be considered as forced opening) by the operating cam A′ of the *armature* A (fig. 9) with short spring length l_1 and the normally open contact is closed via the larger spring length $l_1 + 2l_2$.

Therefore:

- The *contact gap* a is larger (in the example it is the same as the *armature travel* s due to the relationship $l/(l - l_1)$.
- A higher force percentage is stored as *contact force* F_K.
- An improved *temperature compensation* (part function 8) is achieved.
- Because of the points of touch K, K′, K″ the bounce characteristics of the contact are improved.
- The power consumption and contact losses are reduced.

If two *changeover contacts* as shown in fig. 11 or 13 are used in a DS-relay (fig. 294) having a volume of 2 cm³, then the *characteristics* displayed are as shown in table 1:

DS-relay with 2 CO contacts as per figs.		Normal contact 11, 12 and 292		FLOC 13, 14 and 294		Improvement factor	Result and benefit
Switching type		monostable	bistable	monostable	bistable		
Contact force	cN	8		12		1,5	higher contact reliability (fig. 61)
Contact resistance	mΩ	10		8		1,25	lower losses
Contact bounce	ms	2	1,5	0,6	0,4	3,3	larger life
Load switching range	VA	10^{-7} ... 125		10^{-10} ... 250		2000	larger range of application
Power consumption	mW	400	200	150	75	2,6	power saving
Change of pick up voltage	%/K	0,16		0,08		2	higher permissible pick up voltage
Efficiency at 10^5 operations		680	1 500	3690	7400	5,43	high efficiency

Table 1: Difference in characteristics of a second generation DS relay with good and optimal utilization of energy storage (part function 7)

Low stable *contact resistance* throughout the *life* of the relay is the most significant feature of the FLOC system shown in fig. 13. Other attempts to obtain high *contact force* from stored magnetic energy using unsuitable *magnet systems* have failed due to their having too low a storage effect or too great a loss of *contact travel*.

As a comparison it can be reckoned that first generation relays consume approx. 60 mW per cN of *contact force*, and second generation relays having a single *contact spring* (as shown in fig. 11) consume only 28 mW. Due to the almost perfectly optimized *energy storage* of the systems shown in figs. 9 and 13 such relays consume only 6 mW per cN. Table 1 shows that with efficient simultaneous use of individual part functions there is an improvement shown in many other of the features of the relay.

It is a significant feature of well designed second generation relays that they consume practically no power to achieve higher *contact forces*. Only sufficient power is consumed from the power source to overcome the armature holding force F_S. As a comparison, first generation relays require more energy input depending on the required *contact force*, and the number of *contacts* which are to be operated. It is for these reasons that relays utilizing traditional technology cannot be efficiently miniaturized.

If it is considered that the five established part functions of a relay can be optimized with similar results (table 1), and if in addition seven further newly integrated functions are also efficiently optimized one to the other then the following ten fundamental improvements in relay characteristics can be achieved.

1. Up to 99.9% saving in power consumption
2. Up to 10 times increase in operational *life*
3. Up to 100 times increase in contact reliability
4. Up to 1000 times higher *efficiency*
5. Up to 10000 times increase in *switching load range*
6. Reduced storage and transportation costs
7. Reduced noise during operation
8. No unnecessary heat generation
9. Improvement in operating conditions of neighbouring components
10. Negligible operation costs

More part functions of higher quality at low cost

"Quality has its price"
However, if a product is designed from first principles then higher *quality* can be achieved without necessarily incurring higher costs (table 2). The following example illustrates this. The reed changeover contact relay developed by the Bell Laboratories (as shown in fig. 15) is comprised of a glass capsule (3) inside which are a single non magnetic (2) and two ferromagnetic reed contacts (1, 1'). When the *core* (4) is energized the *contacts* 1, 1' close. During the sealing process silicates are given off resulting in high unstable *contact resistances*. Also, due to inherently low *contact force* such relays are suitable for switching only a small range of loads.

If the relay is constructed as in fig. 16 such that:

- The space saving bobbin (3) with the inbuilt fixed contacts 1', 2 also acts as the protective envelope (10).
- A permanent magnet (5) is positioned such that its flux is superimposed with the electromagnetic flux (part function 6), [10, 111].

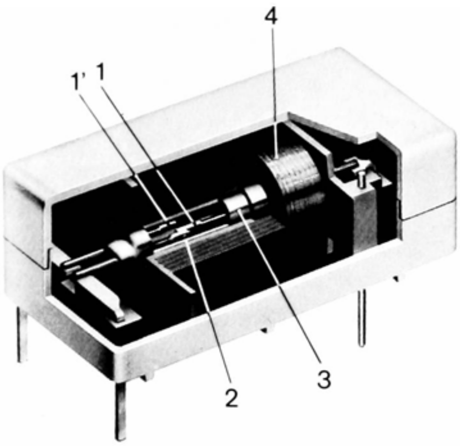


Fig. 15: Section through a traditional reed changeover relay having 5 part functions

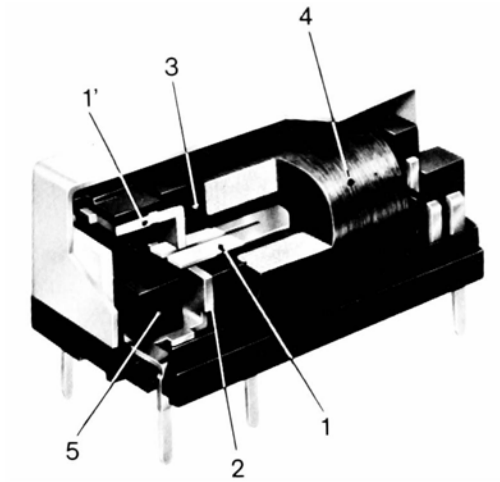


Fig. 16: Section through a modern reed changeover relay having 8 part functions

- The temperature co-efficient of the magnet is tuned to that of the *coil* (4) [12] (part function 8), (→ Temperature compensation)
- The magnet is activated as a *getter* (part function 9), [13]
- The adjustment takes place in the relays own magnetic field [10]
- The reed contacts (1) are split in two (bifurcated) in order to achieve twin contact operation and
- The relay is filled with *protective gas* and sealed in plastic resin [20]

The qualitative features are then improved at low cost as shown in table 2.

The cost of failure has been estimated at approx £ 6/relay. Thus, comparison of the estimated failure rate of 3% of relays similar to that shown in fig. 15 and 0.004% for a relay type as shown in fig. 16 is significant [21] (compare fig. 18).

If part functions 11 and 12 are also integrated into the relay by use of the *C-switching circuit* then the purchase cost is increased by approx. £ 1.00. However in spite of this, RHC- or DRC-relays (table 3) cost less than the traditional relay shown in fig. 15. These relays are the first of the third generation.

Reed changeover relay as per fig.		15	16	Improvement factor	Effect and meaning
Volume	cm^3	3,2	1,7	1,9	lower storage costs
Power consumption	mW	150	100	1,5	lower power dissipation
Contact force	cN	approx. 2	10	approx. 5	higher contact reliability
Contact resistance	mΩ	130	10	13	lower contact losses
Load switching range	VA	10^{-6} ... 2,8	10^{-10} ... 60	210000	larger range of application
Change in pick up voltage	%/K	0,4	0,1	4	higher permissible pick up voltage
Efficiency at 10^5 switching operations		12	720	60	higher reliability
Price each (excl. VAT)	£	4.00	1.60	2.5	lower purchase costs

Table 2: Comparison of characteristics and prices of a traditional reed changeover contact relay shown in fig. 15 with a modern type DR-12V as shown in fig. 16 and fig. 283

Third Generation Relays

Such *IC-relays* are a symbiosis of modern solid state technology and a second generation relay. Example 2, 3 and 4 of table 3 show that third generation relays achieve technical and commercial objectives much better than do traditional technology relays.

The development of third generation relays is already far advanced. In Addition to relays coupled with the *C-switching circuit* (or with an active socket) offering up to 99.9% savings in power consumption, there are now toggle relays, pulse, wiper and time delay relays. Thus, switching applications can now be solved for which previously neither solid state devices nor first or second generation relays were suitable [6, 7]. Relays for use with AC, but without eddy current losses are in development. These will be suitable for a frequency range of 50 to 50 000 Hz (→ SAC coil).

Type-C3-IC relays (fig. 17) are LSI compatible and may be used with *PLA,* PROM, *microprocessors* etc. They can be connected to control system *"bus lines"* so that at the contact side, the well known benefits of electro mechanical relays can be utilized and at the input side, those of solid state devices with the following features:

- Multifunction inputs (set, reset, toggle, monostable or bistable (latch))
- LSI-compatible: Can be controlled with *impulses* of only 100 μs duration, *negative logic*
- Input filter to suppress transient overvoltages and *contact bounces*
- Maintenance of chosen switched condition after voltage failure
- Extremely low power consumption

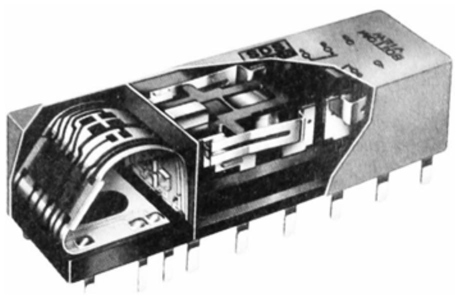


Fig. 17: Programmable IC-relay. An ideal miniature interface between intelligent control systems and peripheral equipment.

Applications of how to apply *IC-relays* (fig. 17) are given in section 3. Typical examples: toggle relays, monostable relays, latching relays, (which can be programmable and thus are of significance for use with sequencers, and switch with or without time delay).

Section 1.2 illustrates how complex a relay can be and how its *economic value* can be increased by careful utilization and co-ordination of its many features (or part functions). The following section illustrates how use of such technology can effect the economy.

1.3 Commercial aspects of relays

The economic value of a relay is decided mainly from its *quality,* its power consumption, its purchase price, its size and its operating time — with particular reference to the application under consideration. Consequently whether or not a given piece of equipment will operate sucessfully can be judged from the types of relays selected for use within it (→ Economic Value). The consequences of such selections on a nationwide scale has an indirectly enormous effect on the economy as a whole.

In a study about the meaning and trend of relay technology, Prof. Dr.-Ing. J. Eichmeier of the Technical University of Munich concluded that if modern technology relays were to be used instead of the billion (approx.) of traditional technology relays actually used in West German industry, an amount of approx. DM 33 billion (approx. £ 9 billion) could be saved [21]. This is made up as shown in figure 18.

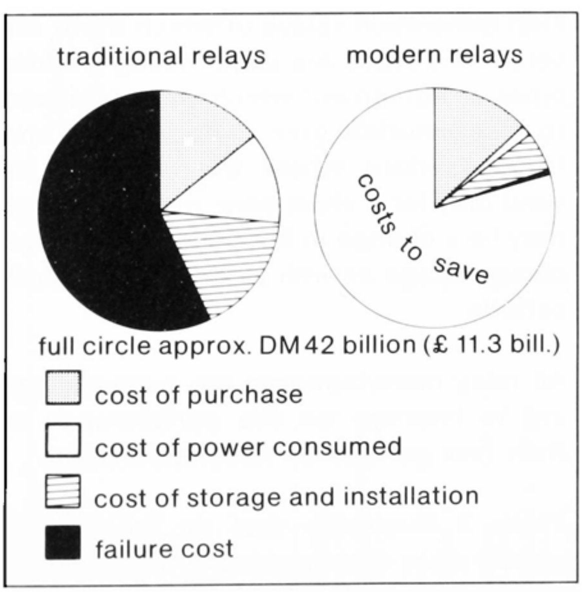


Fig. 18: Cost comparisons between the billion (approx.) traditional technology relays currently in use in Germany and the same number of modern relays.

DM 0.5 billion (approx. £ 0.12 billion) purchase cost; DM 4.65 billion (£ 1.25 billion) power consumption; DM 4.5 billion (£ 1.22 billion) storage costs; DM 23.8 billion (£ 6.4 billion) for costs associated with failures.

Experience has shown that even with modern technology relays negligible failure rates are only achieved when all aspects of manufacturing are completely understood and a quality manufacturing process is realized. As shown in fig. 19 this process can take a number of years. This histogram also shows how cost saving production quality can influence the turnover.

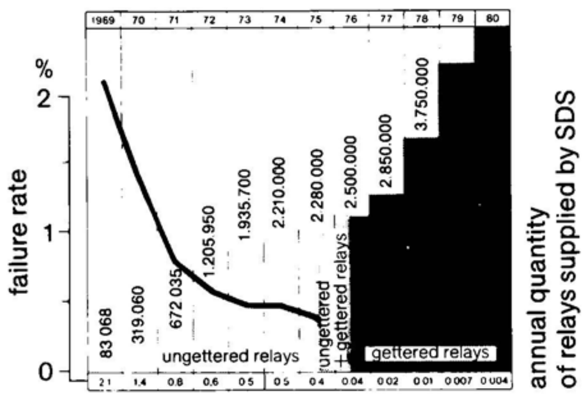


Fig. 19: Quality-turnover histogram of ungettered R-relays (up to 1975) and gettered R-relays. The lower abscissa gives the failure rate in % per year. The quantities refer to the number of R-relays sold per year in Central Europe

In fig. 18 no consideration was given to the possible extra cost savings due to:

- The use of modern relay technology in contactors. This concept is now being successfully applied.
- Lower power losses due to lower *contact resistance.*
- Higher operational life due to the low bounce characteristics of bifurcated contact operation.
- Improvement in operating conditions of neighbouring components due to negligible self heating effects.
- Lower storage charges due to needing a much smaller number of different

relay types (due to the much larger load switching range capability of each relay type).

- Short switching times (reduced by approx. 50%), (→ C-switching circuit).

The possible cost savings due to these factors are much more difficult to estimate than are those shown in fig. 18. In some applications they are important, in others, less so as illustrated in the following examples.

1. Approximately 22 billion telephone calls are made per year via the West German telephone company. From experience it is calculated that, in all probability, twice as many attempts at dialling are made — each of approx. 20 seconds — due to blocked lines, wrong connection etc. for which slow and unreliable relays are at least partly to blame. This gives in total a loss of approximately 122 million hours per year. It is impossible to calculate the effects on business and private life because of such poor, bad connections.
2. Because of a relay having too short an operational life the points of an underground train could not be changed. This cost several thousand would-be passengers several hours in waiting time [22].
3. For a contact resistance of 50 mΩ and a contact current of 2 A, the contact losses for a 2 changeover contact relay in operation for 50 kh amount to 2 kwh. If the contact resistance is 20 mΩ the loss is 12 kwh less (table 3).
   It is generally recognized that a relay contact having a higher initial *contact resistance* will see this increasing faster during operation than one which has a low initial contact resistance. The former will lead more quickly to a relay failure (Fig. 64, → Life, → Weibull diagram, → Reliability).

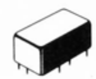
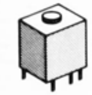
Which relay buyer even considers *contact resistance* or the other relay *characteristics* and their economic consequences when he compares two different quotations? Table 3 indicates that the operating — (and failure) costs are often directly related to the purchase price (→ Economic value).

The cost comparisons shown in table 3 are not fully representative if example 3 (→ Time-delay relays) is ignored [21]. They show the points in addition to cost price which should be considered when selecting relays. Operating costs change depending on the operating conditions (→ Pull-in time, contact current operating time and required *reliability*). They are on average significantly higher than the purchase cost (fig. 18). As an estimation purchase costs per contact based on 1000 pieces vary between £ 0.20 and £ 5.00 for traditional relays, between £ 0.25 and £ 2.00 for second generation relays and between £ 0.95 and £ 3.00 for third generation relays [21]. Table 46 shows a cost comparison with solid state switches for similar applications.

First generation relays of which there are very many types are used mainly in older types of equipment which were designed to accommodate their characteristics and in applications where the relay will be used only for a short time, or where there may be a change in the polarity of the exciting voltage as well as for special applications.

All relay manufacturers are currently trying to improve on the performance of their first generation relay technology.

Table 3 illustrates that an increase in *quality* does not necessarily imply an increase in cost, and that it is worth considering *efficiency, contact resistance,* operational *life,* power consumption and *reliability* before making a decision. The eco-

		Example 1		Example 2		Example 3		Example 4	
		bistable relay		toggle relay		adjustable time-delay relay		reed changeover relay	
									
Relay generation		1	2	1	3	1	3	1	3
Type — No. of contacts		• — 4	S — 4	HCS — 4	VS + S2L2 — 3	• — 4	TS — 4	• — 2	DRC — 2
Volume	cm^3	6,5	3,5	26	4	20	12,3	3,2	1,7
Contact resistance	mΩ	50	10	50	10	50	10	130	10
Operational life (10 V, 0.1 A)	ops.	$5 \cdot 10^6$	$2 \cdot 10^8$	$5 \cdot 10^6$	$2 \cdot 10^8$	+	$2 \cdot 10^8$	+	$2 \cdot 10^8$
Power consumption range	W	0,7 ... 1	0,05 ... 1	0,8 ... 2	0,1 ... 1	0,5 ... 2	0,2 ... 1	0,06 ... 1,4	$0,2^{\times} ... 1,8^{\times}$
Load switching range	VA	$10^{-5} ... 30$	$10^{-10} ... 1000$	$10^{-5} ... 500$	$10^{-10} ... 1000$	+ ... 60	$10^{-10} ... 1000$	+ ... 2,8	$10^{-10} ... 60$
Pick up (time delay)/bounce time	ms (s)	10/4	8/0,5	18/2	8/0,5	(0,1 ... 120)	(0,1 ... 800)	0,5/1	0,5/0,3
Dielectric strength contact/earth	V_{rms}	500	1500	1500	1500	1000	1500	1000	1500
Integrated functions		5	7	6	7	6	8	5	10
Power consumption for 1 s operation	Ws	0,85	0,1	3,5	0,2	1	0,24	0,15	0,0006
Efficiency at 10^5 operations		22	13300	77	3850	3,5	1600	12	100000
Price per 1000 pieces	£	approx. 2.90	2.40	5.60	4.30	approx. 75.00	10.90	approx. 3.80	3.10
Installation costs [21]	£	0.80	0.45	3.25	0.50	2.50	1.50	0.40	0.20
Operating costs (after 5 kh operation) [21]	£	1.10	0.15	4.35	0.25	1.25	0.30	0.20	0.00
Approx. costs of contact losses after 50 kh operating time, 2 A contact current and £ 0.125/kWh	£	2.50	1.00	1.90	0.75	2.50	1.00	3.25	0.75
Estimated failure costs	£	6.70	0.06	6.70	0.06	0.03	0.28	6.70	0.06
Estimated total costs after 50 kh	£	14.50	4.10	23.10	5.70	90.70	12.70	14.70	3.40

• due to restrictions on revealing competitive information may not be released   + unknown   × after the pick up time of 0.5 ms only 10^{-6} W

Table 3: Comparison of economic and technical data of traditional relays of the latest standard (left column) with relays of the second or third generation (right column) for 12 V nominal supply voltage

nomic value of relays can be seen from the increasing worldwide production values shown in fig. 20.

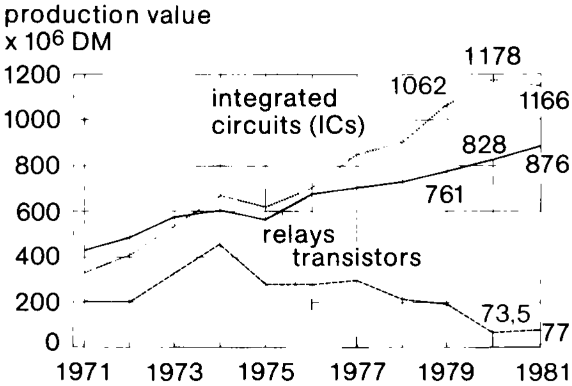


Fig. 20: Annual production volume of relays, *ICs* and *transistors* of German manufacture from 1971 to 1981 [23 extrapolated to 1981]

Due to the advance in development made in relay technology in the last few years, it can be stated that the progress for the future use of modern relays is certain to continue (fig. 1).

1.4 The Culture of Relay Technology

In view of the technical and economic meaning of relays and the fact that they dominate throughout electro technology in the solution of switching requirements, it is almost incomprehensible that virtually nothing is taught to students about relay technology. Further as there are virtually no text books available on the subject there has been no reference source available.

However, inspite of the lack of knowledge generally available on the subject, by a fundamental re-appraisal of the technology, we again become leader in the relay field. This re-appraisal has led to multilateral co-operation, as well as co-operation from employers, pioneering customers, university professors, Institutes, well informed journalists, patent experts and above all an extraordinary conscientious and creative Japanese partner [1]. The co-operation of this partner has complemented our own capabilities to a very large degree in both conception and capability and has allowed these developments in relay technology to take place.

The mutual interaction and optimization of the features described in section 1.2 such as *energy storage* (illustrated in figs. 11 to 14) or the development from traditional *reed relays* (fig. 15) to the new types of reed relays (fig. 16) can only be grasped by a cybernetic thought process.

Creative engineers have thus now been given the capability to cultivate the technology of relays still further. Whoever is prepared to work intensively in this area, would, after only a couple of years be fascinated by the many surprising facets of relay technology.

2 Terms, Definitions and Formulae

2.1 Terms and Definitions

Absolute Dielectric Constant: the product of the relative dielectric constant and the dielectric constant of the vacuum. → Dielectric constant, → Absolute permittivity of the vacuum.

Absolute Permeability: the product of the relative *permeability* and the permeability of the vacuum.

Absolute Permittivity (Electric Constant) ε_0: → Dielectric constant, → 2.3 Formulae of Electro Technology.

AC (a.c.): alternating current.

AC Relays: are operated by alternating current. Eddy current losses and hysteresis losses are reduced by a laminated iron core. In order to avoid chatter or *humming* of the armature, part of a pole face is fitted with a short-circuit ring. The flux created in this short-circuit is phase shifted relative to the main flux, thereby preventing the armature flux from periodically going through zero. A simple solution for preventing eddy current and hysteresis losses in the 50 to 10,000 Hz range is obtained with the *SAC coil.*

Action Quantity: The physical size, which should be monitored and which, on exceeding a defined value, leads to the switching action being triggered.

Active Arc Suppression: The suppression of the *arc* by means of active elements. → Arc extinction.

Active Power: The real part of the power apportioned to the resistive load within the a.c. circuit; *reactive power* is the imaginary part of the vector sum of inductive and capacitive load. *Apparent power* is the vector sum of both powers. → 2.3 Formulae of Electro Technology.

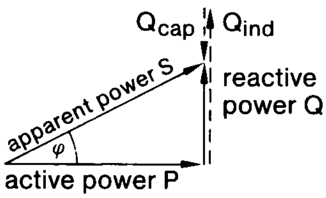


Fig. 21: Vector diagram of power relationships within AC circuit (φ = phase angle)

Active Socket Connector: An SDS designed socket connector for the S-relay with built-in *C-switching circuit* for operation with 9, 12 or 24 V. This active socket connector offers monostable switching behavior on bistable relays having a coil whose nominal voltage is approximately 50% lower than the line voltage.

Actual Value: The value of a parameter at a relay under specified conditions.

Actuate: Bringing armature and/or contacts of a relay from one position to another.

Additional Getter (→ Getter): A getter material (e.g. alumina, see fig. 22) additionally introduced into the contact chamber. This brings about an improvement in the reliability of relays fitted with a ferrite magnet activated as a getter [13, 87].

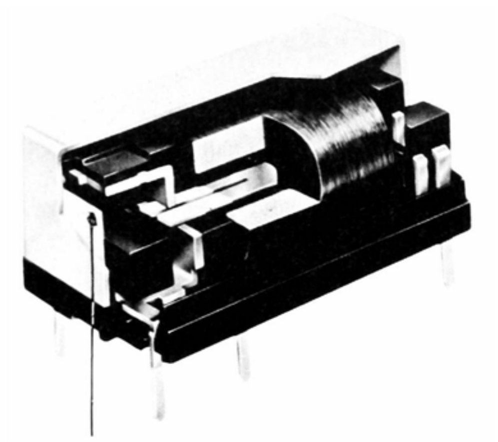


Fig. 22: DR-relay (→ relay table) with ferrite magnet and additional getter

Adjustment: e.g. setting the contact gap, bias and contact force.
Today, relay adjustments are carried out on fully automated production lines controlled by microprocessors. Such a contact force adjustment device, used in the manufacture of MSR [104], can be seen in fig. 23.

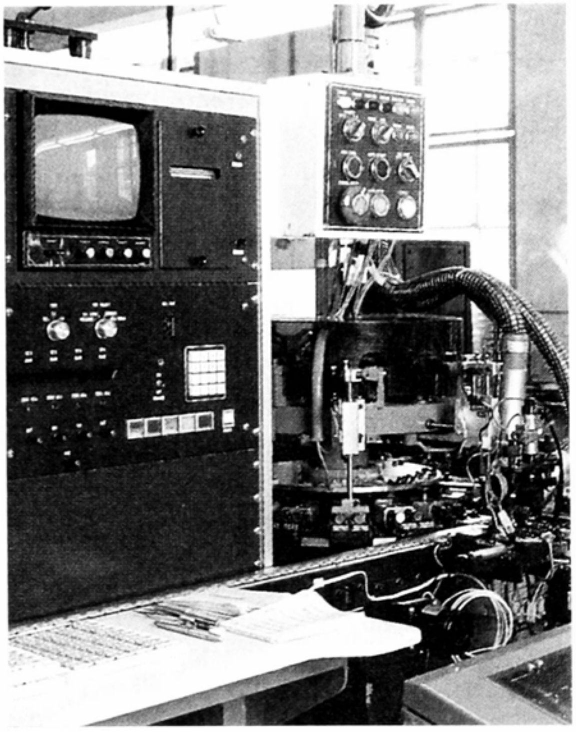


Fig. 23: Fully automated contact force adjusting machine (MSR factory) [104]

Adsorption: Deposit of gases or soluble matters on the surface of solids. → Getter.

AES — Auger Emission Spectroscopy: the preferred method of measuring insulating film (contamination by electrical, mechanical and/or chemical influence with layer thicknesses <100 nm) on contact materials. It is carried out at 10^{-9} mbar with an electron beam of 10–1000 nm diameter and a voltage of 2 to 10 kV. What is analyzed is a volume which corresponds to the product of the electron beam cross-section and emission depth of the Auger electrons (≈ 1 µm). Other methods: electron spectroscopy for chemical analyses (ESCA) and the secondary-ion mass spectroscopy (SIMS) with particularly high detection efficiency. → Corrosion, → Corrosion Test Methods.

Air Distance: → Creepage distances and clearances.

Air Gap: The distance from the center of a pole shoe or magnet core to the opposite point of an armature, including the thickness of any existing layer which acts as a magnetic seperator. → Magnet system.

A_L Value: Self Inductance Coefficient.

All Current Relay: Can be controlled with both AC or DC.

Ambient Temperature: The temperature which prevails in the immediate environment of a component in thermal equilibrium.

Ampere Turns (A. T.): The product of the number of turns of a coil and the strength of the effective current flowing through the coil.

Amplification Factor: The relationship of the load make/break capacity of a relay to its pick-up or rated power consumption.

Amplitude: The greatest extent of an oscillation from the central position.

Anode: positive electrode. → Fine migration, → Coarse migration.

Antenna Switching Relay: For coupling a transmitter to the antenna and for antenna change-over in transmitting/receiving devices by means of an *HF relay*.

Anti-freeze Pin: → Separator.

Apparent Power: → Active Power.

Approvals: As a confirmation for the fulfilment of certain requirements, several institutions at home and abroad issue approval certificates, e.g. CSA, MIL, SEV, TÜV, UL, VDE.
The use of components in certain projects is often subject to the appropriate approval certificate. → Standards and Specifications.

AQL (Acceptable Quality Level): Quality level of products agreed between customer and supplier, which is checked by random sampling. The AQL determines the extent of random sampling n from a supply total (batch) N, and the maximum proportion of failures c. These values are calculated from the probability distributions, depending on checking stringency (single, multiple, random sampling and normal, reduced or intensified check), and are specified in tables (see DIN 40080).
An example of a single sampling plan for normal checking of a component is given in the table below. It makes clear, for example, that in a batch size of 400 with an AQL of 0.025, all components must be checked with no failures allowed, whereas with an AQL of 2.5, 32 items are sampled and there may be a maximum of two failures (table 4).

Arc: A current intensive gas discharge which occurs on opening a switch, (or after a flashover). There must be a limiting current whereby the air path once ionized, is maintained conductive by thermal ionization. The limiting current was established by Heraeus [63] as dependent on the voltage, for several contact materials (fig. 24).

	n–c										
Quality level / N	AQL 0,025	AQL 0,040	AQL 0,065	AQL 0,10	AQL 0,15	AQL 0,25	AQL 0,40	AQL 0,65	AQL 1,0	AQL 1,5	AQL 2,5
51 to 90	N	N	N	N	N or 80–0	50–0	32–0	20–0	13–0	8–0	20–1
91 to 150	N	N	N	N or 125–0	80–0	50–0	32–0	20–0	13–0	32–1	20–1
151 to 280	N	N	N or 200–0	125–0	80–0	50–0	32–0	20–0	50–1	32–1	20–1
281 to 500	N	N or 315–0	200–0	125–0	80–0	50–0	32–0	80–1	50–1	32–1	32–2
501 to 1200	500–0	315–0	200–0	125–0	80–0	50–0	125–1	80–1	50–1	50–2	50–3
1201 to 3200	500–0	315–0	200–0	125–0	80–0	200–1	125–1	80–1	80–2	80–3	80–5
3201 to 10000	500–0	315–0	200–0	125–0	315–1	200–1	125–1	125–2	125–3	125–5	125–7
10001 to 35000	500–0	315–0	200–0	500–1	315–1	200–1	200–2	200–3	200–5	200–7	200–10
35001 to 150000	500–0	315–0	800–1	500–1	315–1	315–2	315–3	315–5	315–7	315–10	315–14
150001 to 500000	500–0	1250–1	800–1	500–1	500–2	500–3	500–5	500–7	500–10	500–14	315–14
>500000	2000–1	1250–1	800–1	800–2	800–3	800–5	800–7	800–10	800–14	500–14	315–14

Table 4: Sampling inspection plan according to AQL

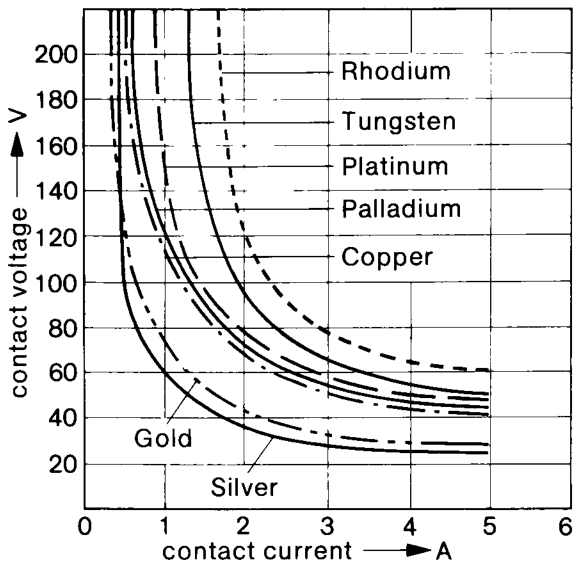


Fig. 24: Arcing limits for pure contact materials [63]

However, the arc is also dependent on the cleanliness and shape of the contacts, both of which conditions are apparently dependent on the surface temperature increase, which can be approximated to the annealing temperature. With higher temperature, the arc reduces. Examinations of the influence of air humidity have produced contradictory results. The current density of the arc is approximately 100 A/mm^2, the temperature between 2,000 and 10,000°C. The arc also requires a minimum voltage U_b which Burstyn [46] states as follows:

Switching material	U_b V
Zinc	11
Copper	12,5
Fine silver	12
Silver-Palladium 30 %	13
Iron	12–15
Gold	15
Brass, German silver	15
Platinum	16
Tungsten	16
Carbon, Graphite	18–22

Table 5: Lowest value arcing voltage U_b

Because of ion formation, the arcing voltage is relatively low. When a contact opens with arcing, the resistance of the contact will initially increase; the consequential temperature increase results in the ignition of the arc. With increase of the contact opening and resistive load, the arc drop voltage rises rapidly above the value of the source voltage, and the arc is extinguished.
In inductive circuits, however, a secondary voltage source of higher potential develops through the energy 0.5 LI^2 stored in the inductance; the arc is maintained until this energy is converted into heat.
With capacitive and inductive elements present in the circuit, high frequency oscillations are likely to occur which would likely cause radio interference. With further contact opening, the arc becomes increasingly unstable, until it collapses. The resistance in the circuit increases and a voltage peak forms which, as per an exponential function, then subsides to the operating voltage. → Discharges. Not every circuit will tolerate such unstable chaotic conditions. → Arc extinction.
The arc erodes the contacts. Contact material migration occurs from cathode to anode with craters and peaks forming. Evaporation also occurs; this increases with the contact gap. This also signifies that the wear of the contact material is greater than the migration: the consequences of which are, in the main, increasing contact gaps, decreasing contact forces, increasing contact resistance and reducing contact reliability.
In sealed housings, there is the danger that the insulation resistance will be lowered due to the precipitation of the evaporating contact material.

Intensity and duration of the arc are further affected by:
- Air pressure (Fig. 25)
- Atmosphere, type and composition of a protective gas
- Magnetic fields (→ Blow-out magnet)

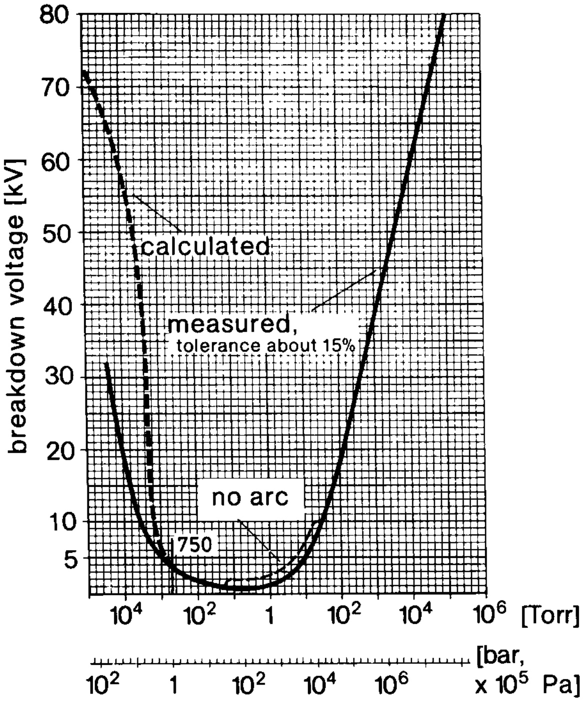


Fig. 25: Breakdown voltage (60 Hz) related to air pressure (contact gap 0.8 mm)

- Inductance, capacitance and frequency of the current to be switched
- Form of the contacts (→ Blow-out magnet)
- Switching speed
- Type of contact materials
- Number of points of interruption per switching point (double interruption with bridge contacts).

Arc Chamber: A device for the spatial restriction or extinction of the arc.

Arc Discharge: → Arc.

Arc Extinction, Arc Suppression: When the critical voltage of the arc (fig. 24), which depends on switching current and contact material, is exceeded, discharge processes will commence at the relay contacts, resulting in damaging material migration. In order to achieve long life and high reliability in spite of such contact stresses, circuit design precautions to suit each particular case are required to ensure suppression of the arc.

Direct-Current Circuits with Ohmic Load

The switching voltage is above the critical voltage of the arc, but must not be higher than the breakdown voltage of the open contact. With polarized relays, the designer will aim to achieve the desired blow-out effect (→ Blow-out magnet) by appropriate positioning of the permanent magnet to increase the switching capacity. (For example, this is practiced with the DX-relay, → Relay Table). Furthermore, an RC network connected in parallel with the contacts, can be used for arc suppression.

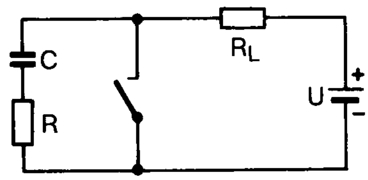


Fig. 26: Spark suppression using RC network.

At the instant of contact break, the voltage U_C at the contacts, jumps from zero to the value $U\ R/(R+R_L)$ and, following the function $U_C=U(1-e^{-t/\tau})$, rises, where $\tau=(R+R_L)C$.

The resistance R must be of such size that at the moment of turn-on, the sum of capacitor discharging current and switching current is smaller than the maximum permissible inrush current. $R>U/(I_{perm}-U/R_L)$. With a switching frequency of 1/T, the capacitor should have discharged before the contacts open again. According to Fuhrmann [64] this is basically ensured when $C[\mu F]<T[ms]/2R[k\Omega]$ is selected.

Direct-Current Circuits with Inductive Load

While with a resistive load on the contacts, there is no more than the switching voltage U applied, with an inductive load it is possible for voltage peaks of approximately ten-fold to occur at the instant of contact break (fig. 27).

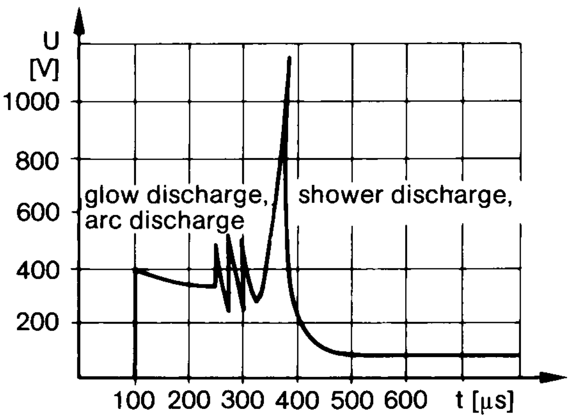


Fig. 27: Relay contact voltage curves for inductive loads

In order to prevent damage due to arcing, it is necessary to avoid a sudden interruption of the inductive load current flow and to simultaneously ensure that the voltage rise at the contacts — brought about by the breakdown of the magnetic field — takes place more slowly than the contact opening, thus countering the development of an arc, and, rapidly after contact opening, creating an air gap whose arcing voltage is far above the voltage which builds up at the contacts. For this purpose, an RC network connected in parallel with the contacts can be used (fig. 28).

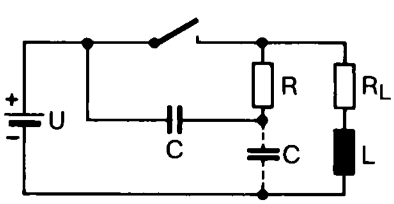


Fig. 28: Arc extinction circuit using RC network for inductive load at contacts

At the instant of contact opening, a charging current, decaying in accordance with an exponential function, flows through the capacitor. The rate of decrease in the inductive current is thus slowed and, at the same time, the peak value of the voltage developing at the contacts is reduced. For rating the capacitor, the practical approximate value is: $C[\mu F] \approx I^2[A^2]/10$, I being the switching current in any particular case. The resistor value must be calculated so that the sum of the capacitor discharge current and the switching current is less than the permissible inrush current;

$$R > \frac{U}{I_{perm} - \frac{U}{R_L}}$$

A further possibility of avoiding high voltage peaks on switching off inductive loads, is by way of connecting an RC network in parallel with the load (fig. 28). In this case, the capacitor discharge current flows through the inductance when the contacts open. This kind of contact protection is in effect equivalent to the parallel connection of the RC network with the contacts. What must be taken into account in both cases, especially with higher switching currents, is that relatively large and expensive capacitors are required, whose discharge or charging currents additionally load the switching contacts at the instant of make.
Further, a voltage dependent resistor or varistor may be connected in parallel with the load, to act as contact protection. The resistance is low at high voltages and high at low voltages. Varistors are also suitable for arc suppression in a.c. circuits.

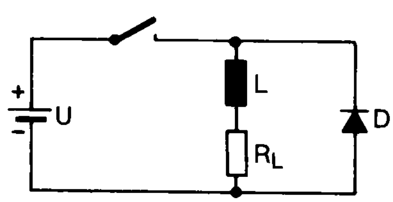


Fig. 29: Arc extinction using free wheeling diode

A further possibility of arc extinction is achieved by connecting a diode in parallel with the load so as to block the switching voltage (fig. 29). The diode blocking voltage selected must be greater than the switching voltage. When the contacts open a voltage develops in the inductive load with polarity opposed to that of the switching voltage. In this arrangement, the diode is biassed in the flow direction and shorts out the voltage. When rating the diode, care must be taken to ensure that the peak current does not exceed the value permitted for the diode. In order to shorten the drop-out time of the relay, a Zener diode can be connected in series with the diode. The voltage at the contacts then rises to the operating voltage U plus Zener voltage U_Z. Such an arrangement will achieve safe arc suppression if the voltage at the contacts is always smaller than the arc drop voltage U_B.

$U_B > U + U_D + U_Z$; U_D being the diode voltage drop. In all other cases where the current continues to flow after contact opening, an arc develops; a diode is not effective. In such cases where a diode alone is not enough, a solution is to connect an RC network in parallel with the contacts (fig. 30). The function of the capacitor in the RC network is to ensure continued current flow through the load from the instant of contact opening, only so far as to avoid the inductive switching peak which would be sufficient for an arc to generate. During charging of the capacitor, the contacts are already opened sufficiently wide so that the ignition voltage is greater than the occurring peak value. The diode now becomes effective and reduces this voltage. Since, in this case, the capacitor needs to accept only a fraction of the inductive energy, a capacitor of only one tenth of the capacity normally required for a quenching capacitor will suffice. Apart from the advantages of space and cost, this arrangement also presents a particularly low contact load at switch on. Taking into consideration the current carrying capacity of the relay contacts, the resistor of the RC network must be dimensioned in the manner previously described.

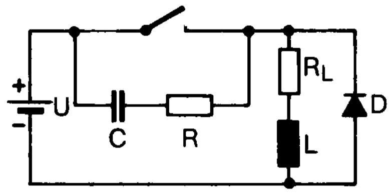


Fig. 30: Arc extinction using RC network and free wheeling diode

However, the circuit shown in fig. 30 does not apply if the inductive load is to remain unconnected. In these cases, a circuit with basically the same effect, as in fig. 31, is recommended. The RC network which is connected in parallel with the contacts should be dimensioned in the same manner as shown in the circuit of fig. 30. The Zener diode used here (whose Zener voltage lies slightly above the switching voltage) will, after the capacitor is fully charged, limit the voltage at the contacts. The graph of this voltage is shown in fig. 32. Inductive peak voltage at the contacts, due to which an arc could strike, will no longer occur in this case.

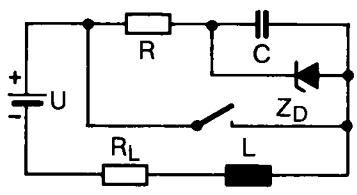


Fig. 31: Arc extinction with RC network and Z diode

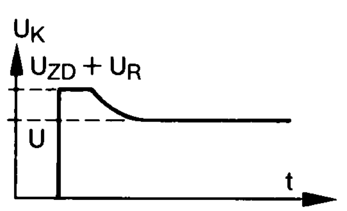


Fig. 32: Voltage seen at the relay contact when using a protection circuit as shown in fig. 31

A further possibility of arc extinction in relay circuits is in the application of a UAFL (Universal-Aktiv-Funken-Löscher = Universal Active Arc Suppressor, Patent CH 588153) [65]. The circuit represents a

universally applicable protective system for low load electrical contacts switching inductive loads and is optimized for good contact protection. Normally the effect on relay switching times is negligibly small.
The UAFL (Universal Active Arc Suppressor) is polarized, and is fitted as illustrated in fig. 33. With contacts k closed, a load current of $I_p \sim U_B/R$ (U_B = battery voltage), flows. When the contacts k open, the active arc suppressor receives the current I_p which previously flowed across the contacts. The voltage rise du/dt at the contacts is kept low, thus preventing arcing.

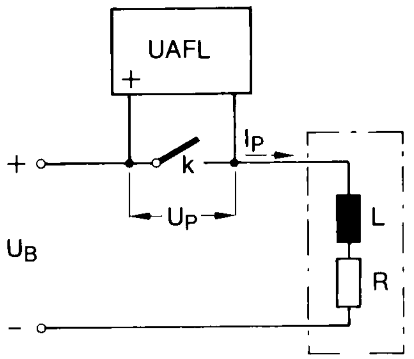


Fig. 33: Schematic of a universal active arc suppressor (UAFL) [65] to protect a contact k whilst switching an inductive load R, L

If in fig. 34 the contacts are closed, all points are at positive potential. If the contacts are opened, the voltage at the transistor emitter drops relative to the positive potential. This voltage drop corresponds to the base emitter voltage plus the voltage drop over R2, caused by the

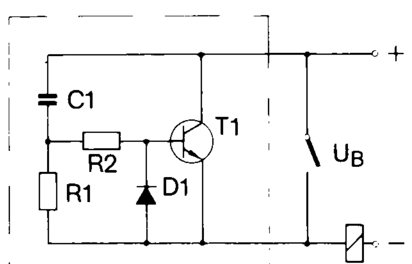


Fig. 34: Schematic of a universal active arc suppressor (UAFL) [65]

base current. The transistor conducts and receives the coil current which previously flowed through the contacts. The gradient of the voltage rise, du/dt, on the capacitor, and therefore on the circuit, is given by I/C, where I is the momentary current through R1 plus the base current, and C1 is the value of the capacitor. The gradient was selected so that, on the one hand, the permissible collector emitter voltage (U_{CER} = 450 V) is not exceeded and, on the other hand, the relay drop-out delay is not significantly prolonged. The capacitor is charged by current I. The voltage over the UAFL continues to rise until the energy stored in the coil is dissipated. The transistor switches off, and the capa-

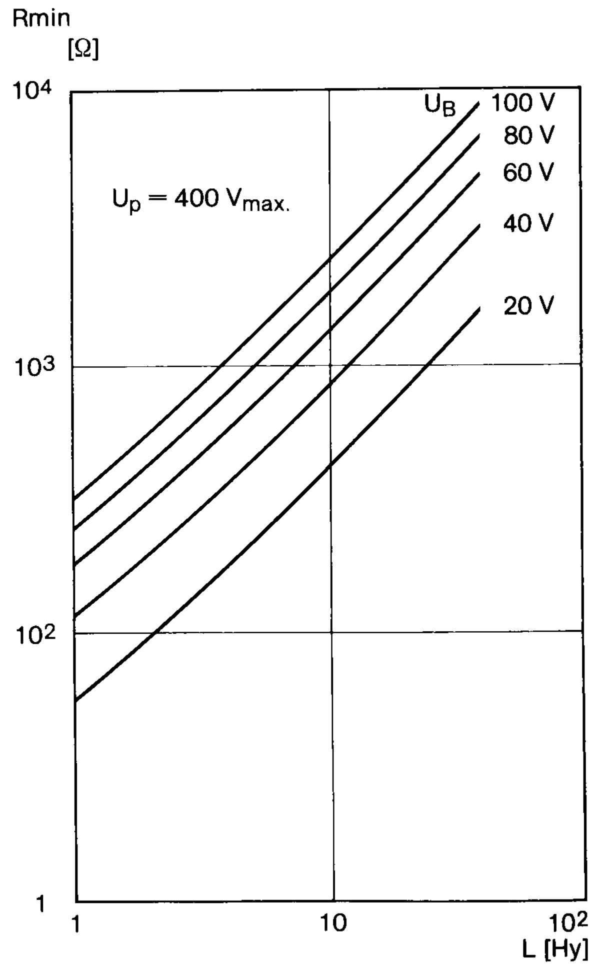


Fig. 35: Permissible load of the universal active arc suppressor (UAFL) $R_{min} = f(L)$. Parameter is operating voltage U_B [65]

citor, except for the battery voltage U_B, is then discharged. When the contacts are again closed, the capacitor is fully discharged; resistors R1 and R2 limit the discharge current to a value which will not damage the contacts. The diode prevents a too high base emitter voltage.

Maximum ratings of the UAFL:

- Application in circuits with direct current.
- The turn-off voltage peak occurring at the contacts, U_P, employing a UAFL system, must not exceed 400 V. Advice: - check with oscilloscope.
- The permitted contact current I_P (current before break) must not exceed 0.5 A.
- Utilization curves for max. permissible RL combinations. $R_{min} = f(L)$ see fig. 35

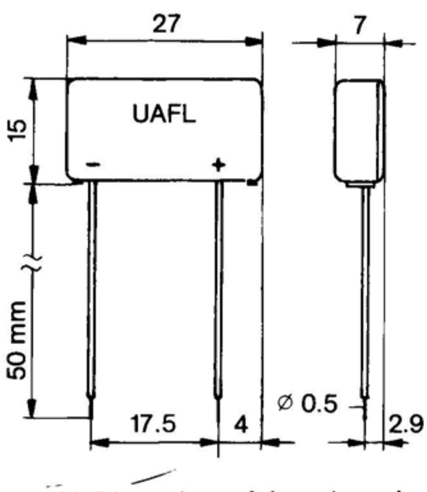


Fig. 36: Dimensions of the universal active arc suppressor (UAFL) [65]

Fig. 37: Construction of the sealed UAFL [65]

A. C. Circuits with Inductive Load

Although in AC circuits an arc can develop on contact opening, it can self extinguish on crossing the zero-axis of the switching current. There is however the danger that contact life will be reduced due to material migration because of the arc. To avoid this, an RC network can be connected in parallel with the inductive load, (fig. 38); the time constant of this RC network should approximately correspond to that of the load. $RC = L/R_L$.

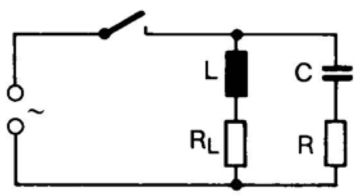


Fig. 38: Arc suppression with RC network

In general, the resistance of the RC network is designed to be approximately equal to the ohmic proportion of the ballast resistance. For the capacitor then:

$C \approx L/R^2$.

A contact protection recommended for higher switching currents is a VDR (varistor) connected in parallel with the load, or two Zener diodes connected back-to-back, with the Zener voltage slightly higher than the switching voltage.

These components will not conduct (or will pass very little current), whilst the switching voltage is applied. The voltage peak, which occurs when the contacts open, will, in effect be short-circuited by this arrangement, thus suppressing arcing at the contacts.

Apart from extinguishing or suppressing the arc, the contact protection measures described will simultaneously ensure that interference with adjacent circuits, due to excess voltage or radio interference, is minimized. → Radio Interference Suppression.

Arc Resistance: The property of an insulator to withstand decomposition by heat of the arc and thus maintain the surface resistance. It is subdivided into six quality gradings, in accordance with DIN 53484.

Armature: Serves to open and close the magnetic circuit of a relay and thus directly or indirectly to operate the contacts. Distinction is made between: rotating armature, usually center-of-gravity supported, with two or four air gaps, (fig. 9); flat armature (fig. 298); balanced or clapper-type armature (fig. 310); clapper-type or plunger-type armature (fig. 305); knife-edge armature (supported on the edge of a yoke); and, reed armature. → Reed relay, → Magnet systems.

Armature Arm: That part of the armature which operates the contact or the contact bank.

Armature Bearing: Distinction is made between: knife-edge, point, spring and axial armature bearing. Knife-edge armature bearings usually have no bearing play, and therefore permit more precise and maintenance-free switching. Axial armature bearings with an armature supported at the C. of G. are preferred for higher resistance to shock and vibration.

Armature Clearance: The distance between the contact spring and the actuating nipple, necessary for compensating the wear of the contacts.

Armature Stop: Usually an adjustable component (screw or adjustable tongue) which restricts the armature opening in order to obtain accurate pull-in values.

Armature Stroke: → Armature Travel.

Armature Travel: This is the distance travelled from the central point of the armature pole face when switching from one position to the other.

ATE: Automatic Test Equipment.

Auxiliary Relay: (also Hilfsrelais) is a term only used alternatively in specialist German language and means: — a switching relay with no intended time delay function. The use of this definition is given by the following:

The IEC publication 255 uses throughout, a definition system which is in part different from that commonly used in the German language practice (VDE 0435, DIN 41215). In particular, in IEC 255:

- the energized states of relays are described by two separate concept groups, while only one concept group exists in the German specialist terminology;
- the relays are divided into the groups according to their operating time delay, whereas in the German system, distinction is made between instantaneously operating, and intentionally delayed (time delay) relays. Switching relays with intended time delays are referred to as "time-delay relays", and the other group as "auxiliary relays".

AWG (American Wire Gauge): Numerical value for the diameter of wire. AWG coding has the following characteristics: — Increasing the AWG by three steps increases the number of turns of a coil by a factor of 2; increasing the AWG number by two steps increases the number of turns by a factor of 1.59; increasing the AWG number by one step increases the number of turns by a factor of 1.26.

An increase of three steps in the AWG number results in a resistance increase by a factor of 4; increasing the AWG number by two steps increases the resistance by a factor of 2.52; increasing the AWG number by one step increases the resistance by a factor of 1.59 (table 6).

AWG	Ø [mm]	A [mm^2]
30	0,2548	0,051
31	0,2268	0,040
32	0,2019	0,032
33	0,1798	0,025
34	0,1601	0,020
35	0,1426	0,016
36	0,1270	0,012
37	0,1131	0,010
38	0,1007	0,008
39	0,0897	0,0063
40	0,0799	0,0050
41	0,071	0,0040
42	0,063	0,0031
43	0,056	0,0025
44	0,051	0,0020
45	0,046	0,0016
46	0,039	0,0012
47	0,036	0,0010
48	0,032	0,00080
49	0,028	0,00062
50	0,025	0,00050

Table 6: American wire gauge (AWG) for non ferrous wire and sheet → enamalled copper wire, → coil

Barkhausen Effect: Acoustic proof that the magnetization of ferromagnetic materials is not a continuous process but takes place in minute steps. The induction pulses occurring on a reversal of *Weiss domains* are made audible via amplifier and loudspeaker.

Baseplate: That side of the relay from which the coil and contact terminals protrude and which forms the termination relative to the mounting side.

Basic Grid System: Standard length of a square grid. For the purpose of universal installation of components and equipment, their electrical connections are arranged at the intersections of such a grid. The grid line distance commonly used for printed circuits is 2.5 mm; in countries with imperial measuring systems, 0.1″≙2.54 mm or a multiple thereof. For components which are not too large, it may be practical to select a mean grid system of 2.52±0.02 mm.

Bathtub Curve: Curve of the *failure rate* λ, shown as related to the main factors of influence (e.g. time, number of operations etc.). This curve can generally be divided into three main areas (see fig. 39):

a) Early failures: In this area, the failure rate tends to diminish. Early failures can, in part, be reduced by so called *burn-in* measures.
b) Random failures: In this area, the *failure rate* is constant; it is called the "utility life".
c) Normal Wear Failures: In this area, the failure rate rises due to phenomena of wear. With knowledge of the useful life, timely replacement of components which are subject to wear can prevent failure.

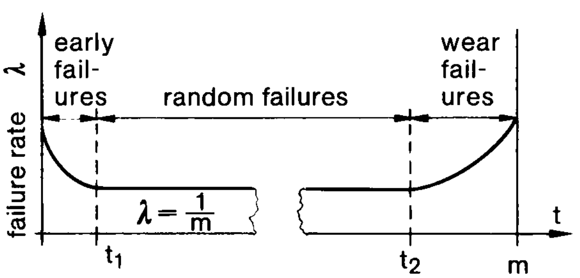


Fig. 39: Bathtub curve

bbm (break before make): Opening before closing is generally the sequence of switching with changeover contacts. → mbb.

Bifilar Resistor: A wire-wound resistor with *bifilar winding* and hence very low self-inductance.

Bifilar Winding: A magnetically ineffective, non-inductive winding. It consists of two equally thick wires wound onto a bobbin, the ends of the wires being connected to each other. The current will flow in each of the wire halves in opposed directions. Example of application: in HF resistors.

Bifurcated Contacts: effect contact make with two independently sprung contact points. This results in a significant improvement of the *reliability*, especially at very low voltages. The reliability conditions of various contact arrangements are shown in table 7 [25].

Bifurcated Linear Contact: → Contact Resistance.

Bilateral Contact Opening: is ensured by a bilaterally guided contact spring. → Forced Operation

Bimetal Relay: → Thermo-electrical relay.

Binary Counting System (Dual System): Counting system with the base 2. Thus only the figures 1 and 0 occur, e.g. corresponding to the two positions of a relay. The digit values are read from right to left, ones (2^0), twos (2^1), fours (2^2), eights (2^3) etc. For example, the binary number: 1101 ($1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$) corresponds to the decimal number 13; ($1 \times 10^1 + 3 \times 10^0$). → Logic.

Bistable Relays: (Latching relays) retain the switched position after interruption of the energizing current. The switched position can be maintained both mechanically or by a permanent magnet. If mono-polar trigger pulses only are available, two energizing windings are required for set/reset. With only one energizing winding, bi-polar polarized trigger pulses are required for one or the other switching positions (→ Polarized relays). The advantages of bistable relays lie in the possibility of energy saving by pulse switching of the coil, low thermo-electric voltage, as well as relatively high contact force, which is practically independent of the power consumption, and the resulting increased contact safety and reliability, (figs. 9 and 14). Bistable relays can also be operated to the same advantage in

RELIABILITY AND FAILURE FREQUENCY IN RELATION TO CONTACT ARRANGEMENT

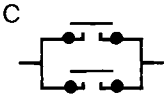
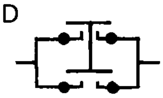
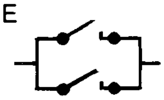
Contact arrangement diagram	A 	B 	C 	D 	E 
Type of contact break	single break	double break	as B but parallel connection	as C but direct connected	as A but parallel connection
R_S system reliability	$R_S = R$	$R_S = R^2$	$R_S = 1 - (1-R^2)^2$	$R_S = [1-(1-R)^2]^2$	$R_S = 1-(1-R)^2$
R_S for a life probability of R = 90%	90 %	81 %	96 %	98 %	99 %
Percentage comparison of failure probability	50 %	100 %	17 %	6 %	5 %

Table 7: Comparison of the reliability of single and double contacts

monostable mode, using *C-switching circuits.* → Relay times.

Black-or-white Switching: Refers to the ON or OFF switching of a relay without regard to relay operating times. Relays whose contacts are not synchronously operated in the switching process, or respond unintentionally at different energising power (e.g. two-coil controlled, independent reed contacts), are usable only in black-or-white switching. → Contact Sequence.

Blow-out Magnet: With an inductive load, the magnetically stored energy in a relay is largely converted into heat in the form of an arc between the contacts. In order to rapidly disperse the heat away from the contact zone, and also achieve rapid energy conversion by raising the arc voltage, the breakdown arc can be diverted by a magnetic field. It can be extended in this way and removed from the contact zone (→ Magnetic force). With direct current, this is easily achieved by a permanent magnetic field (fig. 40).

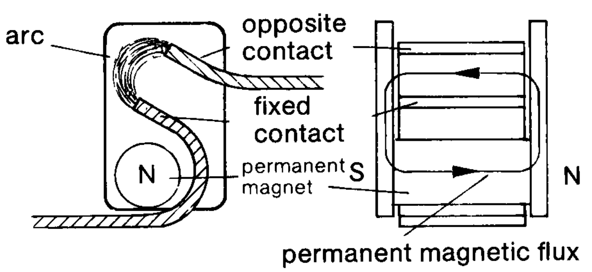


Fig. 40: Arc extinction using a blow-out magnet

With alternating current, a current-carrying coil with iron core is employed instead of a permanent magnet, so that at any instant the polarity corresponds to the momentary direction of flow. Since a very small magnetic field is sometimes sufficient to drive the arc, it is possible to achieve a blow-out effect by using a suitable contact shape — fig. 40 shows an iron core with pole shoes —, since the contact wound around the core represents half a winding. The magnetic deflection of the arc increases contact life, not only because of the shorter burning time, but also because the arc striking points are diverted away from the normally softer zone of the contacts (e.g. Ag), into a harder zone (e.g. Cu). Since the arc voltage is increased, the possibilty of *arc extinction* is made easier.

Bobbin: The carrier of the coil winding(s) and, as a rule, also of their connections.

Bottom View: → Wiring diagram. View of the connections from the bottom side of the relay (wiring side).

Bounce: occurs mainly on closing of an electrical contact when the kinetic energy in the moving contact parts leads to a bounceback of the operated contact, and thus causes contact interruptions. This occurrence is usually repeated several times, with the extent of bounce becoming progressively smaller. The subsequent period of contact quiver (vibrating contact force) is no longer part of the bounce, but of the period of *dynamic contact resistance.* (→ Contact noise).
The contact discontinuity during the opening of a contact is not true mechanical bounce of the moving contact, since at the time of opening no kinetic energy will have been stored, but is rather due to contact resistance changes which occur during the contact force reduction before commencement of separation, through the process of friction and vibration. → Bounce suppression circuit.

Bounce Suppression Circuit: Through downstream *Schmitt-Trigger* circuits or monoflop as IC modules, it is possible to eliminate interference caused by bouncing relay contacts (but not to extend their life). (→ Multi-Vibrator). A new, extremely simple and very effective method of bounce suppression (in which, most importantly, the relay contacts are protected) works in accordance with the following principle:

By contrast to a normal monostable relay, a relay with a second winding is used which has no energizing function. It is therefore possible by means of the induction in this coil, to drive semiconductors (transistors, thyristors, triacs) which lie in parallel with the contacts, electrically isolated from the input circuit. The following advantages stem from this arrangement:

1. Irrespective of the relay type, the pick-up time is only a few µs.
2. Bounce-free contact switching. The contact life is therefore greatly extended.
3. Bounce suppression circuits are not required.
4. The contacts switch almost load-free, serving to extend their life.
5. Particularly demanding applications, such as high lamp or capacitor loads, can now be handled.
6. With a.c. loads, switching at zero volts is possible.

Bounce Time: According to DIN 41215, this is the period from the first to the last closing/opening of the relay contacts on change-over to a different switching position. It is not part of the pull-in or drop-out times of the relay.
What is of importance for the stress of contacts switched under load is not the bounce time, but the number of bounces occurring during that time (→ Bounce). Since every bounce switches the load on as well as off, the electrical life of the contacts will be significantly shortened. → Relay table, → Relay times.

Break Contact: The closed, non-energized contact in a monostable relay. → Contact types.

Breakdown Voltage: The effective voltage at which a breakdown occurs between two opposing electrodes. It is dependent on the type of insulator (with gaseous insulators, temperature and relative humidity, in addition to atmospheric pressure, play a part: fig. 41), on the electrode spacing (fig. 42) and on the shape of the electrodes. → Dielectric strength. With a.c., the breakdown values must be reduced to approx. 0.7 of those stated. → Arc.

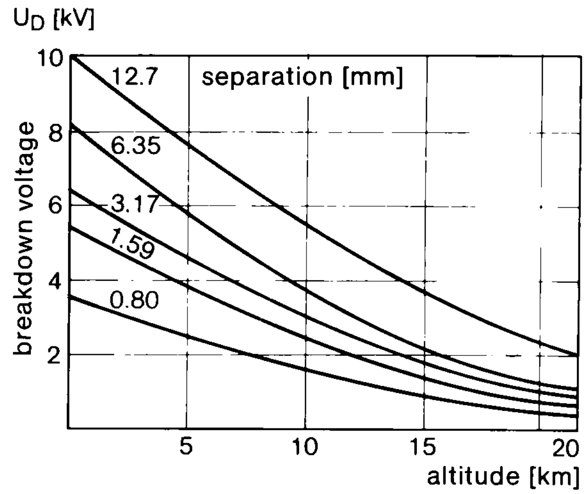


Fig. 41: Breakdown voltage in dependance of altitude (airpressure) at 50% relative humidity

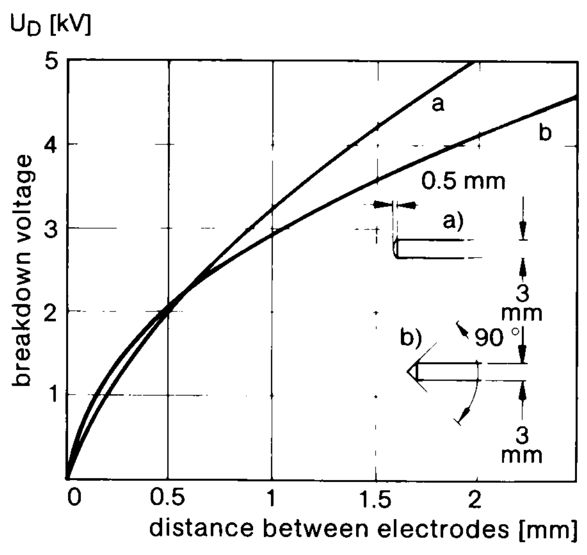


Fig. 42: Breakdown voltage U_D in relation to the electrode separation and electrode shape. Temperature 20°C. Relative humidity 50%.

Breaking Current: The contact current which flows at the instant of contact opening; it is usually higher than the operating current, and is dependent not only on the breaking voltage, the inductance or the capacitance of the circuit, but also on the contact material, the atmosphere and the temperature rise of the contacts. → Switching capacity.

Breaking Current, Maximum: The maximum current which can be safely interrupted by a contact with a predetermined number of switching operations per hour and a stipulated number of operations. → Switching capacity.

Bridge Transfer: A kind of material migration in melted bridges during contact opening; it ends with tearing of the melted bridge.

Brown-Powder Effect: A brown formation on the contact surfaces which occurs especially with platinum, rhodium and palladium alloys in nitrogen atmospheres and organic vapours, and causes high *contact resistance*. *Gettering* is a good method of preventing this.

Burn-In: The term generally used for the pre-aging of components [99]. Pre-aging is supposed to aid timely recognition of early failures (→ Bathtub curve), and their elimination. The type of pre-aging is determined by the type and application of the product. In many cases, operation at higher temperatures is selected for this purpose. → Thirty Per-Cent (30%) Rule.

Bus Line: A data line which links several units (address bus, data bus, control bus).

C3-Relay: → IC Relay, → C-Switching circuit.

C-Switching Circuit: The combination of polarized miniature relays with a simple semiconductor circuit (fig. 43), enabling advantages previously reserved for bistable relays to be used for monostable switching.
A capacitor C is connected in series with the relay coil R, and, taking the coil resistance into consideration, its capacitance is selected so that the charging time-constant lies within the pick-up time range of the relay. As shown in fig. 44, the power consumption on applying the energizing voltage U, is thus essentially limited to the pick-up time of the relay.

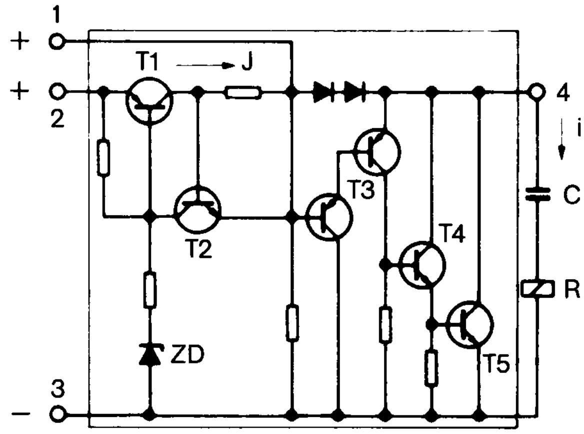


Fig. 43: Circuit diagram of C-switching circuit

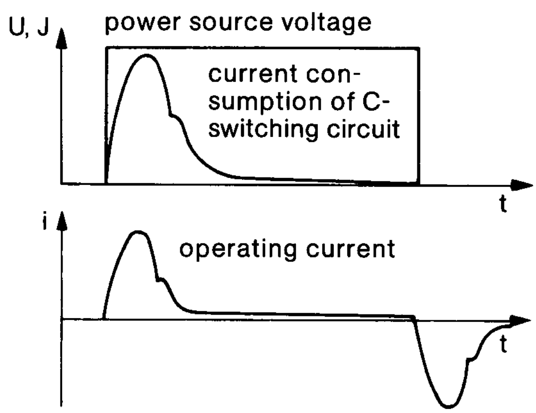


Fig. 44: Principal voltage and current curves of the C-switching circuit

During the operation of the relay at rated voltage, there are minimal leakage currents of 100 μA maximum. If the energizing voltage U is interrupted, the capacitor C will discharge via the trigger circuit T3, T4, T5 in the IC-module. The relay is energized with the opposite potential voltage and switches back.
Part 3 of this book deals in detail with the peculiarities of C-Switching circuit applications.

Capacitance: The storage capacity of electric charges in a two-pole network: defined as the ratio of an electric charge on electrodes adjacent to each other on a two-pole network, to the potential difference existing between them. → 2.3 For-

mulae of Electro Technology. → 2.2 Units of Measurement.
This storage capacity is utilized in *capacitors.* Capacitance also exists between conductors insulated form each other, and between contacts of a relay. → Contact capacitance.

Capacitor: Electrical conducting areas arranged opposite each other and separated by a dielectric, for storing an electrical charge. Distinction is made between paper, electrolytic, ceramic, glass capacitors etc., depending on the dielectric. Charging and discharging of a capacitor occurs in conjunction with a resistor following an exponential function. In relay technology, it is used for arc extinction and for changing relay switching times. → 2.3 Formulae of Electro Technology, → Contact Capacitance.

Cathode: Negative electrode. → Fine migration, → Coarse migration.

c.e.m.f. (counter-electromotive force): → EMF In accordance with the law of induction (Faraday's Law), during current changes in a circuit, the induced source voltage, $U_i = -L\ di/dt$ develops ($L =$ *inductance* of the circuit). This causes a current flow which acts to reduce the change. With rapid current changes, di/dt and large inductances in the circuit, U can attain quite considerable values.

Center Point Tapping: → Rectifier Circuits.

Center-Stable Relay: These relays have their armatures in a non-energized condition in a (neutral) position, in which no contact is made. As a rule, these are *polarized relays* with one or more change-over contacts which, depending on the direction of the energizing current, adopt one or the other of the operated positions. → Three-position contactor.

Change-Over Contacts: Enable one circuit to be switched off and another to be switched on, as required. Where occasions arise, distinction is made between single circuit and two-circuit change-over contacts. Single circuit change-over contacts have three electrically isolated terminals (i.e. the opening and closing contacts have a common base). Two-circuit change-over contacts have four electrically isolated terminals.

Change-Over Relay: A relay with one or more *change-over contacts.*

Characteristic Impedance: $Z = \sqrt{L/C}$ (applies if $f > 100$ kHz): This is one of the characteristic quantities for the high frequency properties of an electrical four-terminal network. → HF Relays.

Characteristics: The properties of relays or contactors which, in part, are related to a specified life. See also part 3.1 and part 4.

Circuit: The closed current path between power source and consuming unit (VDE 0100, part 200); distinction is made between:

a) Main circuits which contain operating facilities for generating, transmitting, distributing, switching and consuming electrical energy; and
b) Auxiliary circuits for additional functions, e.g. control circuits (command signal, interlocking), indicating and measuring circuits. Control circuits always belong to the power plant; indicating circuits belong to the power plant if they are galvanically linked with it. Joint fuse-protected or galvanically interlinked control and indicating circuits, irrespective of the way in which they are linked with the main circuits, are always direct components of the power plant.

Circuit Diagram: Wiring diagram; a graphic representation of electrical connections in a circuit with the symbolically represented components installed therein, without indication as to their spatial arrangement. → Wiring diagram.

Clapper Type Relay: These have an offset armature which rocks about a yoke edge.

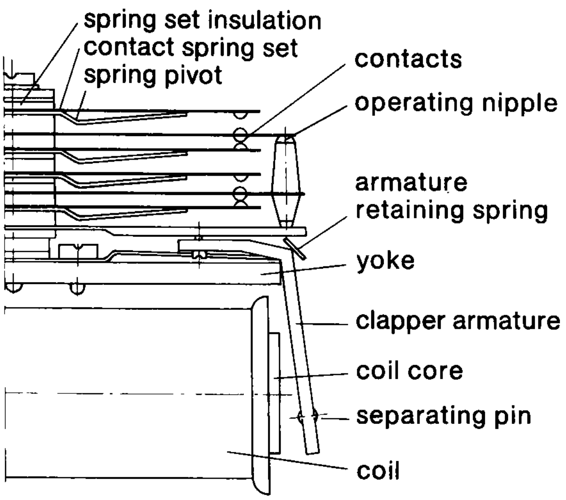


Fig. 45: Armature bearing on a clapper type relay

CMOS (Complementary Metal Oxide Semiconductor): *MOS* technology which operates with complementary *FETs*.
Main characteristics: low power consumption, low sensitivity towards voltage and temperature fluctuations, short delay times, as well as large output load factors.

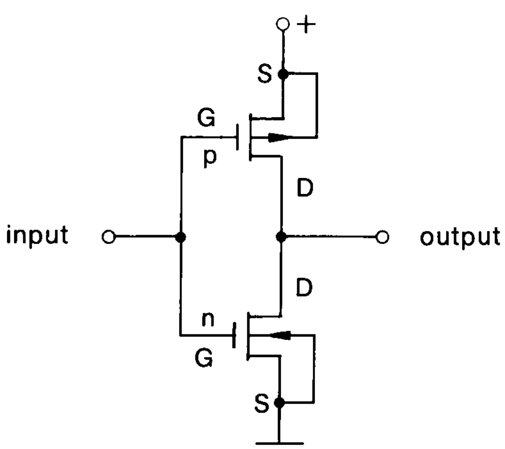


Fig. 46: CMOS field effect transistor G gate, S source, D drain n, p doping

Coarse Migration: presupposes *arc* or *glow discharge.* A portion of the material which evaporates from the cathode, according to [46], will precipitate back onto the cathode, a further portion will form on the anode and a third portion will be deposited in the contact chamber. The anode may not necessarily gain during this process, but may in practice lose rather more than it gains. → Fine Migration.

Coaxial Relay: An *HF relay* which is fitted with HF plug systems for connection to coaxial lines.

Coercive Field: The field strength which is necessary in order to bring the remanent induction to zero value. It therefore represents a parameter for ferromagnetic materials (→ Hysteresis). Unit: A/m (→ 2.2 Units of Measurement).

Coil: The sum of windings on a bobbin or unsupported windings (self-bonding wire). For a winding space of a given mean length, there is a relationship between the number of turns, the wire diameter and the coil resistance. A convenient method of changing from a relay's given coil data to other values, is shown in fig. 47. The calculations are as follows:
Example:
Given that coil 1 with $R_1 = 1000\,\Omega$, $w_1 = 2000$ turns of wire diameter, $d_1 = 0.1$ mm.
Determine coil 2 with $R_2 \approx 2000\,\Omega$.
Method:
The wire of diameter $d_1 = 0.1$ mm produces on the windings/resistance curve the points A and B, with the appropriate co-ordinates $K_{w1} = 6$ and $K_{\Omega 1} = 35$.

$$\frac{R_1}{R_2} = \frac{K_{\Omega 1}}{K_{\Omega 2}} \text{ gives } K_{\Omega 2} = 70.$$

Traced back via B_1, this corresponds to a wire diameter of, $d_2 = 0.0875$ mm. The nearest standard wire diameters are 0.08 and 0.09 mm. The wire of 0.09 mm diameter, being the closest, is selected. The vertical line on the chart at 0.09 intersects at A′ and B′, corresponding to $K'_{w2} = 8$ and $K'_{\Omega 2} = 60$.

$\frac{w_1}{w_2}=\frac{K_{w1}}{K'_{w2}}$ giving $w_2=2667$ turns. The adjustment of wire diameter from 0.0875 to 0.09 mm means a deviation of the coil resistance from the required 2000 Ω. The corresponding value is calculated from:

$\frac{R_1}{R_2}=\frac{K_{\Omega 1}}{K'_{\Omega 2}}$ this results in $R_2=1714\ \Omega$.

If $d_2=0.08$ mm wire is used, the same process of calculation will produce a resistance value of 2857 Ω; which is further removed from the aimed value of 2000 Ω.

Result:

Coil 1: $R_1=1000\ \Omega$; 2000 turns
$d_1=0.1$ mm.

Coil 2: $R_2=1714\ \Omega$; 2667 turns
$d_2=0.09$ mm.

As evidenced in the foregoing calculations, the figures contained in the *Relay Table* under "Coil Resistance and Windings with 0.03, 0.05 and 0.1 enamelled copper wire", are applicable for the calculation of other coils with the same space factor for a given relay.

A more accurate conversion method for all coil values is suggested by Stephan [108] in accordance with table 8.

Example:

Given that a coil $R_1=1000\ \Omega$, $w_1=2000$ turns, $d_1=0.1$ mm wire diameter. Find the wire diameter for a coil resistance $R_2=2000\ \Omega$.

$$d_2=d_1\sqrt[4]{\frac{R_1}{R_2}}=0.1\sqrt[4]{\frac{1000}{2000}}=0.084\text{ mm.}$$

In case wire thicknesses are available only in 0.08 and 0.09 mm, the following alternative results:

In the case of 0.09 mm:

$$w_2=w_1\left(\frac{d_1}{d_2}\right)^2=2000\left(\frac{0.1}{0.09}\right)^2=2469\text{ turns,}$$

$$R_2=R_1\left(\frac{d_1}{d_2}\right)^4=1000\left(\frac{0.1}{0.09}\right)^4=1524\ \Omega.$$

In the case of 0.08 mm:

$$w_2=w_1\left(\frac{d_1}{d_2}\right)^2=2000\left(\frac{0.1}{0.08}\right)^2=3125\text{ turns,}$$

$$R_2=R_1\left(\frac{d_1}{d_2}\right)^4=1000\left(\frac{0.1}{0.08}\right)^4=2441\ \Omega.$$

Value required	d dia-meter	q wire cross section	U coil voltage	n No. of windings	R resist-ance	L induct-ance
$d_2=$		$d_1\sqrt{\frac{q_2}{q_1}}$	$d_1\sqrt{\frac{U_1}{U_2}}$	$d_1\sqrt{\frac{n_1}{n_2}}$	$d_1\sqrt[4]{\frac{R_1}{R_2}}$	$d_1\sqrt[4]{\frac{L_1}{L_2}}$
$q_2=$	$q_1\left(\frac{d_2}{d_1}\right)^2$		$q_1\frac{U_1}{U_2}$	$q_1\frac{n_1}{n_2}$	$q_1\sqrt{\frac{R_1}{R_2}}$	$q_1\sqrt{\frac{L_1}{L_2}}$
$U_2=$	$U_1\left(\frac{d_1}{d_2}\right)^2$	$U_1\frac{q_1}{q_2}$		$U_1\frac{n_2}{n_1}$	$U_1\sqrt{\frac{R_2}{R_1}}$	$U_1\sqrt{\frac{L_2}{L_1}}$
$n_2=$	$n_1\left(\frac{d_1}{d_2}\right)^2$	$n_1\frac{q_1}{q_2}$	$n_1\frac{U_2}{U_1}$		$n_1\sqrt{\frac{R_2}{R_1}}$	$N_1\sqrt{\frac{L_2}{L_1}}$
$R_2=$	$R_1\left(\frac{d_1}{d_2}\right)^4$	$R_1\left(\frac{q_1}{q_2}\right)^2$	$R_1\left(\frac{U_2}{U_1}\right)^2$	$R_1\left(\frac{n_2}{n_1}\right)^2$		$R_1\frac{L_2}{L_1}$
$L_2=$	$L_1\left(\frac{d_1}{d_2}\right)^4$	$L_1\left(\frac{q_1}{q_2}\right)^2$	$L_1\left(\frac{U_2}{U_1}\right)^2$	$L_1\left(\frac{n_2}{n_1}\right)^2$	$L_1\frac{R_2}{R_1}$	

Table 8: Formulae to recalculate from given - to required - coil data [108]

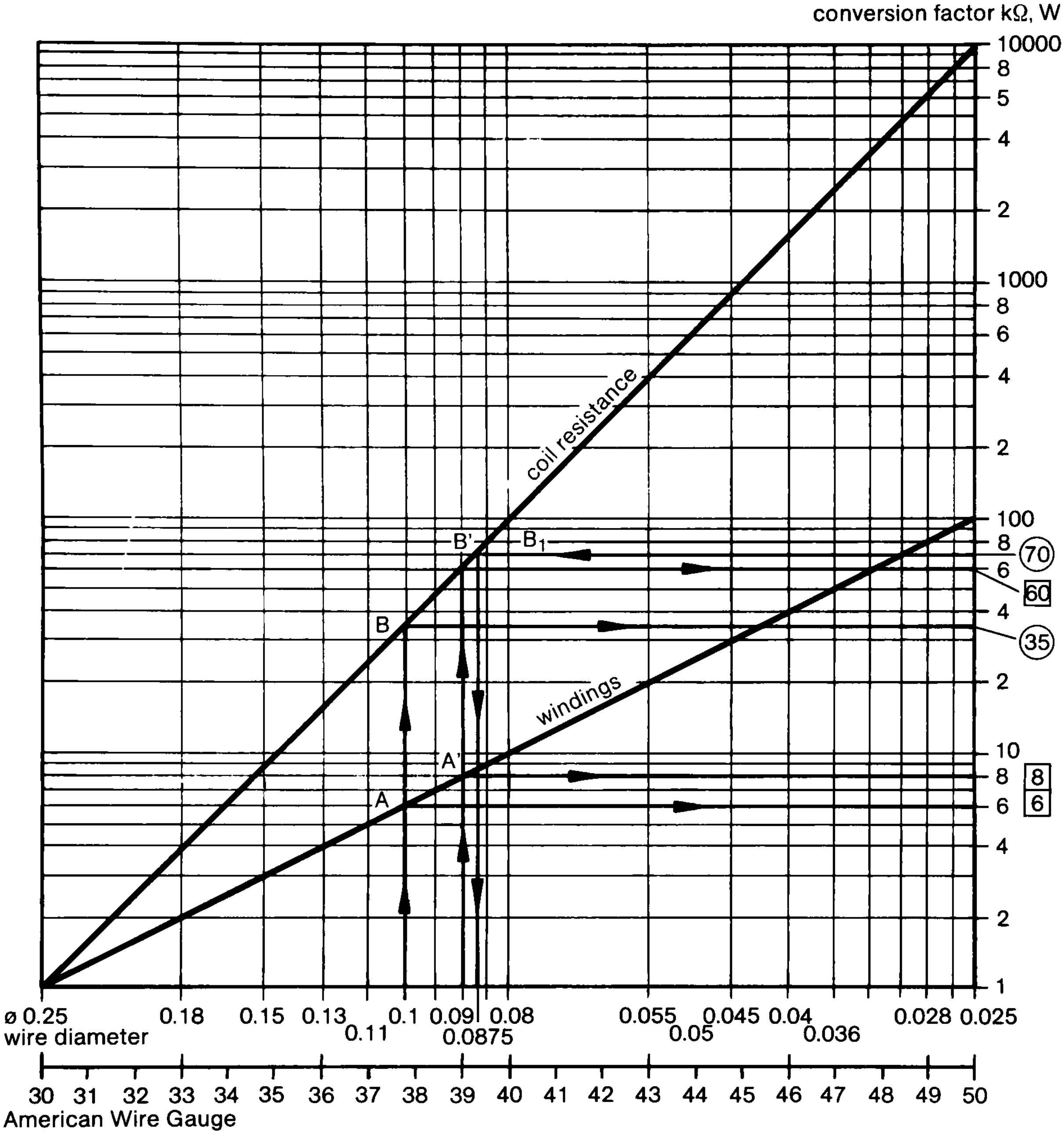


Fig. 47: Coil resistance/No. of turns — diagram for conversion of coil data

Coil Wire: → Enamelled copper wire, → AWG.

Cold Solder Joint: An unreliable, non-constant electrical connection due to inexpert soldering.

Conductance: Reciprocal valve of the resistance. Unit: 1 Siemens = 1/Ω. → 2.3 Formulae of Electro Technology.

Connection Techniques: embraces all methods for the production of permanent metal joints between the connections of a component, such as a relay, and its feeds; e.g. wires or conductors. Distinction is made between soldered joints and solderless joints. Solderless joints include, among others, crimped connections → Crimping; wire wrap connections

→ Wire wrapping; flat plug connections → Faston connections, → WAGO connection techniques.

Constriction Resistance: → Contact resistance.

Contact:

1. Connection, which occurs when two electrically conductive *contact pieces* touch, for the purpose of conducting current (→ Contact resistance).
2. A specially formed *contact piece*.

Contact Arrangement: Combination of different *contact types.*

Contact Atmosphere: Air or gas mixture including any humidity present, as well as particles of impurities in the environment of the contacts. The contact atmosphere affects among other things, the *contact resistance,* the arcing (→ Arc), the *dielectric strength* and the *life* of the relays. With sealed relays, *protective gas* and/or *gettering* are used to ensure a specified and near uncontaminated contact atmosphere.

Contact Bank: The combination of all *contact elements* of a relay.

Contact Bounce: → Bounce, → Bounce time, → Relay times.

Contact Capacitance: Is decisive in evaluating HF suitability of a relay contact. Apart from the contact capacitance, C_2, due to the contacts opposing each other, the capacitances C_1 and C_3 of the contacts to ground are also of importance (fig. 48).
In order to establish these values, the first step is to measure the capacitance C_A between contact 1 and earth (fig. 49). Contact 2 is then shorted to ground and the capacitance C_B between contact 1 and ground is measured again (fig. 50). From a third measurement, the capacitance C_C between contact 2 and ground is obtained, with contact 1 shorted to ground (fig. 51).

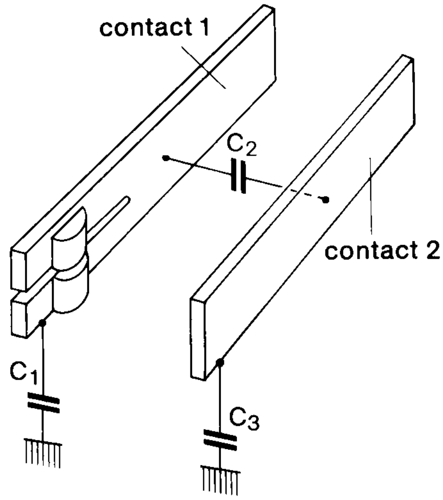
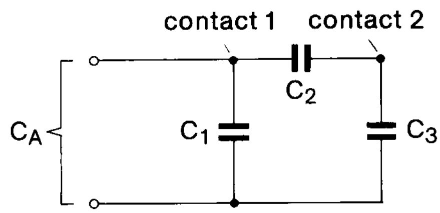
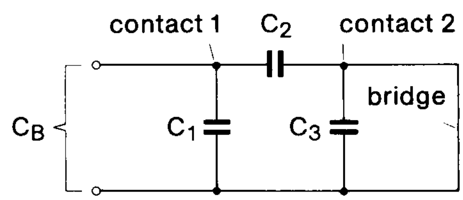


Fig. 48: Contact capacitance



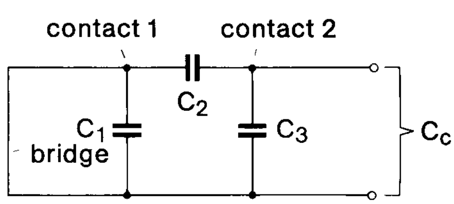
$$C_A = C_1 + \frac{C_2 \cdot C_3}{C_2 + C_3}$$

Fig. 49: Total Capacitance C_A between contact 1 and ground



$$C_B = C_1 + C_2$$

Fig. 50: Capacitance C_B between contact 1 and ground with contact 2 short circuited



$$C_C = C_2 + C_3$$

Fig. 51: Capacitance C_C between contact 2 and ground with contact 1 short circuited

After measuring the values of C_A, C_B and C_C, the values for C_1, C_2 and C_3 can be found by calculation:

$$C_2 = \sqrt{C_C\,(C_B - C_A)}$$
$$C_1 = C_B + C_2$$
$$C_3 = C_C - C_2$$

Contact Class: → Power Relay.

Contact Element (or relay contact): → Switching Element.

Contact Force: The force which the contact pieces exert on each other in the closed state. This is generally reckoned to be approximately 5 cN per ampere of switching current. As the contact force increases, so does the contact reliability and life, as well as shock and vibration resistance of the contacts. The contact temperature rise and the contact resistance diminish with increasing contact force. → Reliability.

Contact Gap: The separation between the contact pieces of an opened contact, measured at the narrowest point.

Contacting: The connection of the contact material with the contact springs or fixed contacts through riveting, welding, electrolysis, rolling-in or rolling-on.
Riveted contacts, especially those which claim to have high wear reserves, should be viewed critically. On comparing the section of the actuated riveted contact (fig. 2) with the welded changeover contact (fig. 52), it is obvious that the riveted contacts have about 5 times more mass, but only about half the wear reserves of the welded contacts; nor is the claim proved in practice that with increasing contact mass, the contact temperature rise reduces, since large contact masses cause correspondingly more bounce and hence more arc heat.
Apart from wasting precious metals through riveting, the electrical connection between the spring and contact is problematic because of the development of galvanic elements (→ Electrolytic Series), the formation of contamination layers and occasionally, because of loosening of the riveting.
By contrast, the welded contact (figs. 3 and 52) has proved more reliable. A CuNi solder ensures good electrical and mechanical connection with the contact spring. A 20 µm thick gold layer is rolled onto the silver base metal. This contact has proved satisfactory for dry switching as well as for the operation of 2 A, 220 V, 50 W or 120 VA (fig. 133). Even in H_2S atmospheres, the contact resistance of this bifurcated linear contact increased to a maximum of only 0.6 Ω after 500 hours, whereas contact designs similar to that of fig. 2 exceeded the 100 Ω limit.
Constriction and current spreading resistance as components of the *contact resistance* are also much smaller with a bifurcated linear contact. → Reliability.

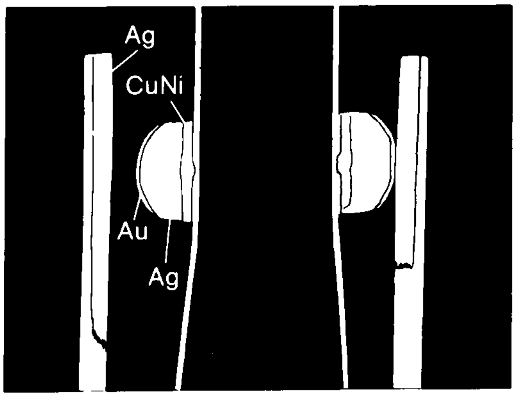


Fig. 52: Welded changeover contact, scale 12.5:1

Contactless Relays: Relays without mechanical contacts, e.g. *optocoupler.* → Solid State Relays.

Contact Make: The touch between two contacts which, as a rule, provide an electrical path of low impedance the contact pieces.

Contact Materials: Tables 9 to 11 contain important properties of metals and metallic compounds which are used in the manufacture of contacts.

Material		Density	Melting temper-ature	Boiling point	Hardness Soft	Hardness Hard	Tensile strength $\frac{N}{mm^2}$		Ultimate elongation %		Heat conduction	Electrical con-duction	Price guideline at 28.02.83
Pure metal		$\frac{g}{cm^3}$	°C	°C	HV	HV	Soft	Hard	Soft	Hard	$\frac{W}{K \cdot m}$ at 20 °C	$\frac{m}{\Omega \cdot mm^2}$	DM/g
Silver	Ag	10,5	961	2200	30	80	200	360	30	2	419	62	0,926
Gold	Au	19,3	1063	2370	25	60	140	240	30	1	297	44	33,05
Platinum	Pt	21,5	1769	4400	40	95	140	400	50		72	9,5	38,20
Palladium	Pd	12,0	1552	4000	40	100	200	480	44	2	72	9	10,90
Rhodium	Rh	12,4	1966	4500	130	280	420		9		88	22	27,20
Iridium	Ir	22,5	2454	5300	220	350					59	19	29,55
Copper	Cu	8,9	1083	2300	50	100	200	450	33	2	394	58	0,0041
Tungsten	W	19,1	3400	6000	250	450	1000	5000			167	18	0,045
Molybdenum	Mo	10,2	2610	5560			600	2500			142	19	0,051
Nickel	Ni	8,9	1453	2730	80	200	450	900	50	2	92	14	0,01109

Table 9: Pure metal as contact material [66]

Material		Density $\frac{g}{cm^3}$	Melting temperature[1] °C	Boiling point[2] °C	Hardness Soft HV	Hardness Hard HV	Heat conduction $\frac{W}{K \cdot m}$ at 20°C	Electrical conduction $\frac{m}{\Omega \cdot mm^2}$	Temperature co-efficient of electrical resistance $\frac{1}{°C} 10^{-3}$
Fine grained silver	0,15 % Ni	10,5	960	2200	55	100	415	58	3,5
Silver-copper	3 % Cu	10,4	900	2200	65	120	372	52	3,5
	5 % Cu	10,4	850	2200	70	125	335	51	3,5
	10 % Cu	10,3	780	2200	75	130	335	50	3,5
	20 % Cu	10,2	780	2200	85	150	335	49	3,5
Silver-cadmium oxide	10 % CdO	10,2	961	2200	70	100	307	48	3,6
	15 % CdO	10,1	961	2200	80	125	307	42	3,5
Silver-cadmium oxide	10 % CdO	10,2	961	2200	50	80	307	48	3,6
"SP"	12 % CdO	10,1	961	2200	60	95	307	47	3,6
Silver zinc oxide	8 % ZnO	10,2	961	2200	60			49	
Silver tin oxide	10 % SnO	9,9	961	2200	84		340	45	3,1
Silver-nickel	10 % Ni	10,3	961	2200	50	90	350	54	3,5
(Sintram® N)	20 % Ni	10,1	961	2200	60	95	350	47	3,5
	30 % Ni	10,0	961	2200	65	105		42	3,4
	40 % Ni	9,8	961	2200	70	115	240	37	2,9
Tungsten-silver	20 % Ag	15,4	961	2200	180	240	245	26–28	0,9
	35 % Ag	14,8	961	2200	100	130	280	34–36	
	50 % Ag	13,5	961	2200	900	100		40	
	65 % Ag		961	2200	80	90			
	80 % Ag		961	2200	70	80		42	
Gold-platinum	10 % Pt	19,5	1100	2970	45	160	54,5	8	
	25 % Pt	19,9	1220	2970	80	155		3,6	2,5
Gold-silver	20 % Ag	16,5	1035	2200	35	90	75	10,5	0,9
	30 % Ag	15,4	1025	2200	40	95		9,8	0,7
Gold-silver-nickel	26 % Ag 3 % Ni	15,4	990	2200	80	120		8,3	0,88
Gold-nickel	5 % Ni	18,2	995	2370	105	160	52	7,3	0,7
Platinum-tungsten	5 % W	21,4	1830	4400	160	250		2,3	0,7
Platinum-nickel	8,5 % Ni	19,2	1670	2370	180	260		3,7	1,5
Palladium-silver	40 % Ag	11,4	1330	2200	100	170	29,3	2,4	0,07
	50 % Ag	11,2	1290	2200	90	160	34	3,3	0,23
	60 % Ag	11,1	1225	2200	70	140	46	4,9	0,36
	70 % Ag	10,9	1155	2200	65	120	59	6,7	0,40
Palladium-copper	40 % Cu	10,5	1200	2300	120	280	37,7	2,7	0,28
Tin bronze	6 % Sn	8,8	910	2270	85	220	75	9	0,7
(CuSn)	8 % Sn	8,8	865	2270	90	230	67	7	0,7
German silver (CuNi18Zn20)	18 % Cu 20 % Zn	8,7	1025		110	210	29	3,5	0,3
Copper-beryllium	1,7 % Be	8,4	950	2300	80	410	84	9–13	1,3
Copper-chromium	0,7 % Cr	8,8	1076	2300	55	145	214	50	3,5

[1] For alloys the solid point is given. For sintered materials the melting point of the lowest melting component.
[2] For alloys the boiling point of the lowest boiling component is given.

Table 10: Contact material alloys [as per 54, 66]

Contact Material	Characteristics
Ag99,95 (fine silver)	Cheapest precious metal, tarnish through sulphur influence, therefore not suitable for particularly high requirements; contact force possibly >15 cN.
AgNi0,15	Compared with fine silver: slightly improved mechanical properties.
AgCu3	"Hard silver"; better contact wear resistance and less tendency to weld, but slightly higher contact resistance.
AgPd30	Better resistance to tarnishing, greater hardness, relatively low contact wear; but more costly.
AgPd50	Markedly better resistance to tarnishing, but even higher price.
AgNi10	Sinter material, good contact wear resistance with higher loads at the expense of a higher contact resistance.
AgCdO10	Little tendency to weld, good wear resistance with higher loads, arc extinguishing properties. Composite material whose properties are influenced, among other factors, by the manufacturing methods employed.
$AgSnO_2 10$	Analogous with AgCdO10, but higher thermal disintegration temperature; more resistance to wear with less material migration.
Au (fine gold)	Not used as pure, solid metal: too soft. Of great importance as plating material (usually in the range of 0.1–10 µm thickness). The hardness (at the expense of conductivity) is variable within wide limits. Non-porous layers above 1 µm. Best corrosion resistance of all metals.
AuNi5	Commonly used material for highest requirements. Contact forces possible down to 1 p.
AuCo5	Density: 18.2 g/cm^3; hardness: 950–1500 N/mm^2; conductivity: 1.8 m/Ωmm^2 (after heat treatment 16 m/Ωmm^2) Properties similar to AuNi5, in particular slight creepage of material after heat treatment.
AuAg25Cu5 AuAg26Ni3	Still good corrosion resistance with slightly lower cost.
Pd	Less commonly used as a pure metal (except in the USA). More often used as a plating material; values for electrical conductivity are not precisely known. – It is necessary to monitor its readiness to react with organic vapours.
PdCu15	Favourable for switching on capacitive loads.
Rh	Essentially used only for plating; normal layer thickness 0.1–1.0 µm, e.g. surfaces for sliding contacts; linings of reeds for reed contacts. Extremely high cost.
W	Highest melting point of all metals. Not a precious metal. In air, for equipment requiring a high number of operations. Contact force >70 cN.

Tabelle 11: Characteristics of the most commonly used contact materials [50, 67, 68]

Contact Noise (or contact vibration) [24]: Undesired phenomenon in telephone installations, whose cause lies in the dynamic resistance behaviour of the contact points in the amplifier of a telephone circuit. The causes for fluctuating volume resistances are:

a) Fluctuating contact force through vibrations or oscillations. Where this occurs on switching electromagnetic relays on and off, it is referred to as *"dynamic contact resistance"*.
b) Forming of contaminating layers (film resistance, → Contact resistance) at the contact points, usually from environmental influences. It has been observed that contact noise increases in aging contacts, and with the *switching cycles*.
c) Contact materials which readily tend to oxidize and sulphide.

Contactor: Remote control switch with a power actuator, e.g. magnet system with reset force, which is held in the operating position. The distinguishing features from those of a relay can be seen in the following definition [26] (see also *switching relays, power relays*):
Relay:
A device intended to effect sudden, predetermined changes of switching conditions in one or more electrical output circuits, when certain conditions have been fulfilled in the controlling electrical magnetic circuit(s).
Contactor:
An electromagnetically actuated switching device which serves to open and close electrical circuits — in accordance with *utilization category* AC1 to AC4 and DC1 to DC4 for motor contactors, AC11 and DC11 for contactor relays which, in appropriate circumstances, act in conjunction with suitable relays for the protection against possible overload of circuits to be switched.

Contactor Relay: A *contactor* with *switching elements* for the actuation of switchgear and the like, in accordance with *utilization category* AC11 and/or DC11.

Contact Overtravel: The distance which contact pieces travel together after making initial contact (DIN 21 215).

Contact Pieces: The parts of a relay contact which, as intended, make the electrical contact. Distinction is made between fixed and moving contact pieces. Mercury may also be used in place of contact pieces.

Contact Protection: → Arc extinction.

Contact Resistance (R_C): The electrical resistance of a closed contact. It can be explained as the sum of physically different principal factors of influence.
$R_C = R_{sp} + R_{const} + R_{film,\ skin}$ in which
R_{sp} is spreading resistance
R_{const} is constriction resistance
R_{film} is contamination layer resistance
R_{skin} is skin resistance

The **spreading resistance R_{sp}** is determined by the shape of the contact parts and the geometric conditions of the contact point (e.g. symmetries). Fig. 53 shows the influence which the eccentricity of two butt contacts has on R_{sp}. Certainly, the size of the contact current will also be of importance.

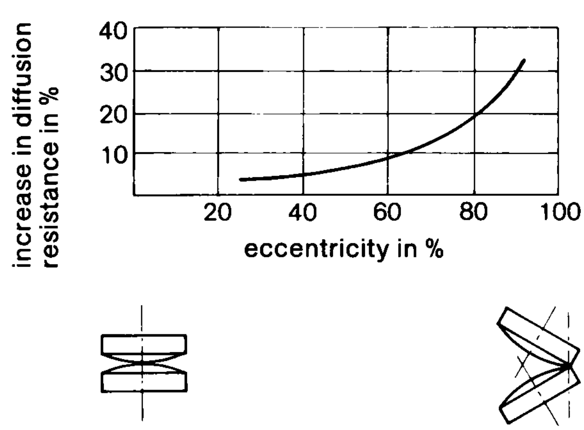


Fig. 53: Diffusion resistance in dependance of the touching contacts [49]

The **constriction resistance R_{const}** is approximately [48]
$R_{const} = \bar{\varrho}/d$ in which
$\bar{\varrho}$ is the mean specific resistance of a contact pair and, d is the diameter of the circular area of touch.
Since d is a function of the contact force, R_{const} can, in the event of a plastic deformation of the metallically clean contact surfaces, be estimated in the following manner [50]

$$R \approx 0.9\, \varrho \sqrt{\frac{H}{P}} \text{ or}$$

$$R \approx \frac{\varrho_1 + \varrho_2}{2} \sqrt{\frac{H}{P}}$$

in which $\varrho_{1,2}$ are the relevant specific resistances of the contact materials. H is the contact hardness of the softer contact material (≊ Brinell hardness) and P is the contact force.
The principal graph of the contact resistance of an all metallic conducting, symmetrical pair of contacts, ($R_C = R_{sp} + R_{const}$) with increasing contact current (voltage drop) or rising contact temperature, is shown in fig. 55.
With increasing voltage on the contacts, i.e. with increasing current strength and rising temperature at the point of contact, the resistance increases up to the softening voltage U_E, under which the contact material becomes plastic. With this voltage, the contact area increases and the resistance reduces. With an increase in the voltage, the resistance increases up to the melting voltage, U_{melt}. The temperature at the contacts rises to such an extent that the contact material melts and the resistance rapidly diminishes. Measurements of R/U characteristic curves on gold and nickel contacts with small contact loads have been published by Holm [51, 52].
Accurate determination of R_{const}, and of the apparent and the actual areas of contact is complex and, in any case, virtually meaningless, as R_{const} changes at least slightly in operation. It can be seen from the diagrammatic view of the area of contact (fig. 56), that the size of the area of contact changes after repeated operations.

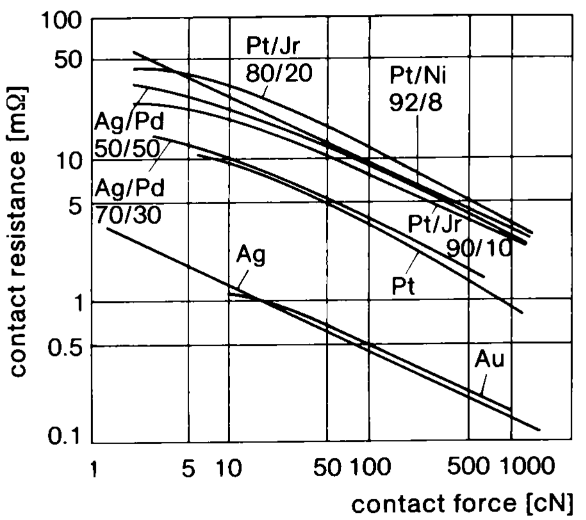


Fig. 54: Contact resistance in dependance of the contact materials free of foreign layers [as per 53]

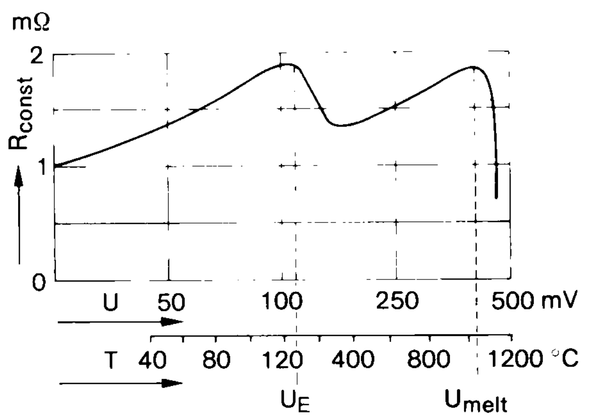


Fig. 55: Contact resistance in dependance of the voltage at symmetrical copper contacts [48]

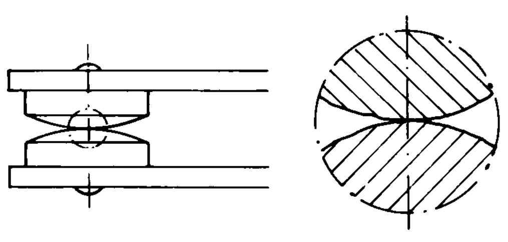


Fig. 56: Schematic representation of the contact point

R_{const} is affected not only by the contact force, but by the elastic and the plastic characteristics of the contact material, and also by the shaping of the contacts. Previous experience has proved that a bifurcated linear contact — achieved by means of a semi-cylindrical form (fig. 3) — shows a constant contact resistance even at 2 × 6 cN contact force, in the load range from 10 μA/30 μV to 2 A/30 V, and a high short-circuit protection of 150 A/0.8 ms, whereas a point shaped contact withstands only about 30 A/0.8 ms.

The **film resistance** R_{film}, presents one of the greatest problems in relay technology. It occurs from multimolecular layer thicknesses of > 10 nm, and leads to relalatively high and unstable contact resistances. Assuming an even contamination layer thickness d, with a specific resistance ϱ_{film}, and the contact area $a^2\pi$ R_{film} becomes:

$$R_{film} = \frac{\varrho_{film}\, d}{\pi a^2}$$

With thin contamination layers, R_{film} becomes almost independent of ϱ_{film} and ϱ_{film} d can — according to Holm [48] — be expressed as ϱ_{skin} ("specific skin resistance"), i.e. the skin resistance R_{skin} results as follows:

$$R_{skin} = \frac{\varrho_{skin}}{\pi a^2}$$

In the case of very thin covering layers (> 10 nm), these can be "tunnelled through" (→ Tunnel effect) by the load carriers, and the film resistance or the skin resistance subsides almost completely. For instance, the "specific skin resistance" of a monomolecular oxygen layer is of a magnitude of 10^{-7} to 10^{-8} [Ωcm^2].

Since very thin skin offers practically no resistance, but increases the contact area and thus reduces the constriction resistance, such a contamination layer can even reduce the contact resistance.

It is, among other things, surface contamined contacts which cause the inter-

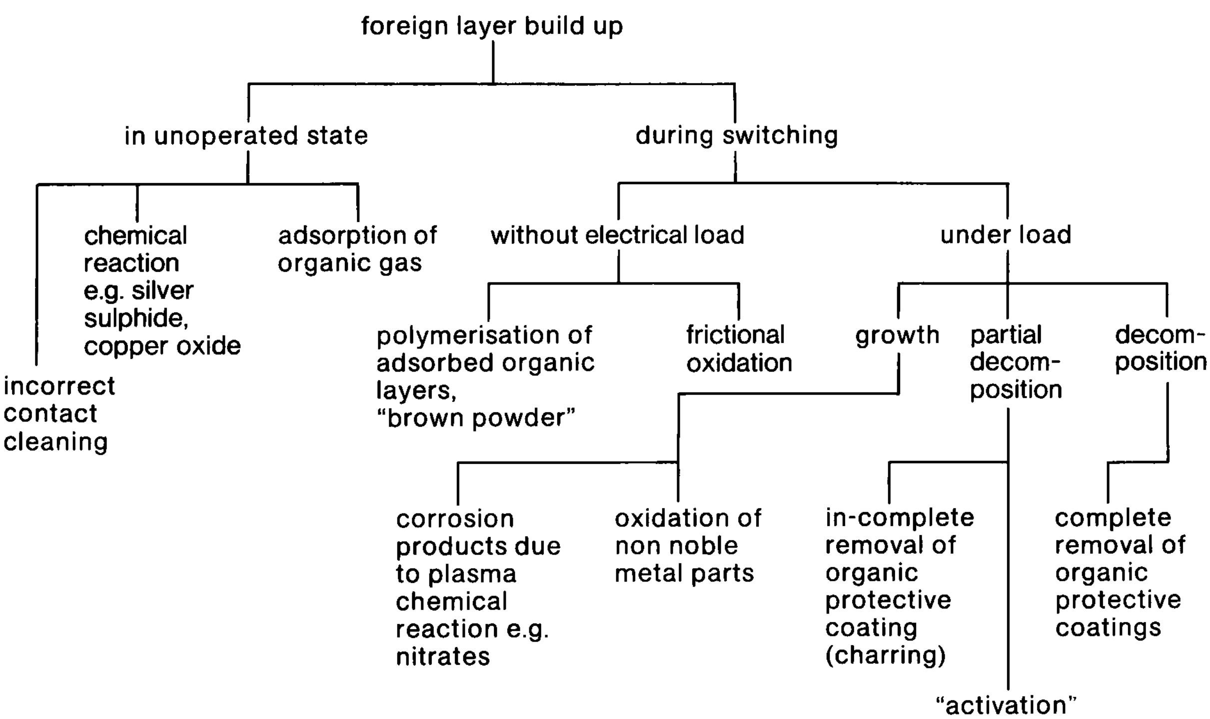


Fig. 57: Foreign layer build up on contact surfaces [as per 54]

ference noises heard in telephones and which, in measuring technology, is completely unacceptable when measuring is carried out with contact voltages of less than 100 mV. The causes of contamination deposits on the contacts are many (fig. 57). Contamination layers can, for example, be deposited during unclean manufacturing or inadequate cleaning processes, or on the finished product,

- through outgassing neighbouring plastics under the influence of temperature;
- during switching of very small loads through catalytic effect (→ Brown-powder effect);
- during switching of medium and higher loads through the build-up or degradation of non-precious metal additives in the contact materials;
- through decomposition of organic vapours under arc influence.

It is certainly true that plastics used in sealed relays are degassed, but as experience has proved, nearly all plastics are subject to an ageing process in the course of time which is accompanied by further degassing.

Fig. 58: Contact surfaces with foreign layer magnified × 1000 [1]

There are often several simultaneous causes for contamination layers on contacts. Illustrations 58 and 59 for example, show areas of AgJ-forming, and droplets of CdCl which formed under no load, and at 100°C storage temperature, after 5000 hours.

It is strikingly obvious from figs. 58 and 59 that the CdCl "drops" exist exclusively in the cracks of the electrolytically deposited Au layer. It may therefore be assumed that these are linked with shrink holes beneath the approximately 17 µm thick Au layer. After changing the cleaning method before and after plating, no CdCl formation could be found.

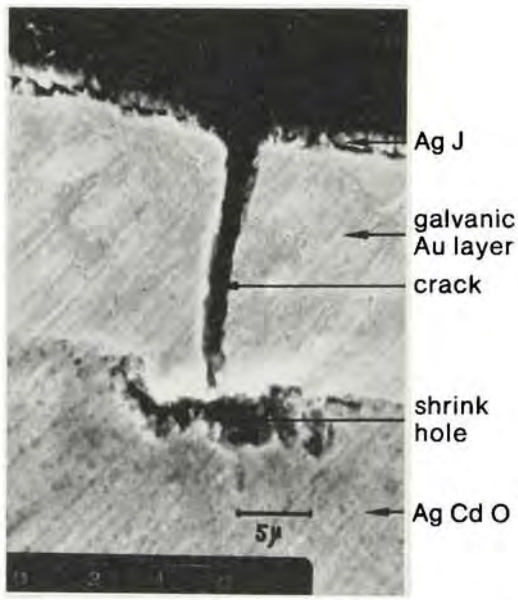


Fig. 59: Section of fig. 58. Magnified × 3000 [1]

In the opinion of Holm [48], a local melt can be formed in thicker layers by an appropriate voltage, which solidifies again when the bridging is thick enough, i. e. when the contact resistance is small enough. This process is called *fritting.* Justi [56], states the fritting resistance for copper in air as being $10^{-3}\ \Omega$ at 50 cN and $10^{-6}\ \Omega$ at 5 kN contact force.

Other measuring results on Ag/Pt contacts [57] were:

$2\times10^{-1}\,\Omega$ at 1 cN
$10^{-1}\,\Omega$ at 2 cN
$2\times10^{-2}\,\Omega$ at 5 cN
$10^{-2}\,\Omega$ at 10 cN

It follows also from this that contact forces <5 cN are the cause of high contact resistance and are consequently interferences.

A typical example of R_C characteristics in the lowest voltage range, U is shown in fig. 60. The contamination layers obviously melt within the 80 mV range. The slight increase in R_C without contamination layer from about 100 mV is, according to Holm [48] due to contact temperature rise. A fall-off in constriction resistance could not be found with softening voltage (for Ag: 90 mV, Pt: 250 mV) [58]. The contact current was aparently too small.

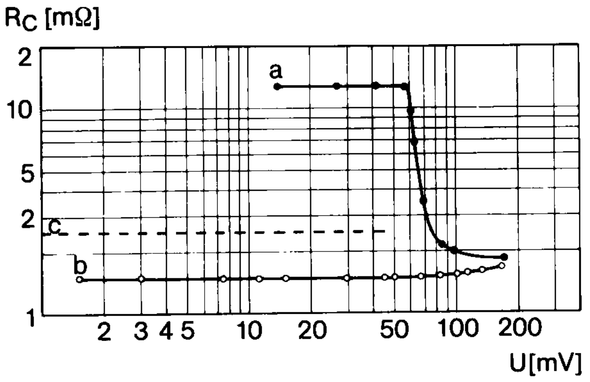


Fig. 60: R_C/U characteristic of Ag/Pt contacts with contact force ≈13 cN
a Contact with foreign layer under DC load
b Contact without foreign layer under DC load
c Contact without foreign layer under AC load

However, fig. 60 also shows that in the lowest voltage range, the share of the film resistance R_{film} is a multiple of the sum of $R_{sp}+R_{const}$, and since R_{film} is constantly changing in terms of time as well as from one contact make to another, the search goes on for counter-measures, such as:

- Cleaning the contacts by friction during the closing action. However, if some considerable time had elapsed after the last contact operation, the contamination layer could not usually be removed within the first few switching operations.
- Hermetic sealing of the relay in a protective gas. The wrong direction was taken in the search for a suitable protective gas (argon, neon, nitrogen) and its optimum relative humidity. The degassing of the materials to be sealed, in particular the plastics and the coil wire prior to filling with protective gas, did not prove adequate. This was due to new contact damaging gasses and vapours that arose under the influence of temperature and through arcing.
- It was finally believed that the contact could be kept free from contamination layers by encapsulation in glass, free from organic plastics. Experience now gained with reed contacts, prove the opposite. It was found that when fusing the reed contact into the glass envelope ends, vapours were sealed in the contact chamber and these made the "protective gas" hostile during contact operation. Mercury contacts, of sufficient volume and depending on the composition of the amalgam build up, proved to be the most reliable. However, Hg contacts are usually position dependent, and function only within a temperature range from:

  −35 to +107 °C.

As can be seen from figs. 54 and 60, there are already considerable contamination layers present with Au or Ag alloyed contact materials with contact forces of approximately 10 cN, when the contact resistance increases to more than 20 mΩ. With these low values it is of course necessary to take the contact connection resistance (line resistance) into account; i.e. what must be determined as contact resistance (R_C) of a relay, is the difference between the volume resistance R_V, (from terminal to terminal), and the line resistance R_L.

Thus $R_C=R_V-R_L$.

It is generally true that the line resistance R_L is constant, and has significance only when a contact current flows, which influences the temperature of the line conductor. In contrast the contact resistance affects the reliability and life of the relay considerably. For this reason it is practical with modern relays to take into account both the contact and volume resistance data as has been done in the relay tables, section 4.
The relay manufacturer will attempt to minimize line resistance. If, however, especially high corrosion resistance is demanded, as for example in equipment on board ships, then corrosion resistant conductors may be preferred (e.g. German silver), even if their resistance is relatively high.
In many applications, constancy of contact resistance is much more important than its low value [59]. However, from repeated measurements of the volume resistance, having taken the line resistance into account, estimates can be made with sufficient accuracy, as to the extent of contaminating layers and thus, the *reliability* of the contacts at low loads. For more precise reliability statements, detailed plotting of the contact resistance is necessary.
Illustrations 61, 62 and 63 show how much the constancy of the contact resistance in continuous operation, with a load of 50 mV, 10 mA, and a switching frequency of ~3 to 10 Hz, depends on the manufacture, even with apparently identical relays. The author comments [59]:
"Out of 21 types manufactured by 16 manufacturers, only one type could be found which fulfilled the requirements described (fig. 61).
All other variants of this design showed a volume resistance behaviour which lay between those shown in illustrations 62 and 63.
Analysis of the causes of failure highlighted the following key points:
- Unsuitable contact material (formation

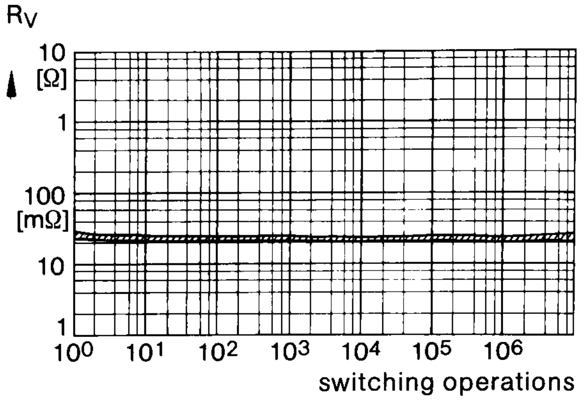


Fig. 61: Contact resistance behaviour of normally open contact of DS-relay (fig. 292) with contact springs as shown in fig. 13 during continuous operation. The max. and min. values of 10 contacts are given (courtesy of Wandel and Goltermann)

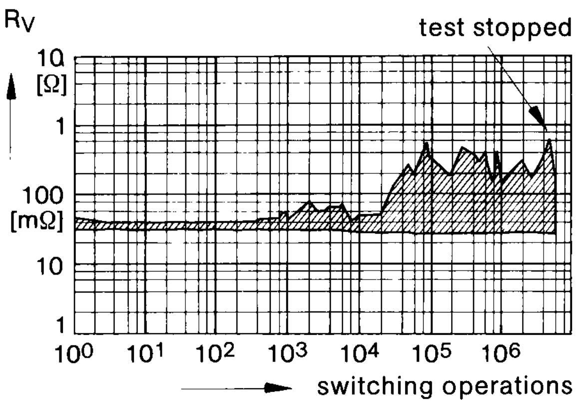


Fig. 62: Relay from manufacturer "B" Contact resistance behaviour of normally open contact. The max. and min. values of 10 contacts are given (courtesy of Wandel and Goltermann)

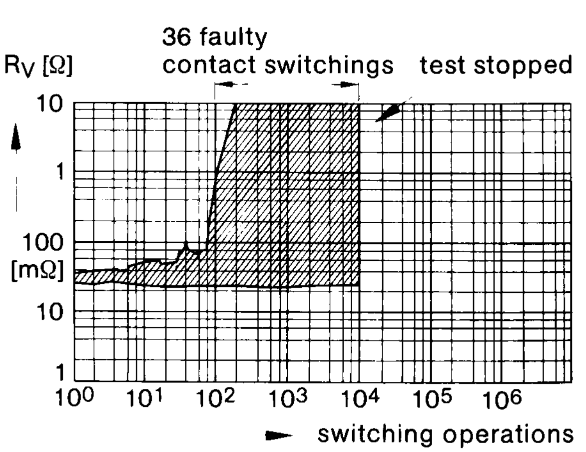


Fig. 63: Relay from manufacturer "Z" Contact resistance behaviour of normally open contact. The max. and min. values of 10 contacts are given (courtesy of Wandel and Goltermann)

of oxide and sulphide layers resulting from too high a proportion of non-precious metals or of silver; formation of polymerization products when palladium alloys are used together with degassing plastics, and the absence of gettering).
- Unsuitable material chosen for points of friction (development of abrasion between actuating nipple and contact spring or in the armature bearing).
- Unclean manufacture, (gross contamination inside the relay).

The fact that the fulfilment of the requirements laid down for use in electronic measuring devices — even if these may appear high to some manufacturers — is not a question of cost, but merely one of "know-how", is proved by the relay which fulfils these requirements. It is only insignificantly more expensive than the unsuitable competing makes!"
If the 18 mΩ line resistance is subtracted from the volume resistances shown, then the pure contact resistance at the commencement of the test on the relay in fig. 61 is <10 mΩ, in fig. 62 <16 mΩ and in fig. 63 <20 mΩ. This confirms earlier examination results by the same author to the effect that contact faults must be expected sooner, the greater the contact resistance in the new condition (fig. 64).

The most effective, and most economical method of keeping the film resistance, and consequently the contact resistance, low as well as stable, has been proved — with clean manufacture — in new kinds of getter methods [13, 43, 44, 60, 61].
The most effective kind of contact make (fig. 13), multi-layer contacts (fig. 4), bifurcated linear contacts (fig. 3), relatively high contact forces which demand little or no operating power (fig. 14), and *gettering,* have made the electrical contact 100 times more reliable and hence of more significance, making contact resistance values of <10 mΩ in miniature relays achievable — and economic.

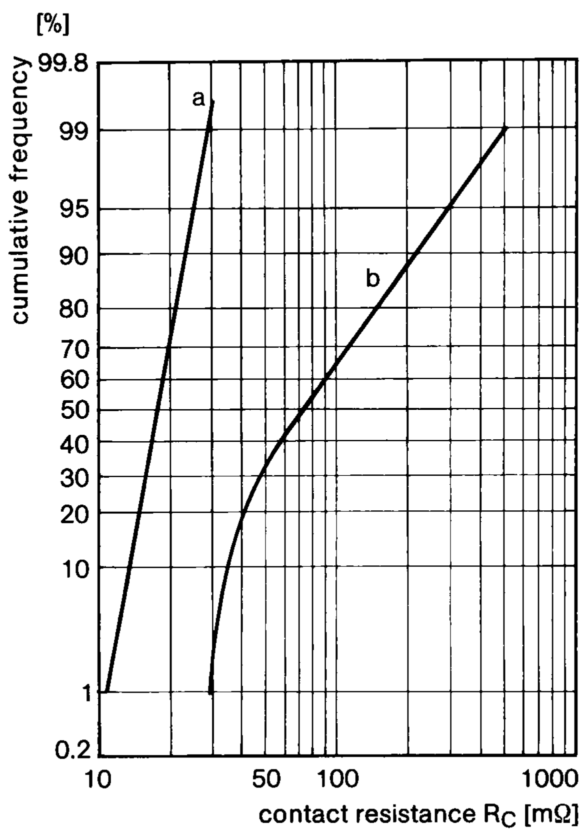


Fig. 64: Frequency distribution curve of contact resistance (max. value of 30 switching operations of each contact studied)
a Contacts free of foreign layer
b Contacts contaminated with foreign layer which lead to early failure (courtesy of Wandel and Goltermann)

Contact Restoring Force: The force with which a contact opens after coil deenergization from the active position.

Contact Rubbing Movement: The amount by which the contact making areas shift against each other during contact overtravel. This self cleaning is a desired feature, which helps to keep the contact resistance low and reasonably constant through self-cleaning. → Self-cleaning contacts.

Contact Sequence: The time difference which occurs in a multi-contact system on opening or closing of the contacts, between the first and last contact make or break. → Relay Times, → Black-or-White Switching.

Contact Spring Material is classified in two groups [125]:

a) Self hardening spring material

Alloy group	Material	Norm
Copper - low alloy	CuAg2 CuFe2P CuNi1Sn1CrTi (K62)	DIN 17666/17670
Copper-zinc (brass)	CuZn37 CuZn23Al3,5Co (S23)	DIN 17660/17670/1780
Copper-tin (tin bronze)	CuSn2 CuSn5 CuSn6 CuSn8 CuSn4Zn CuSn6Zn	DIN 17662/17670 DIN 17662/17670/1780 DIN 17662/17670/1780
Copper-nickel-zinc (German silver)	CuNi18Zn20 CuNi12Zn24 CuNi18Zn27	DIN 17663/17670/1780 DIN 17663/17670
Copper-nickel-tin	CuNi9Sn2	DIN 17664/17670

b) Secondary hardened spring material

Copper-beryllium	CuBe1,7 CuBe2	DIN 17670/1780
Copper-cobalt-beryllium	CuCoBe	DIN 17670/1780

The major comparisons of fatigue strength dependent on electrical conductivity are shown in fig. 65 [126].

Contact Springs: Distinction is made between externally and self loaded spring contacts. Externally spring loaded contacts are often used in switchgear handling higher current loads. They are then fitted with rigid, solid contact bridges.
Relays are mainly fitted with self loaded spring contact systems (→ Contact bank). They are mechanically, electrically and thus thermally loaded. It must be ensured that heating due to electrical load (heating due to arcing and current flow) will not impair the spring characteristics. → Contact spring material. The *reliability* of the contact springs thus depends on dimensioning, conductor cross section and conductivity. It must also be ensured that the *resonance frequency* of the contact springs lies beyond the maximum vibration frequency to which the relay will be subjected; otherwise it will be necessary to provide dampers.
The type of stresses mainly occurring in a relay are listed below. The following symbols are employed:

- b Width of spring in mm.
- h Thickness of spring in mm.
- F Force in N.
- f Flexion of the spring in mm.
- E Coefficient of elasticity in N/mm^2 for normal spring steel 210,000 N/mm^2;

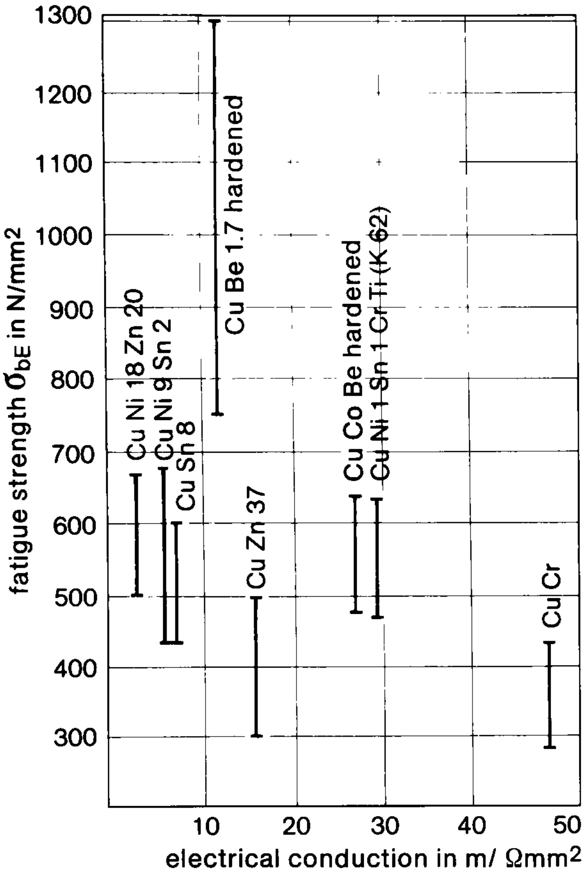


Fig. 65: Contact spring material arranged regarding electrical conductance and fatigue strength

for corrosion-proof steel 180,000 N/mm^2;
for CuBe, CuSn 130,000 N/mm^2.

l Spring loaded length in mm.

σ_{bE} Fatigue strength in N/mm^2 (fig. 66).

σ_z Permissible fatigue strength in N/mm^2 with an alternating bending stress III and 10^8 load changes: approx. 30% of σ_{bE}.

a) Single tensioned spring loaded by a force F

Permissible deflection:

$$f_{perm} = \frac{2\,\sigma\, l^2}{3\,E\,h}\ [\text{mm}]$$

$$F = \frac{f_{perm}\,E\,b\,h^3}{4\,l^3} = \frac{\sigma_z\,b\,h^2}{6\,l}\ [\text{N}]$$

$$f = \frac{4\,F\,l^3}{E\,b\,h^3} = \frac{F\,l^3}{3\,E\,J}\ [\text{mm}].$$

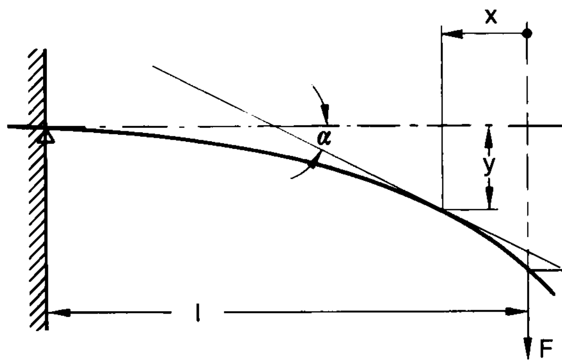


Fig. 66: Single tensioned spring

in which the moment of inertia is:

$$J = \frac{b\,h^3}{12}\ [\text{mm}^4].$$

Defection y of the spring in point l−x:

$$y = \frac{F}{E\,b\,h^3}\,(4\,l^3 - 6\,l^2 x + 2\,x^3)\ [\text{mm}].$$

For the bending angle α_0 (with x=0), the following applies:

$$\tan\alpha_0 = \frac{3f}{2l} = \frac{F\,l^2}{2\,E\,J}$$

and for the load rate c:

$$c = \frac{f}{F} = \frac{l^3}{3\,E\,J}\ [\text{mm/N}].$$

b) Single tensioned spring, loaded at the center, with support for the free end

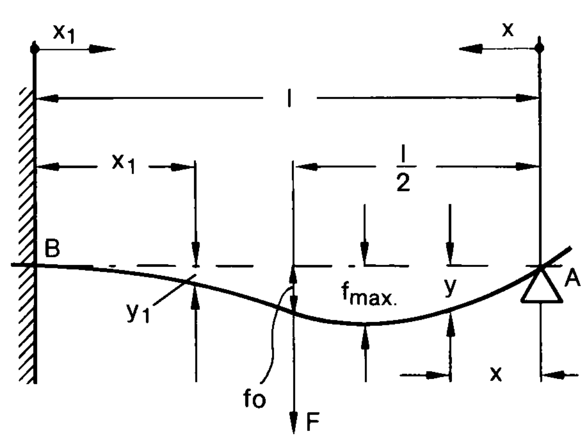


Fig. 67: Single tensioned spring with a bearing point for the free end

Bearing forces A + B:

$$F_A = \frac{5}{16} F; \quad F_B = \frac{11}{16} F \text{ [kg]}.$$

The deflection y_1 of the spring near B corresponds to the function:

$$y_1 = \frac{F\, l^3}{32\, E\, J} \left(\frac{3 x_1^2}{l^2} - \frac{11 x_1^3}{3\, l^3} \right) \text{ [mm]}.$$

The deflection, y of the spring near A, corresponds to the function:

$$y = \frac{F\, l^3}{32\, E\, J} \left(\frac{x}{l} - \frac{5 x^3}{3\, l^3} \right) \text{ [mm]}.$$

The deflection f_0 at the center of the spring $(x = x_1 = l/2)$:

$$f_0 = \frac{7}{768} \frac{F\, l^3}{E\, J} \text{ [mm]}.$$

The maximum deflection, f_{max} occurs where $dy_1/dx_1 = 0$. This is the case with $x_1 = l/\sqrt{5}$. At this point:

$$f_{max} = \frac{F\, l^3}{48 \sqrt{5}\, E\, J} \text{ [mm]}.$$

Contact Sticking (Contact Adherence): In theory, metallic surfaces which are free from contamination layers, stick by virtue of the force of attraction between the metal ions of the uppermost crystal lattice plane when the contacting areas approach to within lattice distance. The adherence forces lie within the range of the lattice bonding forces. Through the drastic reduction of these forces on increasing the separation, even minute layers of contamination will suffice to prevent sticking.
With electrical contacts, the surfaces are, practically always covered with layers of extraneous substances whilst the separating forces are generally much greater than the holding forces.
If however the contact materials can be plastically deformed by the contact forces, then the contamination layers can, in part, be pushed away. The adherence forces will then be increased due to the enlarged clean contact areas (so-called, cold welding; "hooking").
This phenomenon is generally recognized with pure gold contacts, and particularly when used in glass reed relays. In reed relays, there is a major disadvantage which further increases the tendency towards cold welding. For as long as reed contact is not in magnetic saturation, every change in the coil current will cause a change of contact force i.e. if the energizing direct current is not sufficiently smoothed, the closed contact will quiver, and the likelihood of cold welding will be increased due to microscopic rubbing movements of the contacts resulting in surface cleaning and the exposure of pure metal. Such rubbing movements, as a rule, also occur during ultrasonic cleaning of such relays.
The following measures have been adopted in order to reduce the above mentioned phenomenon:

1. Non-use of pure gold as a contact material in glass reed relays.
2. Increasing the contact opening forces in modern reed relays (e.g. "R-", "DR-" relays, → Relay table), to approximately 10 cN as apposed to only 1-4 cN in glass reed relays, by an improvement in design.
3. Alloying the gold contact material with harder metals (e.g. with 1% Co) without significantly changing the gold characteristics of the contact in respect of its electrical properties.
4. For particularly critical applications, (e.g. high ripple content of the energising voltage), rhodium flashing of the contacts (0.1 to 0.5 μm) which again does not significantly affect the gold characteristics of the contacts.

By using these methods, as experience has proved, the cold welding of reed contacts can be prevented.

Contact Temperature Rise: depends on the *contact resistance,* the square of the contact current, the *switching fre-*

quency (due to arc heat), as well as the heat dissipation capability of the contact connections and conductors.

Contact Time: The time from the final closing to the subsequent opening of a contact. → Relay Times.

Contract Travel: This is the distance made up of the *contact gap* and the *contact overtravel*. With increasing contact wear, the contact gap becomes larger and the contact overtravel, smaller.

Contact Types: The contact or switching elements combined in a contact bank have different functions. Distinction is made between the following contact types:
A contact which is open in the rest position of the switching element, and closed in the working position, is called a
normally open contact,
form A contact or make contact.
A contact which is closed in the rest position of the switching element is called a
normally closed contact,
form B contact or break contact.
If a contact is not closed in either the working or rest position, but only during the movement from one to the other, then this switching element is described as a
wiping contact.
Contact elements may be of single break or double break design. The designation of a make contact or a break contact remains unaltered by this.
Where both make and break contacts are present at the same time, these two contacts can be given a collective description:

a) when the bases of the make contact and the break contact are electrically connected (identified by three connections):
change-over contact
or form C contact.
b) When no electrical connection exists between the make contact and the break contact (identified by four connections):
double make, double break contact or
double change-over contact;

with or without overlapping contact make, as appropriate.
The representation of contact types in circuit diagrams is depicted by *graphic symbols*. In addition, code designations (= substitution for contact symbols by alphanumeric characters) have been introduced (see table 12).

Contact Voltage: If two different metals touch, the conducting electrons (→ Electrical conductivity), pass through the area of contact from one body to the other. Since the conducting electrons of these metals (1, 2) generally show different energy levels, the concentration of conducting electrons increases in metal 2 with the lower electron energy until, through the voltage which develops (metal 1 becomes positively charged, metal 2 negatively charged) a further increase in the charge carrier concentration is prevented. For the build-up of this contact voltage it is sufficient for a small proportion of the electrons to pass, so that the conductivity — as experience shows — is not impaired. The contact voltage depends greatly on the temperature and the composition of both metals. The voltage difference is concentrated on a few nm on both sides of the area of contact.
The contact voltage of a chain of metallic conductors is equal to that which corresponds to the direct connection of the two outer conductors. → Seebeck Effect.

Contact Wear: Material loss of the contact pieces due to evaporation under the influence of arcing. → Arc.

Core: Coil core. Iron core inside a *coil,* bobbin or winding which provides for the conduction and amplification of the magnetic flux. In relays with armatures inside the bobbin, the armature can take on the

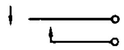
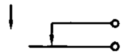
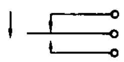
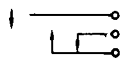
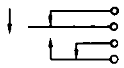
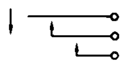
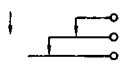
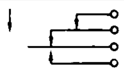
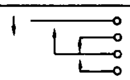
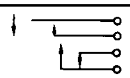
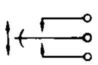
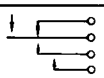
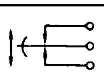
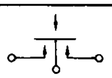
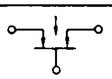
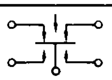
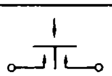
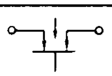
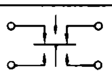
Short NARM description	USASI symbol	NARM description	DIN 41020 description	Practical German description
A		SPSTNO	1	a
B		SPSTNC	2	r
C		SPDT (B-M)	21	u
D		SPDT (M-B)	1 < 2	far
E		SPDT (B-M-B)	21 < 2	fur
F		SPST (M-M)	11	faa
G		SPST (B-B)	22	frr
H		SPDT (B-B-M)	221	frra
I		SPDT (M-B-M)	–	fau
J		SPDT (M-M-B)	11 < 2	faar
K		SPDTNO	1) x (1	ma
L		SPDT (B-M-M)	211	fraa
M		SPDTNC	2) x (2	mr
U		SPSTNODM		(da)
V		SPSTNCDB		(dr)
W		SPDTNC-NO (DB-DM)		du
X		SPSTNODM		da
Y		SPSTNCDB		dr
Z		SPDTNC-NO (DB-DM)		dra

Table 12: Types of contact

function of the coil core. → Core laminations.

Core Laminations (core stampings): Construction of the iron core (→ E core), in the form of alloyed iron laminations for a.c. relays, inductors, or transformers. In order to reduce eddy current effects, laminations are isolated from each other.

Corrosion: The destruction of a material due to chemical, thermal (environmental), electrical or mechanical action taking place on the material surface. Relay contacts are subjected to all of these stresses, including the possibility of a combination of stresses, such as electrochemical or galvanic action, (e.g. due to the action of dissimilar metals in contact with each other) and thus increasing the risk of corrosion. (→ Electrolytic series). In this case, as in the case of purely chemical stresses, electrons are discharged (anode), or absorbed (cathode). Contact currents increase the risk of corrosion particularly when condensation droplets, (precipitated from the atmosphere as a result of a drop in temperature) form on the contacts. Corrosion can be prevented or significantly retarded by keeping materials clean (→ Gettering), and by the correct selection of precious metals, contact materials and *protective gas.*

Corrosion Test Methods: For the assessment of corrosion characteristics of contact materials and contact elements, the following national and international standards have been laid down for corrosion testing:
DIN 40046 Part 36:
10 ± 2 ppm SO_2 / 25 ± 2 °C / 75 ± 5% r.h.
DIN 40046 Part 37:
1 ± 0.3 ppm H_2S / 25 ± 2 °C / 75 ± 5% r.h.
IEC 68-2-42 Test Kc:
25 ± 5 ppm SO_2* / 25 °C / 75% r.h.
IEC 68-2-43 Test Kd:
10...15 ppm H_2S / 25 °C / 75% r.h.

* additional 4500 ppm (max) CO_2 permissible.

The duration of testing is specified for 4, 10, 21 days. Polution gas metering can be effected by miniature pumps, pinhole diaphragms, capillaries, or permeation tubes. → AES.

Cos φ: → Phase angle.

Cradle Relay: A relay with a bar-like or comb-like actuator which, in contrast to the actuation of individual nipples, operates several contacts simultaneously.

Creepage Current: Electric current which may flow on the surface of solid insulating materials between live electrodes, along a *creepage distance.* The causes for creepage currents are, for example, contaminations on the surface in certain circumstances, through hygroscopic substances and non-homogeneities of the insulating material. The resistance of an insulating material against creepage current is identified by the *creepage current resistance.*

Creepage Current Resistance: The withstandability of an insulating material against decomposition under the influence of an electrical potential difference. Testing is in accordance with DIN 53480.

Creepage Distances and Clearances: are safety distances between live components and ground, and are generally defined as follows:
The clearance is the shortest straight-line distance in air between the two reference points.
The **creepage distance** is the shortest path along the surface of an insulating material between the two reference points, along which or through crevices of inserted insulating bodies, a current can flow (see illustrations 68, 69, 70).
The **assembly gap** is the shortest distance between two reference points where at least one of them is not clearly established in its position, either through inaccuracy in fitting or through connec-

tion of an operating device, so that minimum values of the creepage and clearance distances are not definable.
It is the minimum isolation distance for electrically operated devices, including relays, contactors and switches. It is used, with adequate dimensioning, to prevent danger to people or things due to the effects of electric voltages or currents, or functional failures of the operating devices. Environmental influences, type and shape of insulating materials used and any likely deterioration of the insulating conditions are taken into account. The distances specified by VDE 0110 are shown in table 13.

Reference voltage to		Insulation group A_0		Insulation group A		Insulation group B			Insulation group C			Insulation group D		
AC_{rms} value	DC	clearance	creepage distance	clearance	creepage distance	clearance	creepage distance		clearance	creepage distance		clearance	creepage distance	
							a	b		a	b		a	b
V	V	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
12	15	0,06	0,1	0,15	0,2	0,4	0,6	0,8	0,8	1,2	1,7	1,6	2,3	3,2
30	36	0,1	0,15	0,2	0,25	0,5	0,8	1	1	1,5	2	1,8	2,6	3,5
60	75	0,15	0,2	0,25	0,35	0,7	1	1,3	1,2	1,7	2,3	2	3	4
125	150	0,25	0,35	0,4	0,5	1	1,3	2	1,6	2,2	3	2,5	3,5	5
250	300	0,5	0,7	0,8	1	1,6	2	3	2,5	3	4	3,5	5	7,5
380	450	0,8	1,1	1,2	1,5	2,4	3	4	3,5	4,5	6	5	7	10
500	600	1,1	1,5	1,6	2	3	4	5,5	4,5	6	8	6,5	9	13
660	800	1,5	2	2,2	2,8	4	5,5	7	6	8	10,5	8	12	17
750	900	1,8	2,2	2,5	3,2	4,5	6	8	6,5	9	12	9	13	19
1000	1200	2,5	3	3,5	4,5	6	8	11	9	12	16	12	17	25

Table 13: Clearance and creepage distances as per VDE 0110

Insulation group	Insulation reduction due to environmental influences	Stresses through excess voltage	Application example
A_0	Low	Very small	Radio equipment (walkie-talkies)
A	Low	Small	Electrical measurement equipment
B	Medium	Medium	Domestic appliances Lighting The inner parts of sealed relays
C	Large	Large	Electrical equipment of machine tools relays and contactors
D	Very large	Large	Electrical track vehicles (engine room)

Table 14: Classification of insulation groups to VDE 0110

Allocation of the insulation groups is arranged by the VDE 0110 as classified in table 14.
The numerical values, a and b, of the creepage distances, in accordance with table 13, depend on the nature of creepage distance and on the quality of the insulating material (see table 15).

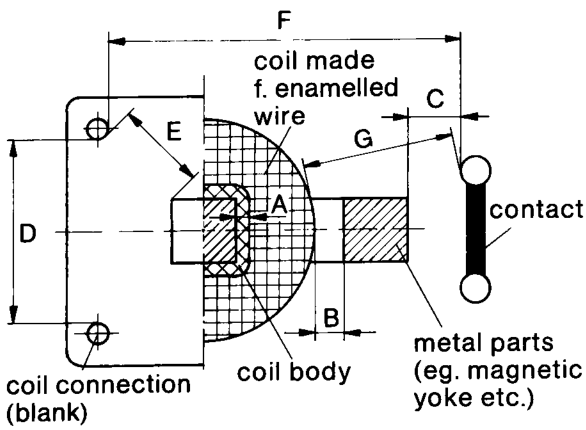
Group	Creepage current withstand* (min.)	Creepage distance without ribs	Creepage distance with ribs to § 8a)
I	Minimum value KB 100	b	$\frac{a+b}{2}$
II	Minimum value KB 380	$\frac{a+b}{2}$	a
III	KB >600	a	a

* Stages of creepage current withstand as per DIN 53480, VDE 0303 part 1

Table 15: Creepage current withstand

In addition, there are special regulations for particular areas of application, e.g. in VDE 0700/IEC 335-1 — these are specifications for the "Safety of Electrical Appliances for Dometic and Similar Usage." — Higher values are specified for creepage and clearance distances, which are illustrated with the aid of proportioning examples, for relays of protection class II.

Example A

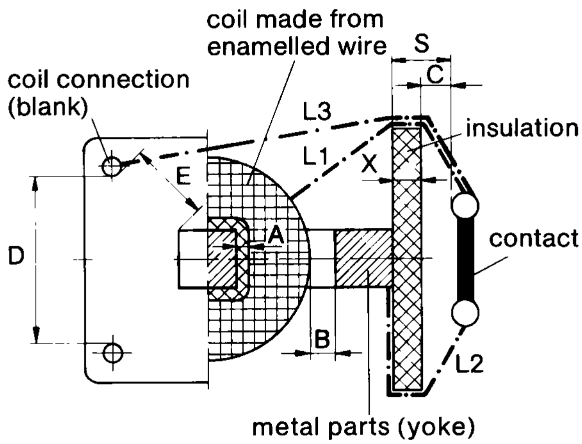


Case 1: Coil for Selv ($\leq$42 V)/contact for max. 250 V
A $\geq$ 1 mm, voltage test 2500 V ~
B $\geq$ 4 mm
C K $\geq$ 3 mm/L $\geq$ 2.5 mm
D $\geq$ 1 mm internally, externally K $\geq$ 2 mm, L $\geq$ 1.5 mm
E $\geq$ 4 mm
F $\geq$ 8 mm
G $\geq$ 6 mm

Case 2: Coil for max. 250 V/contact for Selv ($\leq$42 V)
A optionally small, voltage test 1250 V_{rms}
B $\geq$ 2 mm
C $\geq$ 4 mm
D $\geq$ 2 mm internally, externally K $\geq$ 3 mm, L $\geq$ 2.5 mm
E K $\geq$ 3 mm/L $\geq$ 2.5 mm
F $\geq$ 8 mm
G $\geq$ 6 mm

Fig. 68: Proportioning example A for creepage distances (K) and clearance (L) for protection class II relays

Example B



Case 1: Coil for Selv ($\leq$42 V)/contact for max. 250 V
A $\geq$ 1 mm test voltage 2500 V
B $\geq$ 4 mm
C optionally small, however L1 $\geq$ 6 mm, L2: K $\geq$ 3 mm/L $\geq$ 2.5 mm, L3 $\geq$ 8 mm
D $\geq$ 1 mm internally, externally K $\geq$ 2 mm, L $\geq$ 1.5 mm
E $\geq$ 4 mm
S $\geq$ 1 mm*

Case 2: Coil for max. 250 V/contact for Selv ($\leq$42 V)
A optionally small, test voltage 1250 V
B $\geq$ 2 mm
C optionally small, however L1 $\geq$ 6 mm, L2 $\geq$ 4 mm, L3 $\geq$ 8 mm
D $\geq$ 2 mm internally, externally K $\geq$ 3 mm, L $\geq$ 2.5 mm
E K $\geq$ 3 mm/L $\geq$ 2.5 mm
S $\geq$ 1 mm*

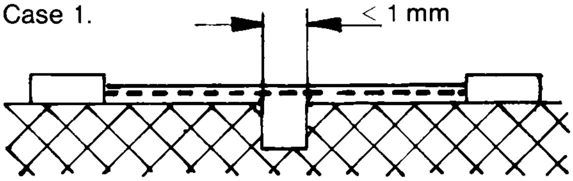
* S can be composed of several clearance (C) and isolation (X) distances. X has to be composed of at least two isolating layers, each having a dielectric strength of 2500 V.

Fig. 69: Proportioning example B for creepage distances (K) and clearance (L) for protection class II relays

With regard to dimensioning, the designer must observe the regulations, e.g. VDE 0700/IEC 335-1, for four special cases:

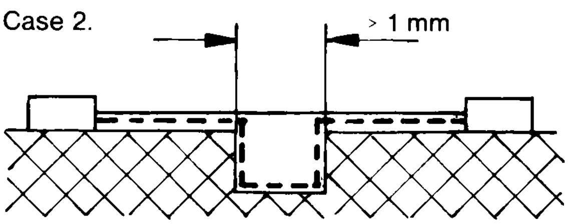
Clearance ————————
Creepage distance – – – – – – – –

Case 1.



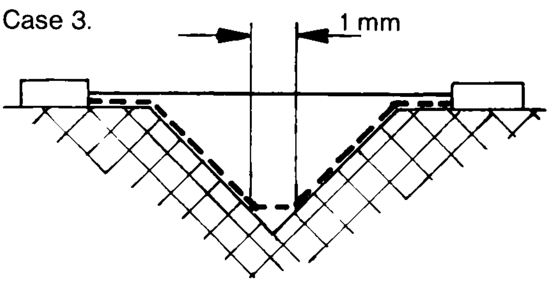
Condition:
Path under consideration includes a parallel- or converging-sided groove of any depth with a width less than 1 mm.
Rule:
Creepage distance and clearance are measured directly across the groove as shown.

Case 2.



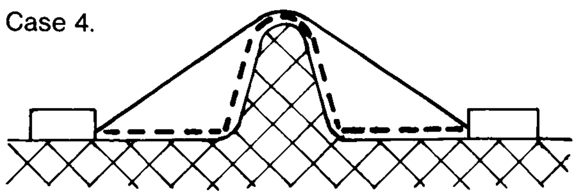
Condition:
Path under consideration includes a parallel-sided groove of any depth and equal to or more than 1 mm wide.
Rule:
Clearance is the "line of sight" distance.
Creepage path follows the contour of the groove.

Case 3.



Condition:
Path under consideration includes a V-shaped groove with internal angle of less than 80 and with a width greater than 1 mm.
Rule:
Clearance is the "line of sight" distance. Creepage path follows the contour of the groove but "short-circuits" the bottom of the groove by 1 mm (0.25 mm for dirt-free situations) link.

Case 4.



Condition:
Path under consideration includes a rib.
Rule:
Clearance is the shortest direct air path over the top of the rip. Creepage path follows the contour of the rib.

Fig. 70: Measurement of creepage distance and clearance as per VDE 0700

Unfortunately it has not so far been possible to prepare an internationally applicable specification for creepage distances and clearances. Table 16 shows comparisons between Germany, Japan, USA, UK, Austria, IEC and Switzerland.

Explanations to Table 16:

1 The VDE specification distinguishes between d.c. and a.c. voltages. Since this is not commonly practiced in other countries, the d.c. voltage has not been included in this comparison.

2 For clearances, the minimum values are between two live parts (L-L) and between a live part and one with contact potential in the event of a fault (L-A). The distance between a live part and an earthed one, (which in the event of a fault is not regarded as a shock hazard) may correspond to that of (L-L) for the associated voltage. The clearances and creepage distances between live parts of the contact circuits and those of the input circuits must correspond to (L-L). The (L-A) distance ratings differ greatly in the various countries. For example the dimension F = 8 mm in the illustration of example A is an (L-A) distance for which the Japanese specification requires only 3 mm, whereas the American specification calls for 12.7 mm, yet the IEC is content with 8 mm. The need for safety is surely equally high everywhere; it can therefore only be a question of concealed, but deliberate trading inhibitions, anchored in these specifications.

3 The Japanese specification lists under "A", such relays which are protected (sealed) so that humidity and dirt will have no harmful effect, and which at the same time are used in a "pure" atmosphere. All other relays must correspong to "B"

What is most interesting and revealing is the fact that as early as 1976, the Japanese specifications already largely provided for what the IEC 255-5 required in 1978.

4 The US specifications distinguish between networks in which "transient voltages are controlled and known", and networks in which these are not controlled or known. The values given are related to the former case.

Rated voltage[1]		Switzerland SEV 1025, 1973	West Germany and Austria VDE 0110/11.72 Group		IEC (amongst others UK) 255-5 (1977) distances		158-1 (1970) and 255-5 for distances C[2]		Japan JIS C 4530 1976 distances[3]		USA UL 508 / 8th Oct. 1980[4] with short circuit[2] <500 VA		>500 VA <10 kVA		>10 kVA	
			B	C	A	B	L-L	L-A	A	B	L-L	L-A	L-L	L-A	L-L	L-A
		mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
to 12 V	K L	–	0,6–0,8 0,4	1,2–1,7 0,8	–	–	–	–	–	–	–	–	–	–	–	–
30 V	K L	–	0,8–1 0,5	1,5–2 1	–	–	–	–	0,4 0,4	1–1,5 1	–	–	–	–	–	–
50 V	K L	1,4–2,8 1,4	–	–	–	–	–	–	–	–	–	–	0,762 0,762	6,35 6,35–12,7	0,762 0,762	6,35 6,35–12,7
60 V	K L	–	1–1,3 0,7	1,7–2,3 1,2	0,5 0,5	1–2 1	2–3 2	2–3 3	0,5 0,5	1–2 1	–	–	–	–	–	–
125 V USA to 100 V	K L	2–4 2	1,3–2 1	2,2–3 1,6	0,5–1 0,5	1,5–2,5 1,5	–	–	0,5–1 0,5	1,5–2,5 1,5	0,762 0,762	6,35 6,35–12,7	–	–	–	–
225 V	K L	–	–	–	–	–	–	–	–	–	1,143 1,143	12,7 12,7	1,524 1,524	12,7 12,7	2,54 1,905	12,7 12,7
250 V	K L	2,8–5,6 2,8	2–3 1,6	3–4 2,5	1–1,5 1	2–3 2	3–4 3	3–4 5	1–1,5 1	2–3 2/3	–	–	–	–	–	–
380 V	K L	4–8 4	3–4 2,4	4,5–6 3,5	1,5–2 1,5	3–4 3	4–6 4	4–6 6	–	–	–	–	–	–	–	–
450 V	K L	–	–	–	–	–	–	–	–	–	1,524 1,524	12,7 12,7	2,54 2,54	12,7 12,7	5,08 3,81	12,7 12,7
500 V	K L	5,6–11 5,6	4–4,5 3	6–8 4,5	2–3 2	4–6 4	6–10 6	6–10 8	–	–	–	–	–	–	–	–
660 V	K L	–	5,5–7 4	8–10,5 6	–	–	–	–	–	–	–	–	–	–	–	–
750 V	K L	8–16 8	6–8 4,5	9–12 6,5	–	–	–	–	–	–	–	–	–	–	–	–
900 V	K L	–	–	–	–	–	–	–	–	–	2,54 2,54	12,7 12,7	5,08 5,08	12,7 12,7	10,01 7,62	12,7 12,7
1000 V	K L	11–22 11	8–11 6	12–16 9	–	–	–	–	–	–	–	–	–	–	–	–

Table 16: Comparison of creepage distances (K) and clearances (L) as specified in Switzerland, West Germany, Austria, UK, Japan and USA.

Crimping: Solderless connecting technique. Solid or flexible line connections are mechanically formed in open or closed sleeves, using appropriate crimping tools, in such a way that gas-tight electrical connections of high reliability are made.

Crystal-Can Relay: A can-shielded, in general, hermetically sealed relay with the dimensions
L=0.8″×W=0.4″×H=0.97″; these dimensions correspond to 20.3×10.2×24.6 mm (in practice, 22.3 mm), also referred to as a "full size relay" (fig. 324). The "half size relay" has the dimensions, 20.3×10.2×10.2 mm (fig. 279), and the "sixth size relay" measures, 12.8×5.8×10.1 mm.

Curie Temperature, Curie Point: The temperature above which the spontaneous magnetization disappears, i.e. where the ferromagnetic phase passes into a paramagnetic (or antiferromagnetic state). → Magnetism.

Cycling Test: The method for testing the reliability of contacts in dry circuits. Series connected normally closed contacts or normally open contacts must not exceed a pre-set contact resistance during 5000 operations with dry contact operation. For this test the following generally applies:

Switching voltage	between	5 and 30 mV
Switching current	between	0.5 and 10 μA
Switching frequency	between	1 and 10 Hz
Max. contact resistance	between	30 and 200 Ω

Damping: Measurement for the effectiveness of electrical or magnetic screening. It is the logarithmic relationship of the field strength of a transmitter at a certain location, without screening, to the field strength with screening. Unit: 1 N (Neper)=8.69 dB.

Damping Resistor: An ohmic resistor which serves for the damping of oscillations, or limits any changes in current or voltage.

Damping Winding: A short-circuited coil (which may be substituted by a copper ring). On relay switching, it delays the current rise and fall, and thus increases the *pull-in* and *release times.* → Delay winding.

DC: Direct Current.

Decimal Powers: The prefix values listed in table 17 are used when stating decimal powers.

E	exa-	$=10^{18}$	=trillion
P	peta-	$=10^{15}$	=billiard
T	tera-	$=10^{12}$	=billion
G	giga-	$=10^{9}$	=milliard
M	mega-	$=10^{6}$	=million
k	kilo-	$=10^{3}$	=thousand
h	hecto-	$=10^{2}$	=hundred
da	deca-	=10	=ten
		10^{0}	=one
d	deci-	$=10^{-1}$	=tenth
c	centi-	$=10^{-2}$	=hundredth
m	milli-	$=10^{-3}$	=thousandth
μ	micro-	$=10^{-6}$	=millioneth
n	nano-	$=10^{-9}$	=milliardth
p	pico-	$=10^{-12}$	=billionth
f	femto-	$=10^{-15}$	=billiardth
a	atto-	$=10^{-18}$	=trillionth

Table 17: Prefix values of decimal powers

Degree of Protection in accordance with DIN 40050 and IEC 144: For the protection of personnel against contact with live parts and for the protection of electrical equipment against the ingress of solid matter and of water, the equipment requires to be sealed. The most important degrees of protection are listed in table 18. By specifying a degree of protection, no statement is implied as to the degree of *gas tightness* under mechanical or thermal operating stress.

Protection classes	Live-part protection (first number)	Foreign body protection (first number)	Protection against water (second number)
IP 00	No protection against contact with live parts	No protection against ingress of solid foreign bodies	No protection
IP 20	Protection against contact with the fingers	Protection against ingress of foreign bodies with Ø > 12 mm	No protection
IP 40	Protection against contact with tools wires etc. with diameter > 1 mm	Protection against ingress of granular foreign bodies with Ø > 1 mm	No protection
IP 41	Protection against contact with tools wires etc. with diameter > 1 mm	Protection against ingress of granular foreign bodies with Ø > 1 mm	Protection against drip water falling vertically
IP 50	Complete protection against contact with live parts	Protection against harmful deposits of dust	No protection
IP 53	Complete protection against contact with live parts	Protection against harmful deposits of dust	Protection against spray water falling at an angle up to 60° from vertical
IP 54	Complete protection against contact with live parts	Protection against harmful deposits of dust	Protection against splash water from any direction
IP 55	Complete protection against contact with live parts	Protection against harmful deposits of dust	Protection against water jets from any direction
IP 65	Complete protection against contact with live parts	Protection against ingess of dust	Protection against water jets from any direction

Table 18: Selection of protection classes according to DIN 40050 and IEC 144

Delay Relay: *Time delay relay* with delayed switching action, without a settable scale.

Delay Winding of a relay coil: A coil which is often equipped with RC networks or diodes, arranged in parallel with the coil, for delaying the increase or fall-off in the energizing current. For example, diodes used for arc suppression give rise to an undesirable delay of relay pull-in or drop-out. → Damping Winding.

Demagnetization: occurs with open permanent magnetic circuits, especially under the influence of opposing or alternating fields, and heat or shock stresses. If a ferromagnetic circuit is to be demagnetized, the iron must be exposed to an alternating magnetic field whose amplitude will gradually be reduced to zero or has to be heated up to the *Curie Point* for a short time. → Magnetism.

Diamagnetism: → Magnetism.

Dielectric Constant: Distinction is made between absolute and relative dielectric constant. The relative dielectric constant of an insulating material is the ratio of the capacitance of the capacitor utilizing the insulating material concerned, to the capacitance of the same capacitor with a vacuum as the dielectric, the relative dielectric constant of which equals 1. The absolute dielectric constant of an insulating material is the product of the relative dielectric constant and the absolute dielectric constant of the vacuum. → 2.3 Formulae of Electro Technology.

Dielectric Strength (withstand voltage): The voltage which can be applied between two electrodes, which are insulated from each other, without causing a discharge. It is dependent on the thickness and purity of the insulating material, its power factor, the effect and duration of temperature, the humidity, and the geometry of the electrodes (→ Breakdown Voltage).

The *Relay Tables* state the effective value of a 50 Hz a.c. voltage which can be applied for a minimum of 60 seconds between coil and ground or contact and ground, without giving rise to a tripping current >1 mA (ANSI/EIA Standard RS-407-A-78). The dielectric strength between open contacts is not stated if this is greater than 2.5 times that of the specified maximum break voltage. However, if the dielectric strength of the open contacts meets the requirements of VDE 0435 or any other specification, this is shown in the "Remarks" column of the relay table. → Test Voltage. → Breakdown Voltage.

Differential Relay: → Protective Relay.

Differential Winding: A relay winding with a tapping, whose part windings are switched in opposition.

Diode: A two-electrode electronic component having effective resistance in one direction only. It is used among other applications for: *arc suppression,* when it is connected in parallel with the contact or the coil; and for rectification.

DIP, DIL (Dual In-Line Package): A housing with a row of connection pins on each of two sides, (modular dimensions usually 2.54 × 7.62 mm). DIPs were originally designed for ICs, and are increasingly used in relays (DA, DR, DS, S relays; → Relay Table).

Discharge: Balancing of load differences. Distinction is made between a discharge through a connection of electrical conductors, discharge in semiconductors, and in gases. For gas discharges, the voltage/current graph fig. 71, shows the transition from the Townsend discharge to the *glow discharge,* which ultimately leads to *arcing.*

Literary sources provide differing information on the voltage/current curve of a discharge. This is the consequence of different discharge conditions, such as gas pressure, type and composition of the gas charge, shape and size of the electrodes, as well as types of charge carrier generation. In fig. 71 therefore, only the approximate course of the gas discharge characteristic is shown, of which the sections "glow discharge" and "arcing" are of prime importance in relay technology.

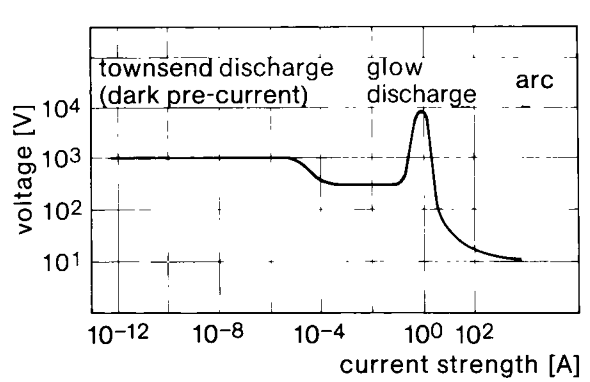


Fig. 71: Curves of gas discharge (approx.)

Discriminating Relay: From a number of circuits the discriminating relay automatically selects one or more.

Distortion: Variation of the contact time from the pulse time. It is caused by electrical and mechanical inertia and the natural resonance of the relay.

Drop-Out Current: The maximum current flowing through a relay coil which, at switch-off, will reliably restore the relay to the rest condition.

Drop-Out Ratio: The ratio of the drop-out to the operating-current, voltage, power or the number of ampere turns, expressed as a percentage. → Ampere turns, AT.

Drop-Out Time Delay: An extension of the release time by means of a short-circuit winding *(delay winding)* which short-circuits the relay winding at the instant of switch-off (or through a resistor, capcitor or a diode connected in parallel with the coil), (see also *C-switching circuit*).

Dry Circuit: Contact making with voltages up to 80 mV and currents of µA magnitude. → Contact resistance.

Duty Cycle: → ED, → Relay Times.

Dynamic Contact Resistance: The fluctuation of the contact resistance during closing or opening of a relay contact caused by the quiver and the resulting fluctuation of the contact force. The period of the dynamic contact resistance behaviour begins with the contact closing after bouncing has ceased and ends with the commencement of the static, constant contact resistance; this is inverted during contact opening. The dynamic behaviour can be overlapped by A and B fritting processes. (→ Fritting). Fig. 72 illustrates the dynamic contact resistance, according to NARM. (National Association of Relay Manufacturers).
→ Contact Noise, → Noise.

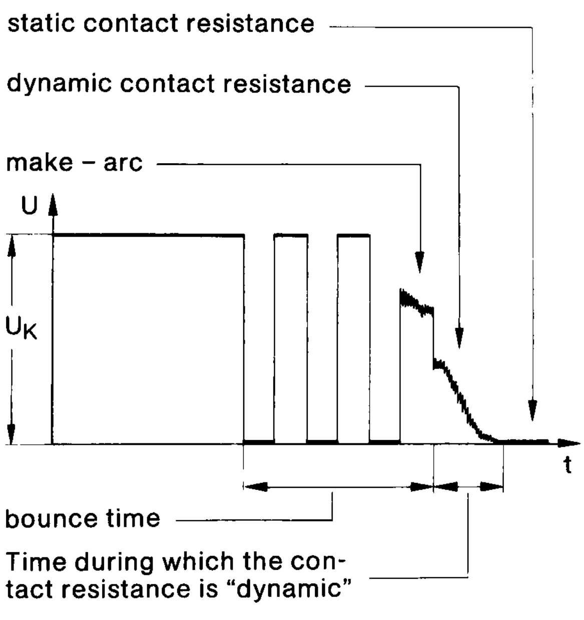


Fig. 72: Interpretation of the make operation of a relay contact [24]
U_k = contact voltage

Dynamic Marginal Current: The peak value of the current whose dynamic effect can be withstood by the switchgear, without risk of damage or upset to its function.

E Core: An "E" shaped iron or ferrite core for transformers or a.c. relays.

Economic Aspects: → Section 1.3, Relay-Evolution.

Economic Value: of relays or other components which fulfil the required equivalent functions, is primarily dependent on the application and is meaningful only in the comparison with the economic value of alternative components.
As a rule, the *life* L, required under given *environmental influences* and contact loads, is set against the following costs [according to 21]:

- A Purchase price
- B Operating costs (costs of the power consumed and lost)
- R Space costs (at average packing density, approx. £ 0.15/cm³)
- T Transport costs (air, sea or rail freight + packaging)
- Q Quality maintenance and failure costs, in relation to the failure probability. (→ Weibull Diagram).

The economic value

$$N_R \triangleq \frac{L \cdot \text{No. of contacts}}{A + B \cdot K_1 + (R+T) \cdot K_2 + Q \cdot K_3}$$

$$\left(\frac{\text{switching cycles} \times \text{No. of circuits}}{\text{costs}}\right)$$

$K_{1,2,3}$ being corrective factors for costs which arise later than the purchase price and, as a rule, lie between 0.70 and 0.96. In most applications it is not the purchase costs which dominate, but the cost of failure. This is also evident from table 3, in which a dependence of the economic value on the *efficiency* can be recognized. The estimated total costs by comparison with alternative relays are lower, the greater their *efficiency.* Since several *characteristics* of relays of the same kind differ so widely, as illustrated in table 3, it is worthwhile to establish the economic value of several components under consideration, by using the above formula, or by addition — as in table 3.

ED (Relative Duty Cycle. German, **Ein**schalt **D**auer): The ratio of the operated time to the cycle time (→ Switching cycle), expressed as a percentage. It affects the coil temperature rise. The final temperature of the coil is usually reached within 30 minutes of energizing, which means that such an ED can be described as 100%.

Eddy Current: Generally, an undesirable induction current in solid metal conductors (e.g. coil cores) when these are within alternating magnetic fields. It effects a lowering of the permeability and increases the loss factor with increasing frequency. (Eddy current losses rise in proportion to the square of the frequency.) By using bundles of laminations in magnetic circuits, eddy currents can be reduced. → SAC.

Edge Steepness: The rate of rise or fall (or slope gradient) of a signal. In modern IC-modules, (→ C-Switching Circuit), the steepness of the operating edge, (du/dt) is of importance for the selection of the most suitable connection terminal.

Effective Value of an alternating current (RMS): In terms of magnitude, it corresponds to the direct current which would produce the same power.

Efficiency η: A qualitative feature of relays. The switching capacity with a certain life, the number of contacts, the necessary operating energy for 1 sec. duration and the relay volume are combined into the following formula:

$$\eta_{(L)} = \frac{\text{No. of contacts} \times \text{switching capacity (VA or W)}}{\text{power consumption (Ws)} \times \text{Relay volume (cm}^3\text{)}}$$

The "No. of contacts" for a single normally open or normally closed contact equals 1; that of a change-over contact equals 2. Example: The contact arrangement 2 NO 1 NC 2 CO has the contact count 7, namely: $2 \times 1 + 1 \times 1 + 2 \times 2 = 7$. With contacts of differing switching capacity, the appropriate sum must be found.

(L) represents the life resulting from the switched load, e.g. 10^6 switching cycles with either no faulty switching allowable, or a proportional or specific number of such, depending on the application or specification. → Life, → AQL Values, → Weibull.

The efficiency shows how well a relay is designed. It will further be seen from table 3 that it increases considerably with the number of functions, (see 1.2), integrated within the relay. The efficiency is, therefore, one of the most important points of data of a relay, not least because by including the life, it indirectly covers the effects of design measures. The measures include contact bounce, type of contact (point, or bifurcated linear contact), contact resistance, self-heating and the quality of the gettering. In addition it takes account of the contact, magnet and plastic materials used.

Efficiency: The ratio of power supplied to power available for use. However, since it is the function of a relay to switch and carry a load reliably, and since this happens in many different ways, other criteria must also be taken into consideration for the purpose of comparing different relays. What is of foremost interest, is to establish how the energy which is fed into a magnetic system, is ultimately used.

Hanisch [103] has shown a possibility of defining (a degree of) efficiency for relays, through the allocation of the so-

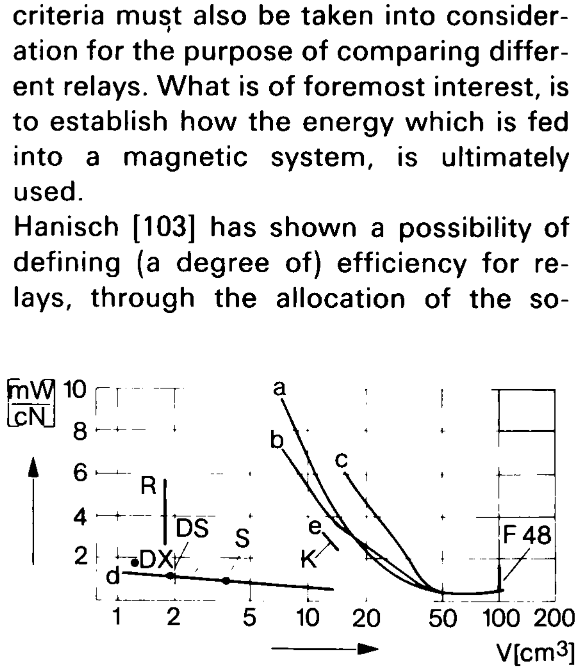


Fig. 73: Contact force resulting from pick up power consumption shown as a function of the relay volume

called "energy utilization of the Pull-In Power" to the relay volume. The various contact forces are added to form one total force, and the pull-in power consumption of any given case is related to it. The "Energy Utilization of the Pull-In Power" for different relays, of differing volumes is illustrated by the curves a, b, and c in fig. 73.

The conclusion reached, which states that the power consumption to attain the same contact force increases by a greater amount than in proportion to the physical size reduction of the relay, can no longer be accepted as valid. Neither is it true in general that sensitivity, adjusting effort, switching capacity, production costs and life, are negatively affected by miniaturization. For example, the S relay (→ Relay Table) represented by the curve d, (fig. 73), is much smaller, more sensitive, cheaper and with comparable life, has a higher switching capacity than the K relay (→ Relay Table) represented by curve e, although the energy utilization and reliability of the latter have already been substantially optimized (figs. 96 and 127). Even a relay with a volume of only 2 cm^3 (DS relay, → Relay Table) has a better energy utilization than a 20 cm^3 relay represented by curves a, b and c; the reason for this is to be found in the design described in figs. 9 and 14.
A more comprehensive and justified parameter for the comparison of relays is given by the efficiency (η) which relates to a given specified life.

Electrical Conductivity σ: The capability of a material to conduct electric current; i.e. it is the reciprocal value of the specific electrical resistance. (→ 2.3 Formulae of Electro Technology). A table of the conductivity of different materials, (at 20°C ambient temperature) is given in fig. 74.

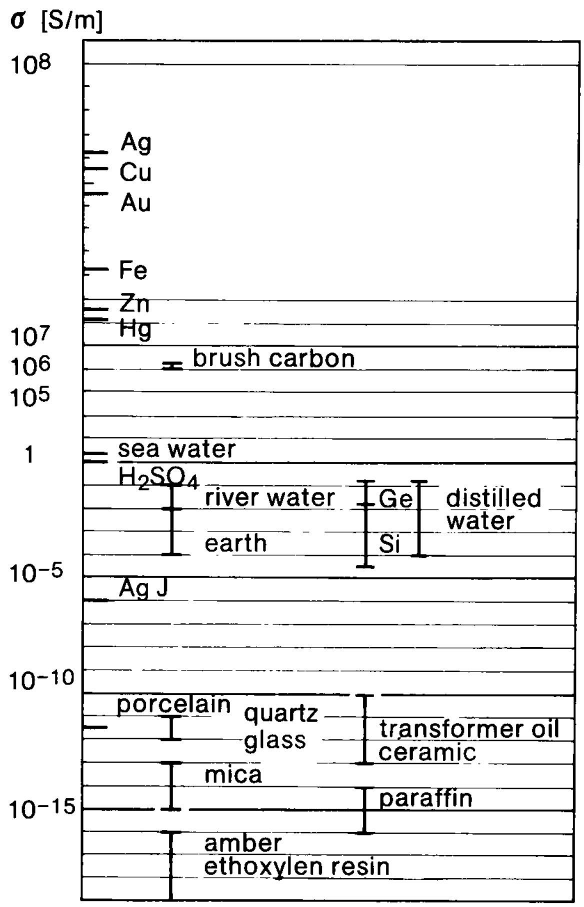


Fig. 74: Conduction capability of various materials at 20°C ambient temperature

Electrical Life: → Life, electrical.

Electrical Time Constant, L/R: determines the minimum length of time from the closing of the energizing circuit to the commencement of armature movement (→ Start-up Time, → Relay times). Generally, after the time L/R has elapsed, 63% of the final current value will have been achieved. (L = relay coil inductance; R = coil resistance).

Electrolytic Series: During contact of different metals, galvanic action, assisted by humidity, develops. The smaller the separation distance between the two metals in the electrolytic series, the smaller will be the voltage arising, and the amount of metallic erosion or corrosion will also be smaller (table 19).

Electrolyte: 3% salt solution,
±0,02 volt tolerance,
values stated in volts

Cathode \ Anode	Magnesium	Zinc	Thorium	Aluminium	Cadmium	Wood's alloy	Cadmium solder	Indium	Dynamo core sheet	Lead	Soft solder	White metal	Tin	Iron, steel	Cobalt	Chromium	Tantalium	Brass	Cond. bronze	German silver	Copper	Bronze	Nickel	Constantan	Tungsten	Steel, rhodium	Titanium	Molybdenum, silver pallad.	Silver	Steel (anoxin)	Gold	Carbon, graphite
Zinc	0,76																															
Thorium	0,96	0,20																														
Aluminium	1,05	0,29	0,08																													
Cadmium	1,05	0,29	0,08	0,01																												
Wood's alloy	1,07	0,31	0,09	0,01	0																											
Cadmium solder	1,11	0,35	0,11	0,03	0,03	0,02																										
Indium	1,14	0,38	0,18	0,10	0,10	0,09	0,07																									
Dynamo core sheet	1,21	0,45	0,28	0,19	0,20	0,19	0,17	0,10																								
Lead	1,26	0,50	0,29	0,22	0,21	0,20	0,18	0,11	0,01																							
Soft solder	1,32	0,56	0,34	0,27	0,28	0,27	0,25	0,16	0,08	0,05																						
White metal	1,33	0,57	0,34	0,27	0,28	0,27	0,25	0,16	0,08	0,05	0																					
Tin	1,36	0,60	0,39	0,31	0,31	0,30	0,28	0,21	0,11	0,10	0,05	0,05																				
Iron, steel	1,36	0,60	0,40	0,32	0,32	0,31	0,29	0,22	0,12	0,11	0,07	0,06	0,01																			
Cobalt	1,39	0,63	0,42	0,34	0,34	0,33	0,31	0,25	0,14	0,13	0,08	0,08	0,03	0,02																		
Chromium	1,39	0,63	0,42	0,34	0,34	0,33	0,31	0,25	0,14	0,13	0,08	0,08	0,03	0,02	0																	
Tantalium	1,53	0,77	0,57	0,49	0,49	0,48	0,46	0,41	0,29	0,28	0,23	0,23	0,20	0,20	0,15	0,05																
Brass	1,54	0,78	0,61	0,50	0,50	0,49	0,47	0,43	0,30	0,32	0,27	0,27	0,22	0,20	0,19	0,09	0,03															
Cond. bronze	1,56	0,80	0,61	0,53	0,54	0,52	0,50	0,44	0,33	0,32	0,27	0,27	0,22	0,21	0,19	0,09	0,05	0,01														
German silver	1,58	0,82	0,62	0,54	0,54	0,53	0,51	0,44	0,34	0,33	0,28	0,28	0,23	0,22	0,20	0,10	0,05	0,02	0,01													
Copper	1,58	0,82	0,63	0,55	0,55	0,54	0,52	0,45	0,35	0,34	0,29	0,29	0,24	0,23	0,21	0,11	0,06	0,02	0,02	0												
Bronze	1,58	0,82	0,63	0,55	0,55	0,54	0,52	0,45	0,35	0,34	0,29	0,29	0,24	0,23	0,21	0,11	0,06	0,02	0,02	0,01	0,01											
Nickel	1,58	0,82	0,64	0,56	0,56	0,55	0,53	0,46	0,36	0,35	0,30	0,30	0,25	0,25	0,22	0,12	0,07	0,03	0,03	0,02	0,01	0,01										
Constantan	1,60	0,84	0,65	0,56	0,57	0,56	0,54	0,47	0,37	0,36	0,31	0,31	0,26	0,25	0,23	0,13	0,08	0,04	0,04	0,03	0,02	0,02	0,01									
Tungsten	1,61	0,85	0,65	0,57	0,57	0,56	0,54	0,47	0,37	0,36	0,31	0,31	0,26	0,25	0,23	0,13	0,08	0,04	0,04	0,03	0,03	0,02	0,01	0								
Steel, rhodium	1,67	0,91	0,72	0,64	0,64	0,63	0,61	0,54	0,44	0,43	0,38	0,38	0,33	0,32	0,30	0,20	0,15	0,11	0,11	0,10	0,10	0,09	0,08	0,07	0,07							
Titanium	1,74	0,98	0,77	0,68	0,69	0,68	0,66	0,59	0,49	0,48	0,43	0,43	0,38	0,37	0,35	0,25	0,20	0,16	0,16	0,15	0,15	0,14	0,13	0,12	0,12	0,05						
Molybdenum, silver pallad.	1,76	1,00	0,79	0,70	0,71	0,70	0,68	0,61	0,51	0,50	0,45	0,45	0,40	0,39	0,37	0,27	0,22	0,19	0,18	0,17	0,17	0,16	0,15	0,14	0,14	0,07	0,02					
Silver	1,78	1,02	0,83	0,75	0,75	0,74	0,72	0,65	0,55	0,54	0,49	0,49	0,44	0,43	0,41	0,31	0,26	0,22	0,22	0,21	0,21	0,20	0,19	0,18	0,18	0,11	0,06	0,04				
Steel (anoxin)	1,82	1,06	0,86	0,78	0,78	0,77	0,75	0,68	0,58	0,57	0,52	0,52	0,47	0,46	0,44	0,34	0,29	0,25	0,25	0,24	0,24	0,23	0,22	0,21	0,21	0,14	0,09	0,07	0,03			
Gold	1,91	1,15	0,94	0,85	0,86	0,85	0,83	0,76	0,66	0,65	0,60	0,60	0,55	0,54	0,52	0,42	0,37	0,33	0,33	0,32	0,32	0,31	0,30	0,30	0,29	0,22	0,17	0,15	0,11	0,08		
Carbon, graphite	1,94	1,18	0,99	0,89	0,89	0,88	0,86	0,81	0,69	0,68	0,65	0,65	0,60	0,57	0,55	0,45	0,42	0,38	0,38	0,37	0,37	0,36	0,34	0,33	0,34	0,27	0,22	0,20	0,16	0,13	0,05	
Platinum	1,96	1,20	1,02	0,92	0,92	0,91	0,89	0,84	0,72	0,71	0,66	0,66	0,63	0,60	0,58	0,48	0,45	0,39	0,41	0,40	0,40	0,39	0,37	0,36	0,37	0,30	0,25	0,23	0,19	0.16	0,08	0,03

Table 19: Electrolytic series

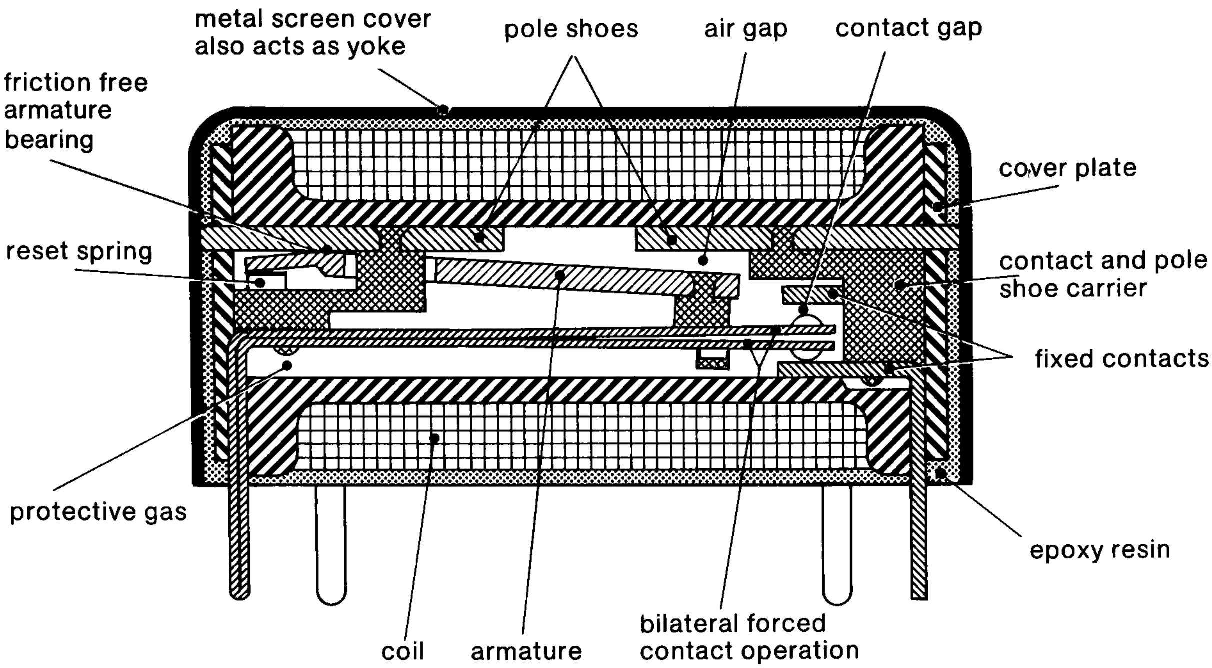


Fig. 75: Diagram of a new style unpolarized electromagnetic relay with indirect forced contact operation [27]

Electromagnetic Relay: A component which uses electromagnetic energy directly or indirectly for the operation of contacts. Fig. 75 shows a section through a modern, non-polarized relay with bilateral forced contact operation. What should be noted as being of new design is that the armature gap is in the coil center, thereby avoiding leakage losses, (→ Magnet Systems), and that the interior of the bobbin serves as a contact chamber filled with protective gas.
If more than one change-over contact is to be provided, an indirect operation which covers all contacts simultaneously is recommended, so that practically no *contact sequence* occurs. (→ Relay Times).
Polarized electromagnetic relays with direct contact operation are shown in figs. 84 and 279.

Electronic Relay: → Solid State Relay.

Electronic Switch: → Solid State Relay.

EMF (electromotive force): The electromotive or no-load voltage supplied by a power source.

Enamelled Copper Wire: is mainly used for relay coils, electric motors and transformers. The tolerances for the enamel covering, and the resistance per metre are laid down in DIN 46435. Closer tolerances are frequently required in practice. Since the drawing process for fine wire causes a hardening of the structure, the conductance changes accordingly. Table 20, therefore gives data of a working standard [62], in addition to the data of DIN specification 46435.

Energization: Application of an energizing voltage to a relay coil, which is necessary for the complete change of the relay switching condition. The measure of the energization is the number of ampere turns; i.e. the current flowing through the coil multiplied by the number of turns.

Energizing Winding: → Coil.

Nominal ⌀ mm	Enamalling „L" (Grade 1) DIN 46435	Synflex [62]	DC resistance per metre at 20° Ohm DIN 46435	Synflex [62]	No. of windings per mm² of winding cross section. Estimated value for Synflex [62]	Price factor for Synflex [62] (08.06.84)
	±	±				
0,015		3-1		88,8 -109,0	1750	33,80
0,0175	4-1	4-1		65,4 -80,60	1400	11,20
0,02	4-1	4-1	46,65 -63,11	50,2 -61,20	1100	6,50
0,025	5-1	5-1	30,21 -40,04	32,43 -39,20	725	3,00
0,028	6-1	6-1		26,22 -30,75	580	1,50
0,03	6-1	6-1	21,22 -27,56	22,65 -26,66	520	1,30
0,032	6-2	6-1	18,88 -24,02	19,75 -23,17	460	1,14
0,036	6-2	6-1	15,23 -16,65	16,10 -18,25	370	1
0,04	7-3	8-1	12,49 -14,95	13,17 -14,56	300	0,50
0,045	8-3	8-1	9,995 -11,69	10,40 -11,50	255	0,36
0,05	9-3	10-1	8,166 9,396	8,50 9,31	210	0,22
0,056	9-3	10-1	6,552 7,448	6,77 7,34	160	0,19
0,06	10-4	11-1	5,732 6,464	5,94 6,36	150	0,16
0,063	10-5	12-1	5,196 5,848	5,39 5,78	135	0,15
0,071	11-6	14-1,5	4,104 4,610	4,24 4,56	105	0,12
0,08	13-5	15-1,5	3,235 3,625	3,38 3,63	86	0,10
0,09	14-6	16-1,5	2,556 2,864	2,64 2,84	70	0,08
0,10	15-6	17-1,5	2,072 2,318	2,14 2,29	55	0,07
0,112	16-6	18-1,5	1,646 1,864	1,725 1,852	44	0,06
0,125	17-7	20-2	1,328 1,488	1,369 1,468	35	0,05
0,13	18-7	21-2	1,230 1,373	1,267 1,338	32	0,05
0,14	19-7	21-2	1,064 1,186	1,096 1,163	29	0,05
0,15	20-7	22-2	0,9276- 1,025	0,955 1,015	25	0,05
0,16	20-7	22-2	0,8192- 0,898	0,814 - 0,894	22	0,05
0,17	21-7	23-2	0,7272- 0,7940	0,748 0,786	20	0,04
0,18	22-7	23-2	0,6499- 0,7068	0,666 - 0,701	18	0,04
0,19	22-8	23-2	0,5843- 0,633	0,600 - 0,631	16	0,04
0,20	23-7	24-2,5	0,5282- 0,5706	0,541 - 0,568	15	0,04
0,212	24-7	24-2,5	0,4708- 0,5069	0,480 - 0,505	13	0,04
0,224	25-7	25-2,5	0,4224- 0,4534	0,431 - 0,453	11,8	0,03
0,236	25-8	25-2,5	0,3810- 0,4079	0,3880- 0,4075	10,6	0,03
0,25	26-8	27-2,5	0,3374- 0,3659	0,345 - 0,363	9,5	0,03
0,265	27-7	27-2,5	0,3008- 0,3251	0,3068- 0,3235	8,6	0,03
0,28	28-7	29-2,5	0,2698- 0,2907	0,2755- 0,290	7,8	0,03
0,30	29-7	30-3	0,2355- 0,2527	0,238 0,251	7,0	0,03

Table 20: Enamelled copper wire, → AWG, → coil.
The price factors are approximate. On 08.06.84 factor 1 equated to a price of DM 288.00 per kg (in small quantities)

Nominal Ø	DC resistance per metre at 20°C lowest value - highest value Ohm		Enamelling thinest layer µm		External Ø largest size µm		No. of windings per mm² of winding cross section Estimated value	Estimated price LOTAN L1 and C1 [112] on 25. 08. 83
mm	DIN 46435	LOTAN	1L Gr. 1	C1 LOTAN	1L Gr. 1	C1 LOTAN	LOTAN	DM per 1 kg
0,012		145,1 -160,4	-	1,1	-	15,5	3540	18590,—
0,013		124,1 -136,1	-	1,1	-	16,5	3020	9762,—
0,014		104,4 -120,4	-	1,3	-	18,0	2600	
0,015		91,37 -104,4	-	1,3	-	19,5	2263	5046,—
0,016		80,63 91,37	-	1,3	-	20,5	1990	
0,017		71,68 80,63	-	1,8	-	22,0	1760	2895,—
0,018		64,14 - 71,68	-	1,8	-	23,0	1570	
0,0185		60,81 - 67,75	-	1,8	-	23,5	1490	1730,—
0,019		57,73 - 64,14	-	1,8	-	24,0	1410	
0,020	46,65 -63,11	50,98 - 59,24	0,7	1,9	25,0	25,0	1280	1112,—
0,025	30,21 -40,04	33,11 - 37,33	0,6	2,1	31,0	31,0	840	520,—
0,030	21,22 -27,56	23,22 - 25,66	1,0	2,6	38,0	38,0	560	361,—
0,032	18,87 -24,01	20,47 - 22,48	1,0	2,6	40,0	40,0	500	305,—
0,036	15,24 -18,63	16,25 - 17,67	1,0	3,1	45,0	45,0	400	221,—
0,040	12,49 -14,95	13,22 14,25	1,0	3,5	50,0	50,0	330	135,—
0,045	9,995-11,69	10,49 11,21	1,6	3,6	56,0	56,0	260	95,—
0,050	8,166- 9,396	8,44 9,143	2,2	3,6	62,0	62,0	250	55,60
0,056	6,552- 7,448	6,757- 7,257	2,2	4,0	69,0	69,0	190	50,25
0,060	5,732- 6,464	5,900- 6,306	2,2	4,0	74,0	74,0	180	41,80
0,063	5,196- 5,848	5,360- 5,711	1,6	4,0	78,0	78,0	150	39,60
0,071	4,104- 4,610	4,18 4,47	1,6	4,5	88,0	88,0	104	30,75
0,080	3,235- 3,625	3,30 3,51	3,0	4,5	98,0	97,0	100	25,25

Classification of LOTAN fine enamalled wire
C0 thin insulation (not covered by IEC or DIN standards)
C1 single insulation (complies with 1L and Gr 1)
C2 double insulation (complies with 2L and Gr 2)

Table 20a: Fine enamelled copper wire for miniature relays [112]

Energy Density, Magnetic: The product of magnetic induction, B, and field strength, H. It corresponds to the rectangular area below the demagnetization curve with an inflection point at the *working point* of the magnet. Since the greatest magnetic energy exists when B and H have a maximum, the magnet material and the air gap should, if possible, be so dimensioned that the working point lies in the $(B \cdot H)_{max}$ point. This means that with a given induction in the air gap and the given dimensions of the gap, the volume of the magnet material may be correspondingly smaller, the greater the energy density; i.e. the closer the operation is to the maximum of $B \cdot H$.

Energy Storage: Through suitable design of the magnetic circuit of a *polarized relay* and appropriate adaptation of the spring characteristics of the contact system, permanent magnet forces can be converted into contact forces or stored, (part 1.2), thus enabling a considerable portion of excitation energy to be saved. → Temperature Compensation.

Environmental Influences: usually occur in combination. In general, climatic influences are connected with mechanical influences; [95], e.g. motional actions at temperature fluctuation. The simulation of environmental influences is produced in special laboratories. AEG-Telefunken [96] reports fully on this. → Thirty Per-Cent (30%) Rule.

Exponential Current: Current with exponential rise and/or fall-off. It is usually caused by capacitors or inductors in connection with resistors on instantaneous excitation. → Switching Behaviour of Current and Voltage.

Exponential Line: A HF line in which the characteristic impedance changes exponentially, depending on the line length.

Failure Rate λ: The value which denotes the *reliabilty* of a product. (→ Fault rate). It is the negative value of the time related derivative of the logarithmic value of the *survival function* R (t) at the measured point in time, t_i

$$\lambda(t) = -\left[\frac{d \ln R(t)}{dt}\right]_{t=t_i}$$

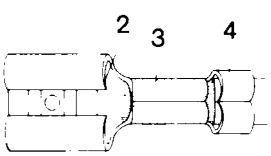
The failure rate is constant within the range of random failures (→ Bathtub curve) and in practice, is estimated by the expression:

$$\lambda \approx \frac{n}{Nt}\left[\frac{1}{h}\right]$$

in which
n = observed failures
N = extent of random check
t = testing time (or number of operations etc.). → Weibull.

Faston Connection (Faston, is a protected trademark of the AMP company): Solderless and non-threaded plug-type connector, as shown in fig. 76.
The female receptacle A, which has an embossed locking facility, is pushed onto the flat pin B, until the embossed contours lock (increased pull-off resistance). The sprung sides 2, ensure reliable, positive contact. The connection wire and the insulation are crimped tight at 3 and 4.

A) Receptacle for tabs



B) Flat pins (tabs)

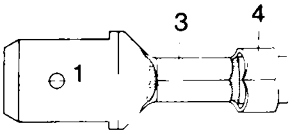


Fig. 76: Faston connectors

Fault Rate: Since very extensive tests are necessary to determine the *failure rate* (for definition see DIN 40041), in order to arrive at statistically supported results, and moreover, since the failure rate is not constant; (being dependent among other factors, e.g. on the life expectancy); the use of the term "fault rate" is recommended as a measure for quality comparisons.
For defined switching conditions, the fault rate is the mean number of faulty switching actions per 1000 switching operations.
The fault rate permits a comparative assessment of different contact systems, (contact material, friction). → Reliability.

Fault Voltage Circuit Breaker (Fault Voltage protection switch): A trip device or relay which trips out when a certain fault voltage occurs [29]. These devices offer protection against the hazard of electric shock; but give fire protection only under certain conditions. → Leakage current circuit breaker.

Ferromagnetism: The property of materials (e.g. Fe, Ni, Co, and their alloys), to become magnetized through the influence of a permanent magnet or a magnetic field. In the absence of outside influences these would normally be unmagnetized. Ferromagnetic materials have a high permeability which is dependent on the degree of magnetization. → Magnetism.

FET (Field Effect Transistor): In FETs, in contrast to bipolar transistors, the current is carried only by one charge carrier type (unipolar transistor). The resistance of the 'n' or 'p' conducting channels (and hence the load current) is controlled by an electric field and not, as with bipolar transistors, by a control current. Distinction is made between junction gate (PN-FET) and insulated gate FETs (IG-FET, MOS-FET).

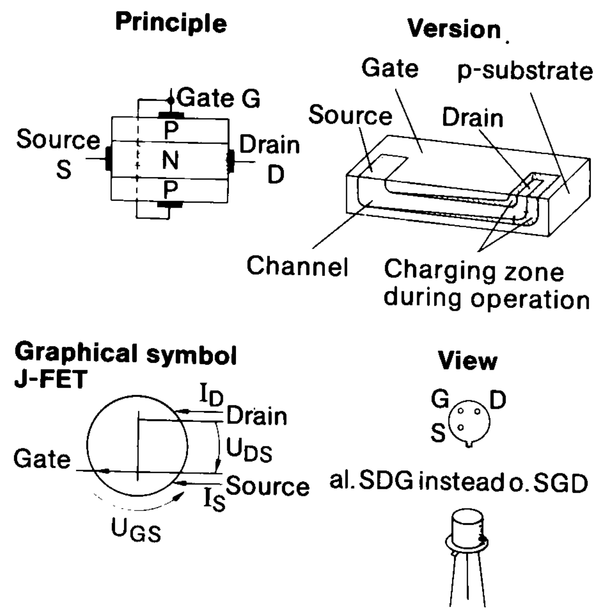


Fig. 77: PN-FET (J-FET) with n-channel

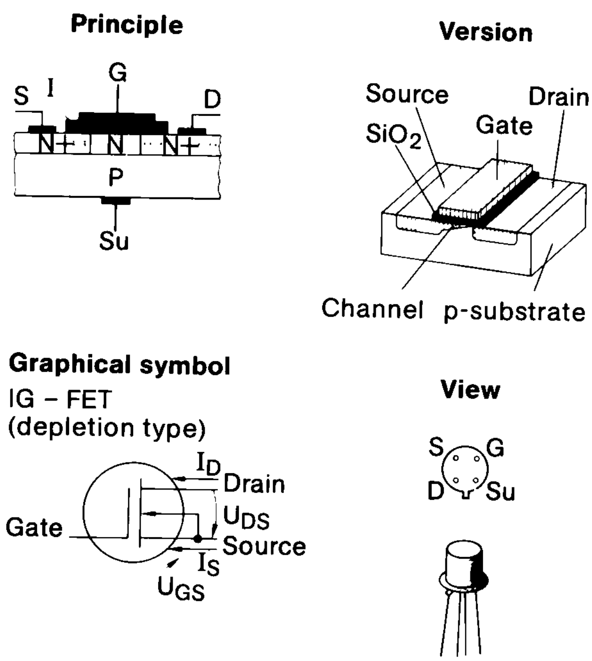


Fig. 78: IG-FET with n-channel

FI Circuit Breaker: → Leakage Current Circuit Breaker.

Filament Winding: In thermo-electric relays, this is usually wound on a body of insulating material (asbestos, mica) and influences a contact-making bimetal strip.

Filtering: A damping of the ripple of rectified alternating voltage or to prevent oscillations. A measure which is often necessary in order to operate sensitive d.c. relays efficiently with rectified a.c. supply. Filtering with an electrolytic capacitor and resistor is often sufficient. Inductors and low-loss capacitors are suitable for filtering higher frequencies. A ripple of 5% will have minimal influence on the pull-in value of a relay.

Fine Migration: This occurs with voltages between the boiling voltage and the arc threshold voltage of the contact material. In this process, material migrates in short plasma-free arcs from anode to cathode, where peaks and heads form, leaving appropriate craters on the anode. These rises and pits on the contacts can, under certain circumstances, so firmly latch on to each other that the contacts can no longer separate. Where voltages and currents are above the arc limit curve, material migration known as *coarse migration*, from cathode to anode, will occur [30, 31].

First Cycle Effect: occurs in time-delay relays or time lag relays which have a RC timing network, when, after the end of a switching cycle, the capacitor does not fully discharge or does not discharge to a defined level. When a first cycle effect occurs, the actual delay time varies from that intended, depending on the interval since the last switching cycle. This undesirable effect can be avoided by rapid pre-charging of the timing capacitor to a defined voltage level, e.g. the threshold voltage of a diode, to be followed by the actual charging process [32]. The required delay time can thus be precisely reproduced. The proposed switching was first applied in the TR relay. → Relay Table (fig. 378).

Flash-Over Voltage: Ignition voltage of a clearance → Breakdown voltage.

Flat Relay 48: exists in the telephone network of the Deutsche Bundespost (DBP = German Federal Postal Services), with many contact types; also as remanent relays, pole changing relays, two-step and latching relays.
Since it can accommodate three separate windings, it is universally applicable. Double contacts of fine silver (KW 50) are predominantly used. For higher demands, Pt-W 90/5 (KW 14), Pd-Cu 85/15 (KW 32) or W (KW 40) are suggested, and for smaller loads, Au-Ni 95/5 (KW 21) or Pd-Ag 30/70 (KW 31).
Through a skillfully arranged slideway (trip link made from Hostadur®), several characteristics have been considerably improved. Including: mechanical life, from 2×10^7 to 10^8 switching cycles, and the contact bounce reduced from 35 to 5 ms [33, 34].

Further Characteristics:

Contact arrangement:	up to 3 × 5 contact springs
Contact load:	1 A, 100 V–, 30 W
Contact force:	approx. 20 cN
Contact gap:	approx. 0.5 mm
Max. switching frequency:	40 Hz
Electrical life:	2×10^7
Coil winding area:	3.1 cm^2
Coil winding volume:	15.2 cm^3
Coil mass:	approx. 120 g
Dimensions:	10.9 × 2.63 × 3.33 to 3.81 cm
Volume:	95–109 cm^3
Total weight:	approx. 180 g

The characteristics show that the flat relay 48 is grossly overdimensioned. With today's relay technology, 90% of the coil wire, structural volume and weight could be saved, and more quality features added. Noise and contact bounce times could easily be reduced by 90%, switching times (selecting action) enormously reduced and over 99% of power consumed could be saved. (→ Reliability → Economic aspects, → Contacting, → Polarized relays, → Efficiency).

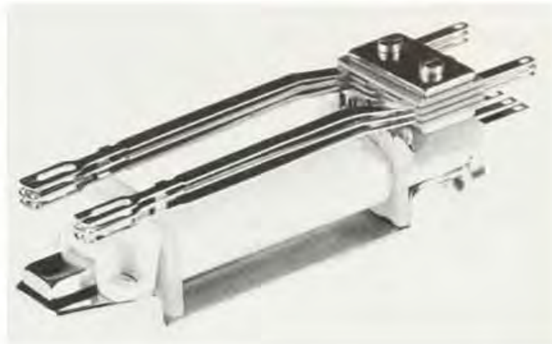


Fig. 79: Flat relay type 48
(The German Federal Postal Services have more than 60 million pieces in service. There are more than 10 companies producing it.)

All official bodies and companies authoritatively involved with the flat relay 48 have not only been successful in improving it, but they have also developed modern techniques which appear to be very promising.
Finally, it should not be forgotten that the very reliable and well proven flat relay 48 once received universal acclaim for its technical achievement and progessive design.

Flip-flop Circuit: A trigger circuit with two stable switching states (bistable → Multivibrator). This means that the output retains its operated condition even after cessation of the input pulse (storage behaviour). It is easily constructed using a bistable (latching) polarized relay.

Forced Opening (lift-off system): ensures that, with an opening contact element (NC contact) of a snap-action switch, on breakdown of normal functions, (e.g. breakage of flexible members, or welding of contacts or contact pieces), the circuit to be interrupted by the NC contact will be opened safely.
It is allowed that with the forced opening, the contact opening routes may differ from those of normal function.

Since the operating force in a snap-action switch can be transmitted to the NC contacts only in an interlocked action, the forced opening can take place only with normally closed (NC) contacts.
It is clearly evident that, by the definition of forced opening according to VDE 0660 and VDE 0113, in general flexible contact operating elements are prohibited. For snap-action switches, only rigid bridge contacts may be used. Fig. 80 illustrates a modern snap-action switch which fulfils these requirements. The snap-action switch is held by the sprung latches Z of the holding adaptor B (→ Snap-in system). The bridge contacts are "forcibly opened" by the switch-off lever H, via the operating plunger A.

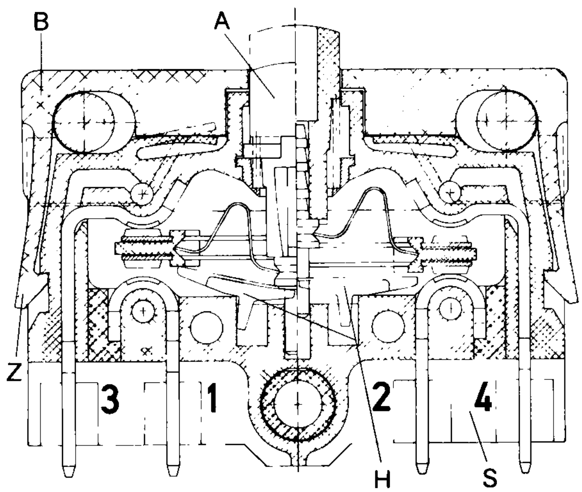


Fig. 80: In development. The SDS type S150 microswitch with forced opening. The inoperated condition is shown on the right. The operated condition is shown on the left.

Forced Operation Contacts: Forced contact operation of safety relays implies that contact pairs are mechanically linked so that the associated normally open and normally closed contacts cannot both be simultaneously closed. It must also be ensured, over the entire operational life even during fault conditions, that the contact gaps are at least 0.5 mm.

Forming: With new unused contacts and particularly with a higher break load, there is often a larger arc than is seen in contacts which have already performed some 100 switching operations. This phenomenon is referred to as forming. It is governed by the contact material. With silver, for example, there will initially be more intense forming and thus a more intensive arc than with tungsten.

Four-Terminal Network: An electrical circuit in which linear and non-linear interrelationships exist between input and output variables. These can be determined by measurement or by calculation. The relay is a non-linear four-terminal network.

Frequency Band (or frequency range): embraces the frequencies of the electromagnetic spectrum which largely correspond to similar transmission behaviour, and technical usefulness (table 21).

Frequency Relay: → Resonance relay.

Fritting: A collective term for all processes which destroy a film contamination layer in a closed, resting contact. Several layer stresses act as causes of destruction:
a) Electrical load: Destruction through voltage breakdown; disintegration of the surface through ionic conduction.
b) Thermal stress: Destruction of insulating layers through disintegration, decomposition or melting.
c) Mechanical stress: Tearing of layers through softening or melting of the contact material.
The following classifications relate to 'A' and 'B' fritting:

'A' Fritting
Occurs if, as a result of a voltage breakdown through an insulating contamination layer covering the contact point, a continuous, largely metallic conducting path through the locally destroyed dielectric is created.
This fritting process, i.e. this voltage breakdown, takes place in less than 10^{-6} sec., and can in some circum-

Frequency Band

$\lambda = \frac{300\,000}{f}$; $f = \frac{300\,000}{\lambda}$ in km, Hz or m, kHz

$\lambda = \frac{300}{f}$; $f = \frac{300}{\lambda}$ in m, MHz or mm, GHz

Wavelength λ	Waves	Range	International description	Frequency f
10^8 m = 100 000 km				3 Hz = $3 \cdot 10^0$ Hz
10^7 m = 10 000 km				30 Hz = $3 \cdot 10^1$ Hz
	16⅔ Hz to 300 Hz technical alternating current		16 Hz to 16 kHz low frequency, NF	
10^6 m = 1 000 km				300 Hz = $3 \cdot 10^2$ Hz
10^5 m = 100 km			International description:	3 kHz = $3 \cdot 10^3$ Hz
	Very long waves		VLF (very low frequency)	
10^4 m = 10 km				30 kHz = $3 \cdot 10^4$ Hz
	Long waves (LW) (kilometer waves)	16 kHz to 300 MHz	LF (low frequency)	
10^3 m = 1 km				300 kHz = $3 \cdot 10^5$ Hz
	Medium waves (MW) (hectometer waves)		MF (medium frequency)	
10^2 m = 100 m				3 MHz = $3 \cdot 10^6$ Hz
	Short waves (SW) (decameter waves)	high frequency HF	HF (high frequency)	
10^1 m = 10 m				30 MHz = $3 \cdot 10^7$ Hz
	Ultrashort waves (USW) (meter waves)		VHF (very high frequency)	
10^0 m = 1 m				300 MHz = $3 \cdot 10^8$ Hz
	Decimeter waves	300 MHz to 300 GHz highest frequency HHF	UHF (ultra high frequency)	
10^{-1} m = 1 dm				3 GHz = $3 \cdot 10^9$ Hz
	Centimeter waves		SHF (super high frequency)	
10^{-2} m = 1 cm				30 GHz = $3 \cdot 10^{10}$ Hz
	Millimeter waves		EHF (extreme high frequency)	
10^{-3} m = 1 mm				300 GHz = $3 \cdot 10^{11}$ Hz
10^{-4} m = 100 µm				3 THz = $3 \cdot 10^{12}$ Hz
	Heat rays			
10^{-5} m = 10 µm				30 THz = $3 \cdot 10^{13}$ Hz
10^{-6} m = 1 µm	Infrared			300 THz = $3 \cdot 10^{14}$ Hz
	Light waves (visible light)			
10^{-7} m = 100 nm	Ultraviolet			3 PHz = $3 \cdot 10^{15}$ Hz
10^{-8} m = 10 nm				30 PHz = $3 \cdot 10^{16}$ Hz
10^{-9} m = 1 nm				300 PHz = $3 \cdot 10^{17}$ Hz
	X-rays			
10^{-10} m = 100 pm				3 EHz = $3 \cdot 10^{18}$ Hz
10^{-11} m = 10 pm				30 EHz = $3 \cdot 10^{19}$ Hz
10^{-12} m = 1 pm	Gamma rays	↓		300 EHz = $3 \cdot 10^{20}$ Hz
	Cosmic rays			

Table 21: Frequency ranges of the electromagnetic spectrum [36]

stances (depending on the shunt capacitance of the contact points or of the link lines), be repeated several times until a durable connection is established.
An 'A' fritting is not automatically followed by a 'B' fritting.

'B' Fritting
Occurs if, after an 'A' fritting, the locally restricted current path destroys the limiting contamination layers due to current flow, and the current-carrying contact area increases.
The destruction of the insulating contamination layer by 'B' Fritting is not directly due to a mechanical cause, but principally to a change in the state of the layers. The irreversible disintegration of the contamination layers depends on the temperature of the contact point and on the effect of the duration of the current flow. The stable end value of the contact resistance cannot, in certain circumstances, be anticipated to establish itself until after several minutes, or even hours.
If on measuring the volume resistance on gold or hard silver contacts of relays or switchgear, this phenomenon is found to be only slight, it is because the sulphide layers of silver contacts are of low durability and in auriferous contacts only insignificant contamination layers may be anticipated. With the intended presence of fusion or wear inhibiting non-precious metal oxides (e.g. cadmium oxide), measuring must be carried out, with the volume resistance determination coupled to heat measuring and with current loads which correspond approximately to the permitted rated current.
Two examples (figs. 81 and 82), illustrate possible misinterpretations if these observations are not taken into account [24].

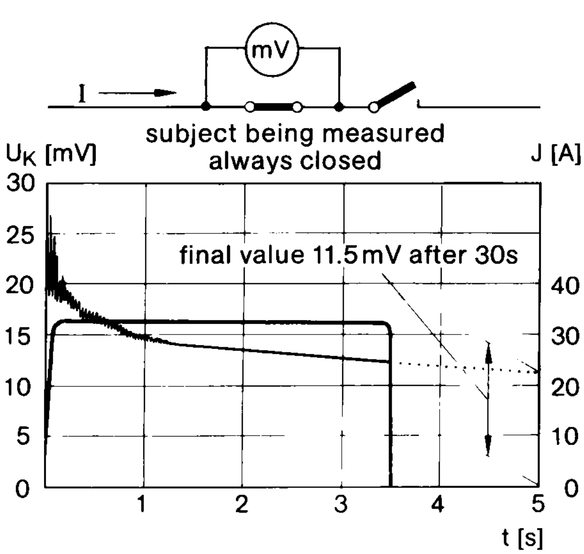


Fig. 81: Voltage drop (U_K) against time of AgCdO 90/10 double break contacts of a 30 A contactor

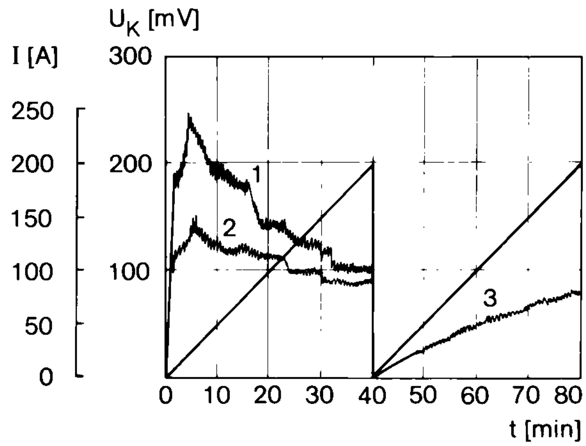


Fig. 82: Voltage drop (U_K) against time of AgCdO 90/10 double break contacts of a 200 A contactor
1. The test device is switched without load. Contact pressure 4.5 N. Load continuously monitored up to 200 A
2. Test device used for curve 1 was switched off and then the test performed with contact force of 6 N
3. After 40 minutes, the sample at 2. had its load reduced to 0 A. Immediately after cooling down it was again increased to 200 A. As can be seen it then acts almost as a resistance

Fritting Voltage: The voltage which is necessary for the *fritting* of a contact. It increases in accordance with [37], with increasing film resistance from 0.2 V at 6 nm to 4 V at 148 nm film thickness.

FU Voltage Circuit Breaker: → Fault Voltage Circuit Breaker.

Galvanometer Relay: Polarized moving coil relay, with the moving coil arranged in the center between the two pole shoes of the permanent magnet. The air gaps

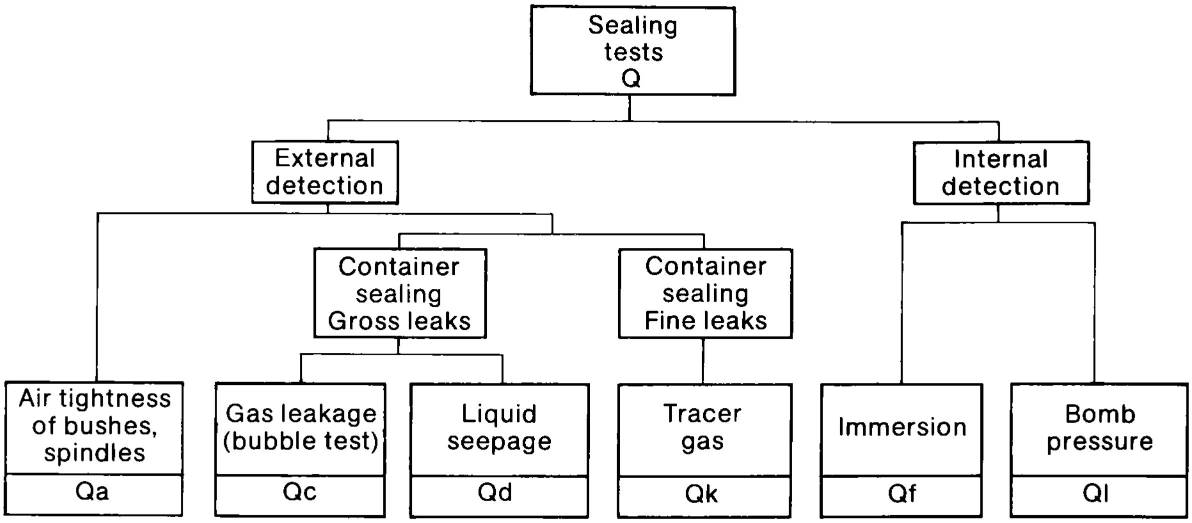


Fig. 83: Possible ways of testing sealing to IEC 68

can be kept very small. It is extremely sensitive, but it requires relatively long pull-in and drop-out times.

Gas-tightness: must be checked in accordance with IEC 68, part 2-17 (DIN 40046, sheet 15). Depending on the type and size of the leaks and stresses, various test methods are prescribed, as illustrated in fig. 83.

Gate: Switching or logic element of a circuit. A gate with "AND" function produces an output quantity only for all the provided input quantities, whereas an "OR" gate will produce an output quantity for one or several inputs provided.

Getter: Materials for binding undesirable gas molecules. The concept became known initially through vacuum technology, where getter materials contributed towards further pressure reduction by absorbing residual gas molecules.
In relay technology, getters are used for the selective adsorption of harmful substances, (mainly of gas emissions from the plastics used), which, through polymerization, form highly resistive contamination layers on the contact areas and lessen the reliability of the contacts. In order to maintain the dielectric strength in the contact chamber, a getter method must be applied which alters neither the protective gas nor the total gas pressure in the sealed relay. → Arc.
Formerly, activated carbon was recommended as a getter for relays [41]. Such getters whose pore diameters would mostly be <2 nm, adsorb small-molecular gases, (i.e. including the protective gas in the relay itself!). However, if the protective gas is in a hermetically sealed housing, the adsorption of the protective gas will give rise to a reduced pressure which, as shown in fig. 25, will reduce the dielectric strength of the contacts to such an extent as to render the relay useless. In an inadequately sealed encapsulation, such a getter will be saturated after only a few hours, and become ineffective before the relay is ever put into operation. Furthermore, due to there being a requirement of embedding the powdered getter material in plastic, the getter activity is considerably reduced.

Since getter materials for relays — (by contrast to those used in vacuum technology) — do not absorb harmful substances, but adsorb them, (physisorption) and the molecules of the harmful substances are very much larger than those of the protective gas, only such getters are suitable the pores of which are so large that large-molecular harmful substances are adsorbed selectively.

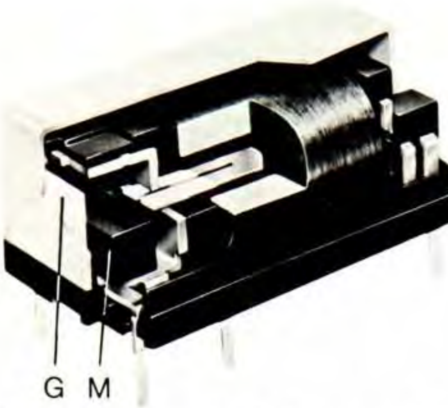


Fig. 84: DR-relay with ferrite magnet M activated to a getter and additional getter G

Fig. 85: Surface of a getter activated ferrite magnet (REM print × 2600 enlargement)

An effective and practical solution has been the activation of the ferrite magnet (fig. 84) which is already present in modern miniature relays, to act as a getter. This was effected by heating the relay to 130 °C in a vacuum of approximately 10^{-8} bar [13]. The pores thus released (fig. 85), with diameters >100 nm, are very well suited to binding the harmful substances which occur in the contact chamber over a long period of time (aromatic polymers) [43, 44].

This has enabled the quality of the relays to be improved in the following manner:

1. Comparison with ungettered relays showed a contact resistance reduced on average by about 30%, with a standard deviation lower by about 50%.
2. Whereas with ungettered relays, the first faulty switching operation occurred at 0.56×10^6 switching cycles, (load: 150 mV, 15 mA, 100 Hz at 20 °C), the life figure was 22.77×10^6, i. e. approximately 40 times longer with gettered relays.
3. The contact reliability, evidencing one faulty switching operation over 7.04×10^9 switching cycles, was more than 100 times higher, against 31 faulty switching operations over 1.5×10^9 switching cycles.
4. The getter effect can be seen in the photographs in fig. 86, of various relay contacts before and after 52×10^6 switching cycles with a load of 150 mV, 15 mA, 100 Hz at 20 °C.

Fig. 86a: R-relay reed contacts (above) and fixed contact (below) in new state

Fig. 86b: Ungettered R-relay reed contacts and fixed contacts after 52×10^6 switching operations at 150 mV, 15 mA load

Fig. 86c: Gettered R-relay reed contacts and fixed contacts after 52×10^6 switching operations at 150 mV, 15 mA load

The most impressive indicator for the positive effect of this getter method, following its introduction, was the drastic drop in the failure rate (fig. 87). Taking into consideration the high costs on average, caused by failure, an enormous financial loss to the national economy could be avoided.

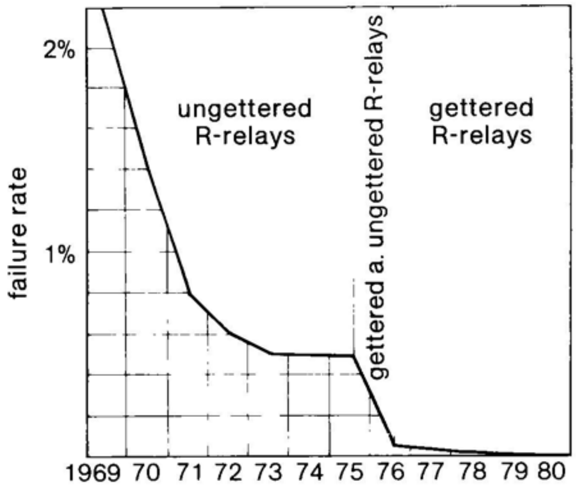


Fig. 87: Quality histogram of ungettered and gettered R-relays during a period of 7 years (or 5 years)

Additional getters, such as alumina (fig. 88; special Al_2O_3 complexes) which, having pores of 4 to 20 nm, can significantly expand the adsorption range of the ferrite magnet. These getters can be universally mounted within the contact chamber, and can be expected to provide further improvements.

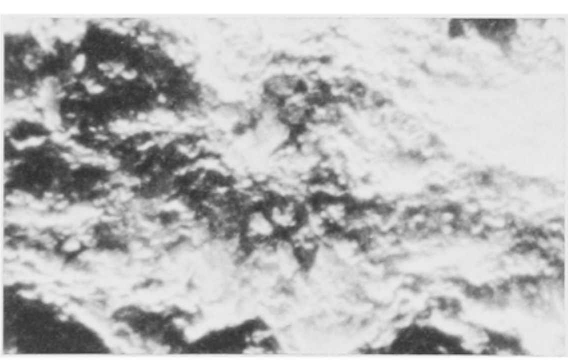
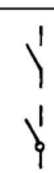
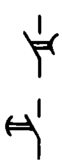
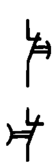


Fig. 88: Surface of an additional alumina getter (REM-print × 2600 enlargement)

Glow Discharge: also referred to as glow light, is a glowing gas discharge between the contacts. It has a relatively high arc drop and a low current density (approx. 0.1 A/mm^2). The current strength lies between 10^{-5} and approximately 0.5 A. Above this, arcing commences. The threshold can also be determined acoustically, because glow discharge is silent, whereas arc discharge generates a noise. The glow discharge is also visually recognizable from a low brightness and from the colour. The glow discharge shows the spectrum of the gas in which it burns, whereas the arc shows that of the contact materials. The minimum ignition voltage for a glow discharge in air at normal pressure is between 200 and 350 V [46], depending on contact material and the contact gap. → Discharge.

Graphic Symbols: are an important prerequisite for quick evaluation of electrical switchgear or of an electrical unit. All elements of an electrical circuit and the function of any electrical switchgear can be clearly represented by standard symbols, i.e. graphic symbols. Some commonly used graphic symbols, standardised in accordance with DIN 40708 to 40722, (largely conforming to IEC recommendation 117-0 to 117-16) have, in part, been reproduced below, (where graphic symbols have been standardized that deviate from each other, preference has been given to the IEC recommendation):

	Make contact
	Break contact
	Change-over contact (break before make)

	Two-way contact with centre-off position
	Change-over contact (bridging)
	Contact with two makes
	Contact with two breaks
	Passing make contact closing momentarily during operation
	Passing make contact closing momentarily during release
	Passing make contact closing momentarily during operation and release
	Make contact (of a multiple contact assembly) which is early to operate relative to the other contacts of the assembly
	Make contact (of a multiple contact assembly) which is late to operate relative to the other contacts of the assembly
	Break contact (of a multiple contact assembly) which is late to operate relative to the other contacts of the assembly
	Break contact (of a multiple contact assembly) which is early to operate relative to the other contacts of the assembly
	Make contact delayed when operating
	Break contact delayed when operating
	Make contact delayed when operating and releasing

	Make contact with spring return
	Make contact without spring return (stay put)
	Break contact with spring return
	Two-way contact with centre-off position with spring return from the left-hand position but not from the right-hand one (stay put)

Table 22a: Graphical symbols for contacts

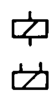
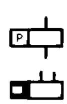
	Relay coil
	Relay coil with one winding
	Relay coil with two windings, same polarity
	Relay coil with two windings, opposite polarity
	Relay coil with two windings, opposite polarity
	Relay coil, wattmetric
	Actuating device for a thermal relay
	Relay coil of a polarized relay
	Relay coil of an a.c. relay

Table 22b: Graphical symbols for relay or contactor coils

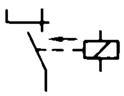
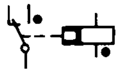
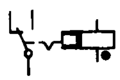
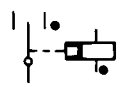
	Relay with one coil, with mechanical connection between magnetic system and contact, with one make before break contact, with mechanical return to the resting position, i. e. to the position of unenergized coil
	Polarized relay, self restoring, operating for only one direction of current in the winding
	Polarized relay with two stable positions, non self restoring
	Polarized relay with neutral position, self restoring, operating for either direction of current in the winding

Table 22c: Graphical symbols for complete relays (characteristic examples according to IEC 117-3, 1977)

H_2S Atmosphere: A hydrogen sulphide enriched atmosphere has a severely damaging influence, mainly on contacts containing silver. Due to the highly resistive silver sulphide which will readily form, contacts exposed to air will rapidly become useless for many applications (fig. 54) [47].

Half-Wave Rectifier Circuit: (Single-pulse centre point switching) → Rectifier Circuit.

Hall Effect: Where a conductor or semiconductor, with a constant current flowing through it in a longitudinal direction, is brought into a magnetic field (<10 Tesla), a measurable **Hall voltage** will develop in its transverse direction, due to the Lorentz force (particularly large with semiconductors such as indium arsenide or indium antimonide), which is directly proportional to the normal component of the magnetic field strength. The proportionality factor is called the **Hall Constant**. It is material dependent, and is a measure for the ion density in the conductor. Such **Hall probes** (semiconductor probes) are now the most commonly used measuring devices for determining magnetic field strength and flow density. Hall probes are frequently used in conjunction with small permanent magnets as contactless signal transmitters for control functions.

Hall Generator: Semiconductor component, in which the *Hall effect* is used to generate voltage.

Harmonic Oscillations: occur in every non-sinusoidal oscillation and must be taken into account, especially during vibration tests. Harmonic oscillations and resonances can increase the acceleration value to a multiple so that the cause of a contact opening during a vibration test may in some cases be due to the harmonic oscillations of the oscillation generator. → White noise.

Heating Power: The power consumption of *thermo-electric relays.*

Heavy Duty Switch: must be able — in accordance with VDE 0660 — to switch approximately twice the nominal current on and off.

HF Relays: For switching higher frequencies. Normal *switching relays* are optimized by having higher isolation, ensuring they have low *contact capacitance* and by adapting the resistance to HF application. The criteria for HF application are: large *isolation loss,* adapted *characteristic impedance*, small *reflection factor.* The types DR, DX, and RF (fig. 283, 323 and 303) are very often used as HF relays.

High Level (h-level): Condition in a *logic* circuit which is represented by a higher voltage. For example, in binary 5 Volt logic circuits, h identifies the value 1 for voltages between 2 to 5 V. The *low level* (l-level) corresponds to the value 0 with voltages from 0 to 0.8 V. (→ Negative logic).

High-Speed Relays: have very short pull-in and drop-out times. This is achieved either through high energizing power or good *efficiency.* Short switch-on times result from low-inductance windings, over-excitation, low mass actuating elements and short operating distances. → Telegraph relay, → Reed relay.

Histogram: Clear graphic representation of the distribution of measured values or characteristics, in which the widths of the contiguous vertical bars are proportional to the class widths of the variable, and the heights are proportional to the class frequencies. An example of the bounce time distribution of the S relay, (→ Relay Table) is shown in fig. 89.

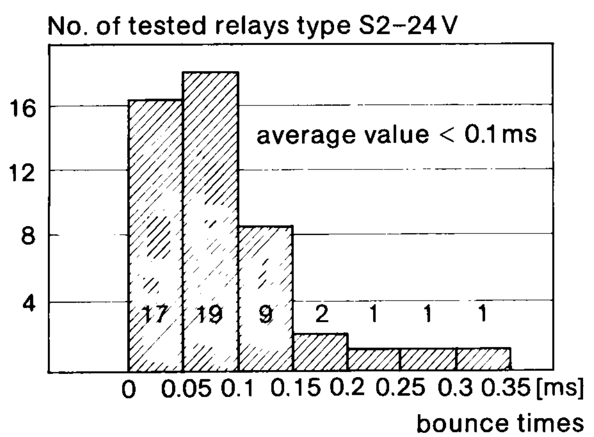


Fig. 89: Histogram of bounce times

Holding Current: The minimum coil current which will hold the armature in the operated condition.

Holding Winding: The second winding, the function of which is to hold the relay armature, which was operated (pulled in) by the energizing winding, and thereby to save energy.

Hot Wire Relay: → Thermo-electric relay.

Humidity, Relative: The ratio of the actual water vapour pressure to the pressure which, given the same temperature, would exist with complete saturation of the air with water. Due to its effect on insulation strength, dielectric constant and loss factor as well as corrosion, in particular in combination with higher temperatures, it can cause damage to equipment, resulting in failure. It represents an important factor in determining the permissible environmental conditions of electrical equipment.

Humming: A vibration of the armature which can occur in relays energized with a.c., if the short-circuit ring or the pole faces are incorrectly dimensioned or the operating power is too low.

Hybrid Relay: A combination of electro-mechanical and electronic components which permit a switching function such that control circuit and load circuit are electrically isolated from each other. Distinction is made between:

a) electro-mechanical hybrid relay, with the components combined in such a way that the output (load circuit) is represented by an electro-mechanical relay; and
b) a semiconductor hybrid relay. In this combination the output is taken over by a semiconductor component.

The expectations placed in the conventional hybrid relay have not been fulfilled. The manufacturing costs, as well as the failure rate have been relatively high.
By contrast, relays of the third generation, a symbiosis of modern relays of the second generation with microelectronics, (fig. 17 and section 3), present technically and economically, interesting solutions.

Hysteresis, Hysteresis Loop: This describes the lag of an effect with respect to the associated state of the changing force which causes it. The magnetic hysteresis (curve A-B-C-D-E-F-A, fig. 90), describes the relationship between the magnetic field strength and the magnetic induction (or magnetization) caused by it, in a ferromagnetic material for a closed magnetic reversal cycle.

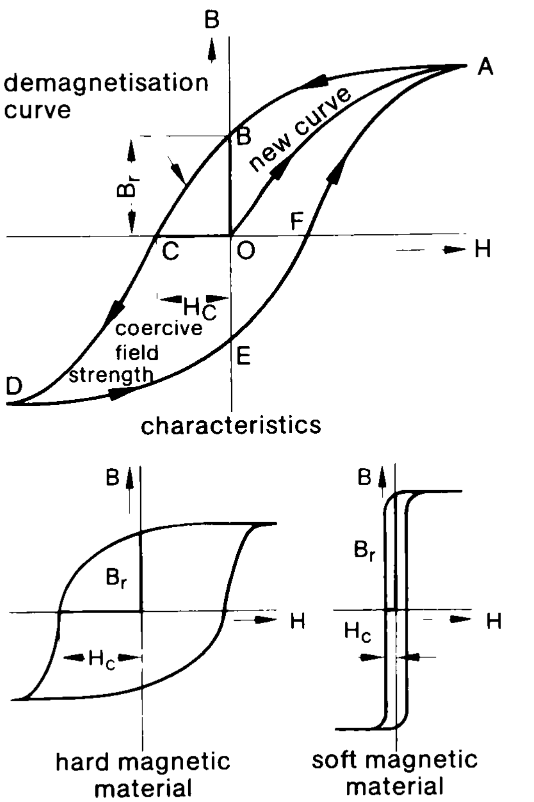


Fig. 90: Schematic diagram of hysteresis curves

The terms used:
New curve ("virgin curve"; 0–A): rise of induction, B, with increasing external field strength, H, in a demagnetized ferromagnetic material.
B_r: The remanent induction (residual magnetism, remanence), i.e. the induction which remains in the ferromagnetic material after the external magnetic field has been switched off.
H_c: The coercive field strength, i.e. the size of an external opposing field which causes the induction in the ferromagnetic material to disperse.
High coercive field strength is a characteristic of hard magnetic material (permanent magnet); soft magnetic materials show narrow hysteresis curves with low coercive field strength. → Magnetic materials.

IC (Integrated Circuit): Whereas in printed-circuit-board technology, only the printed conductors are integrated; resistances and capacitances can still be incorporated in thick-film or thin-film circuits. In epitaxial or planar technology, components such as inductance or resistance are also simulated by tansistors on a chip.

IC-Relays: Designation for relays of a new generation (see also part 3). Highly efficient polarized relays are combined with a special *IC* which — depending on the choice of input — provide the possibility to operate relays as either monostable or bistable, or also as toggle relays. In the event of a power failure, the switching position obtaining at the time of failure can be selected to be maintained, or the relay can be reset, when the power is restored.
A number of logic operations are quickly realized with IC relays:

1. Binary counter
2. Sequential setting and sequential resetting
3. Sequential setting and simultaneous resetting
4. Shift register
5. Step-by-step switching function

In addition they have the following characteristics:

1. Operation with pulses of only 100 µs
2. Input filters for the suppression of noise voltage peaks and contact bounce pulses
3. Extremely low power requirement (µA), by limiting the coil current to the pull-in time. (Battery operation!).

The LSI compatible IC-relays (*negative logic* operation), can easily be combined within electronic control systems such as PLA or PROM, or can be linked to the bus line of control systems. Since IC-relays combine within themselves the advantages of integrated solid-state electronics at the input, and the advantages of modern relays at the output (very low *contact resistance,* high *insulation resistance,* high *dielectric strength,* high *switching capacities* and short-term overload withstandability); they represent an ideal miniature *interface* between automatic controls and various periphals.

Ignition Voltage: → Breakdown Voltage.

Impregnated Coil: also referred to as saturated coil, is generally impregnated with *insulating varnish* under vacuum in order to protect the coil from humidity, vibration and oxidization.

Impulse: A short current or voltage surge. It can occur periodically or non-periodically, have differing energy contents, duration or form (e.g. rectangular, sinusoidal or exponential).

Impulse Relay: Special time-delay relay with a fixed pulse time (during which the switching element is in the operated position) and pause period (during which the switching element is in its non-operated position).

Inductance: The coefficient of self-inductance which states the relationship between a time-related current change in a coil and the reverse voltage, U, developing at its ends: $U = -L di/dt$ (Henry = Vs/A). → 2.2 Units of Measurement, → 2.3 Formulae of Electro Technology.

Induction:

1. Electrical induction: In accordance with the law of induction, a voltage U, is induced in a closed conductor loop located within a magnetic field. This voltage is proportional to the time-related change of the magnetic induced flux Φ which permeates the loop. Hence $U = -d\Phi/dt$.
2. Magnetic Induction: The magnetic flux density; the magnetic flux which passes through an element of area that is vertical to the line of flux. → 2.3 Formulae of Electro Technology, → 2.2 Units of Measurement, → Magnetic force

Initial Capacitance: The capacitance of contacts, plates and conductors at the commencement of the switching action.

Initial Permeability: The permeability μ_a with infinitesimal field strength or induction. For practical reasons, the usually stated value is not the limit value μ_a, but the value with a very low field strength. → Permeability, → Hysteresis.

Inrush Current (make current): The largest current occurs at the instant of switch-on. Particular care must be taken when capacitors, heater windings or lamps are in the circuit, since the inrush current can be significantly higher than the operating current. Inrush current can have more than 10 times the value of the switch-off current. In accordance with VDE 0435/IEC 255, the relay contact must be able to switch and conduct the stated current for 200 ms with *contact class* III (→ Power Relays), (current <100 A) and ≤ 25 ms with contact classes I, II (current <0.1 or <1.0 A). (→ Relay Table). The minimum number of permissible switching cycles is to be stated by the manufacturer, but must be greater than 10.

Insertion Loss: The frequency dependent power loss (stated in dB), which occurs between a generator and a receiver on insertion of a linear four-terminal network (e.g. a relay contact).

Insulating Resistance: The smallest resistance which can be determined on components insulated from each other, using an ohmmeter or a galvanometer at 100 V d.c. (→ Relay Table). If the contacts are significantly better insulated from the coil or from the earth, this is appropriately noted in the relay table.

Insulating Varnish: Varnish for insulating the coil wire. It must be heat resistant, abrasion-proof, expandable, non-porous and non-ageing. Polyurethane based insulating varnish enables copper wire to be soldered without the need for prior stripping.

Insulator Current, Leakage Current: The current which flows through an *insulating resistance.* It is dependent on voltage, temperature and time.

Interface: Mostly a standardized point of separation which ensures the mutual compatibility of two or more components of a system; usually of electronic devices or circuits.

Interface Module: A functional unit which, for example, makes the connection between electronic, (→ Sequencer), and power devices (e.g. drive motors). → Mini Contactor.

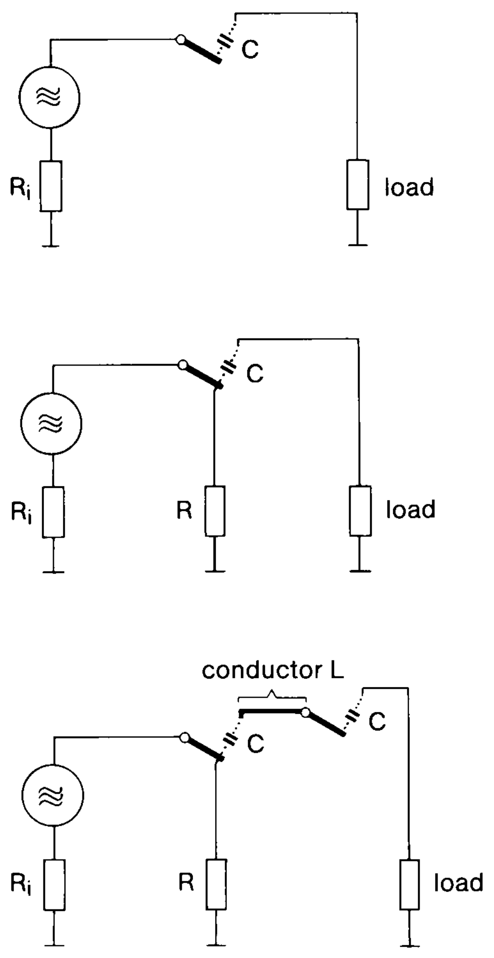


Fig. 91: HF circuits having different isolation loss

Interval: The time from the end of one pulse or event to the beginning of the next.

Ionization: The conversion of atoms or molecules into ions. It is caused, for example, through *arcing;* it increases the conductance of the air and reduces its insulating properties.

Iron Loss: occurs on reversal of a magnetic field, for example, within a magnetic circuit of a relay or in a transformer core. With ferromagnetic substances in alternating magnetic fields, iron losses occur mainly due to losses from *hysteresis* during reversal of the magnetic field, and from *eddy current* losses.

Isolation Loss: A measure for the HF switching behaviour of a contact (see Fig. 91).

With increasing frequency, a steadily increasing proportion of the generated energy passes through the coupling capacitor C, between the open contacts, to the load (fig. 92, curve 1).

A significant improvement of the isolation loss can be achieved by converting the contact to a change-over contact and coupling the opposite pole via resistor R, (R approx. R_i), to earth (fig. 92, curve 2).

A further possibility for improvement is by connecting two contacts in series. The resulting capacitance will then be halved, and the effective attenuation increases accordingly by 6 dB. The insertion of a conductor L with an electrical length, $l = 0.1 \ldots 0.4\,\lambda$ will provide a further improvement [102] (fig. 92, curve 3).

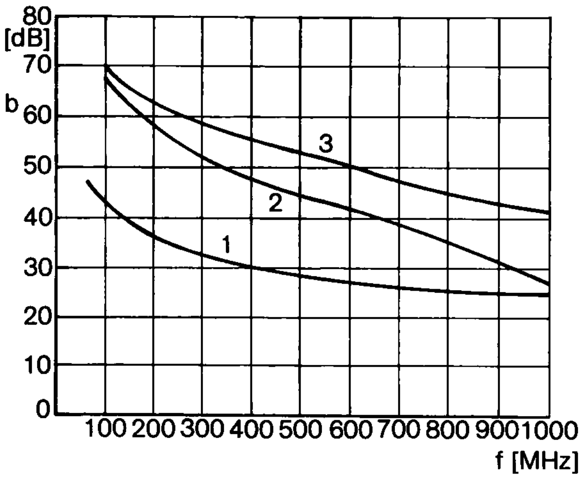


Fig. 92: Frequency dependent isolation loss b for the circuits shown in fig. 152 [102]

Key Relays: are used for the interruption or change-over of a telegraph transmitter or similar devices. High operational demands are made of key relays, with regard to switching times and contact capacity.

Knife Contact: Plug type contact with rectangular cross section and conically pointed ends.

Knife-Edge Relay: The term used for a relay whose armature is supported on a knife-edge. The flux conduction of knife-edge relays, as shown in fig. 5, is unfavourable.

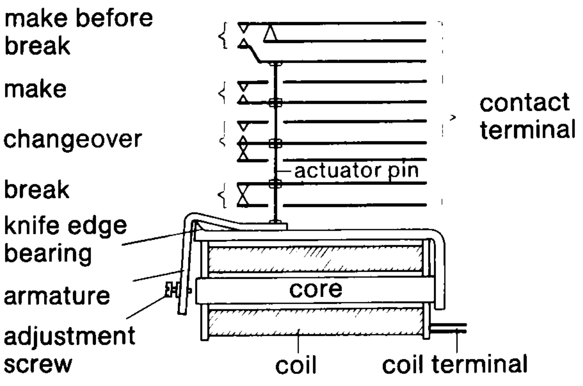


Fig. 93: Construction of a "knife edge" armature relay (telecommunications relay)

LCD: Liquid Crystal Display.

Leakage Current: In semiconductor components, this is a current which flows in the off-state due to surface contamination, adsorbed contaminating substances and similar pollutants.

Leakage Current Circuit Breakers: Offer extensive protection against electric shock hazard, earth faults and damage to electrical plant or equipment through short-circuiting or fault currents. The leakage current circuit breaker contains a current transformer whose ring core encompasses all the live feed lines, i.e. including the neutral.

In normal operation, with fault free equipment, the magnetizing effect of the current flowing through the transformer is cancelled out. For example, if 10 A flow through the main conductor in one direction and through the neutral conductor in the other direction, then this has the effect — as far as the transformer is concerned — as if no current were flowing at all. But if — due to an insulation fault behind the leakage current circuit breaker — an ground leakage current of approx. 0.5 A flows, then 10.5 A will flow from the main conductor through the transformer, and only 10 A will flow back through the neutral conductor. Because of this 0.5 A difference, a magnetic field develops in the iron core, generating a voltage in the transformer secondary winding, thereby triggering the leakage current circuit breaker within 0.2 sec. This example for single phase equipment also applies, analogously, to three phase operation.

In order to cater for insulation faults which develop between the main conductors, a bare grounded conductor is included within the line, behind the leakage current circuit breaker.

The minimum operating current of electromechanical leakage current circuit breakers is 30 mA; with electronic activation it is 5 mA.

LED: Light emitting diode.

Life: The number of switching cycles which a relay should achieve with 95% probability with switched load and operating data as given in the data sheet.
Influences on the life are: switching load (voltage and current), load (inductive, capacitive), voltage (d.c., a.c., half-wave), *contact* and film *resistance,* contact form, *contact material,* bouncing of contacts, opening speed, switching frequency, temperature, *"white noise", contact force, contact overtravel, environmental influences, protective gas,* and *gettering.* Regarding this plurality of influences on the life of a relay, it is not possible to give certain statements for all stresses. Most appropriate are *Weibull diagrams* which show the failure probability of various contact loadings.

Life, Electrical: The number of switching cycles which, with a given contact load and under specified conditions (maximum switching frequency, max. contact resistance, pull-in/drop-out values, insulation resistance etc.), is permissible with a 95% probability of survival. → Weibull diagram.

Life, Mechanical: The number of switching cycles which a relay with no contact load must achieve at ambient temperature at rated power consumption and approximately 50% duty cycle, and maintaining all other guaranteed characteristics and operational functions. Criteria for failure are:

a) Increase of minimum pick-up voltage by more than 20% or reduction of the drop-out voltage by more than 50% of the values specified for new relays.
b) Reduction of the dielectric strength (voltage withstand) by more than 25% against that specified for the new condition.
c) Decrease of the insulation resistance to a value 10% below that specified for a new relay.

The switching frequency must be set so that after every switching cycle, any oscillating process will cease. Where the *relay table* states for any particular relay that it must fulfil the conditions of VDE 0435, paragraph 35 of this specification will be authoritative.

Life Test: → Test Equipment for Life and Quality

Limit Temperature: The influence of the limit temperature (maximum temperature) must not cause any indication of damage, permanent distortion or other changes of the component. The sum of ambient temperature and temperature induced by self-heating must not exceed the limit temperature. For insulating materials, the limit temperature, according to VDE 0435, must be at least 20° above the maximum temperature to which the insulating materials will be subjected during continuous operation.

Line of Force: An imaginary line in a force field for illustrative representation of fields. Distinction is made, for example, between electrical and magnetic lines of force.

Line-up: describes the alignment of the pole faces in rotating magnet drives.

Load Limit Curve: specifies the upper limit for current and voltage which must not be exceeded if the guaranteed properties, (e.g. *switching capacity* or *electrical life*), under specified circuit conditions, (e.g. *electrical time constant* or *cos* φ), are to be ensured. → Section 3.8.

Load Ranges: Five load switching ranges are normally designated for relay contacts. These are more specifically defined under a) to e) below. The load type g) is reserved for contactors. In load range f), the border between a relay and a contactor is floating, i.e. not precisely definable.

a) Dry circuits
b) Low level circuits

		I < 10 mA	I < 100 mA	I < 300 mA	I < 10A	I < 50A	I > 50A
stable arc zone	U > 300 < 1kV						g
	U > 10V < 300V					f	
	U < 10V			d 1)	e		
short arc zone	U < 10V		c				
upper limit melting voltage U_S	U < 300 mV	b					
upper limit softening voltage U_E	U < 100 mV	a					

Table 23: Current and voltage for load ranges a) to g)
1) I = 50 to 400 mA
U = 28 VDC are specified in Engineer's relay handbook, Hayden Book Company Inc., New York, page 92

c) Minimum current circuits (small-load circuits in which "short arcs" will occur)
d) Intermediate level circuits
e) High level circuits (heavy-load circuits in which stable arcs are characteristic)
f) Low power contacts (power current contacts for low switching capacity)
g) Power contacts

In table 23, an attempt has been made to arrange the voltage and current limits in some order. In the case of the current, it is not the thermal limit current, but the contact load during switch-on and switch-off [24].

Logic: A switching system which, as a rule processes binary input signals and outputs binary signals (→ High level, → Low level). The two discrete signal levels correspond to the binary values "1" and "0" or to the logical statements "true" and "false" (→ Negative logic).

Loss Angle δ: Inductive and capacitive loads cause a phase difference between voltage and current. The loss angle is the angle which reactance and impedance form in the vector diagram (fig. 94).

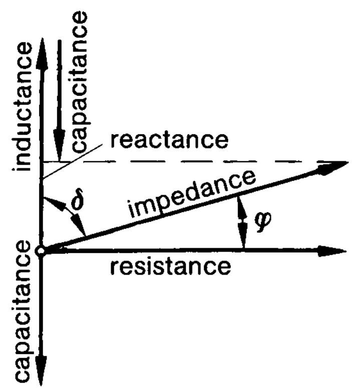


Fig. 94: Vector diagram of a circuit having inductive and capacitive loads

Low level (l-level): is used in logic circuits to represent a binary signal. Generally, the low level 'l' denotes logic 0, and 'h' denotes logic 1 level.

Magnet System: The sum total of components in a magnetic circuit whose flow of flux effects a function. The efficiency of a magnet system depends on the meaningful utilization of the field, for which purpose the pattern of the useful and stray fluxes should be known. In a

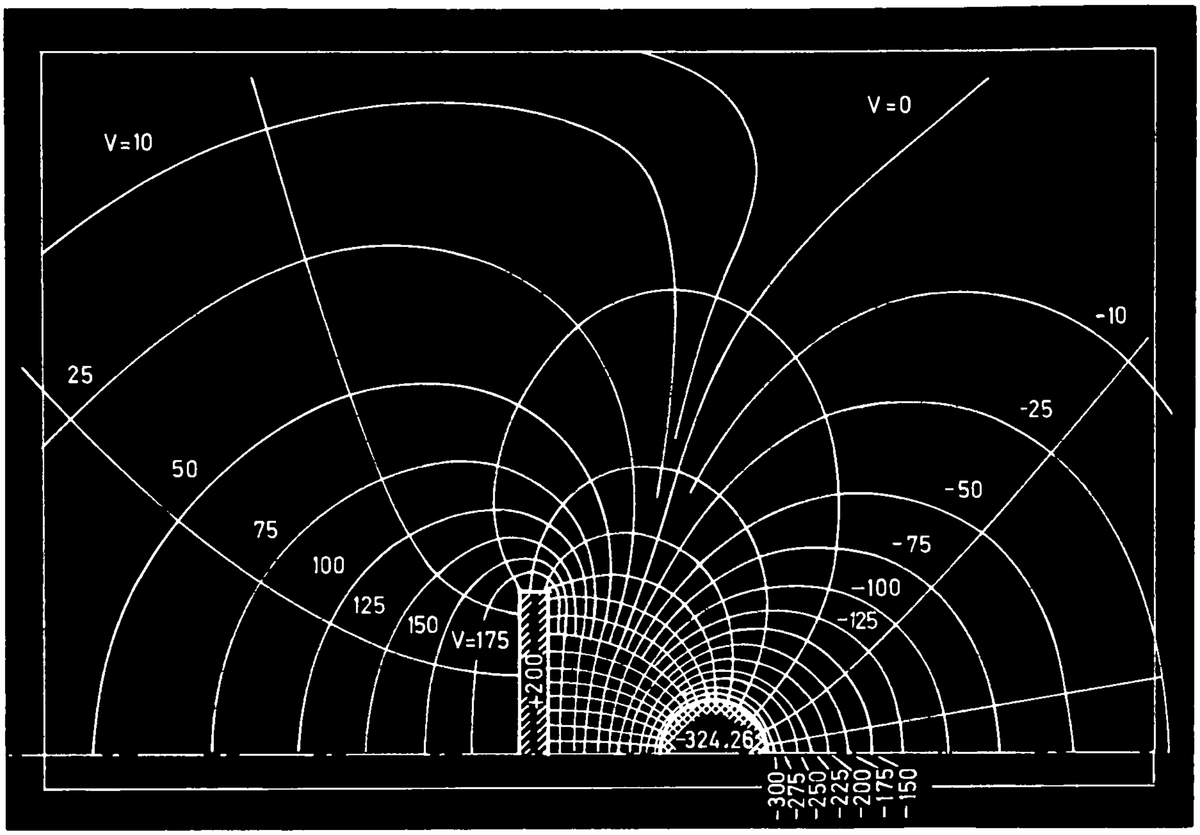


Fig. 95: Magnetic field and equipotential lines in a balanced armature relay

noteworthy study [70], Cohen and Großer, following Southwell's Relaxation Method [71] have established the effective and stray flux for a balanced armature relay and laid down the lines of equal potential (fig. 95).

What is worth noting is the fact that of the field lines generated in the core of the coil, only 62% reach the yoke. The remainder is stray flux, approximately 20% of which, trapped by the armature, again becomes effective flux, but more than 25% of the flux generated is lost in this process. Moreover, the degree of saturation of the iron parts is usually inadequately taken into account. This is shown in the comparison of a single air-gap system (fig. 5) with a system, (fig. 6) whose U-shaped yoke ends form additional air gaps. Both systems have the same iron cross section.

Textbooks may lead readers to assume that the magnetic resistance of the soft iron is practically negligible, and that only the resistance of the air gap ($\mu_r = 1$) counts, i.e. that a double air gap can bring no improvement in efficiency. With a very small air gap, the flux conducting parts (core, armature, yoke) become saturated even with a relatively small energizing power, so that it is advantageous to utilize the given field lines more than once. Fig. 7 shows the force/travel course of the two systems illustrated in figs. 5 and 6, at differing excitation, and the separating line "x" beyond which the single air-gap or the multi-air-gap system offers higher pulling forces. The fact that, according to curve "x", a higher excitation is allocated to a greater actuating travel or air gap, proves the influence of saturation. However, the fact that the pulling force with the air gap closed is not only twice, but 2.6 times as great, is because of the smaller stray flux and the more favourable lever flux effect of those field

lines which run further away from the bearing axis than those which act between core and armature.
However, in many applications, such a sharp course of force/travel is not desirable, since, the ratio of pull-in/drop-out energization will in turn increase, or, — with a larger air gap —, greater force will be required! For such applications, a magnet system with an armature arm which, during the actuating process, dips into the specially provided yoke cutaway section, has proved successful (fig. 96) [18, 73].

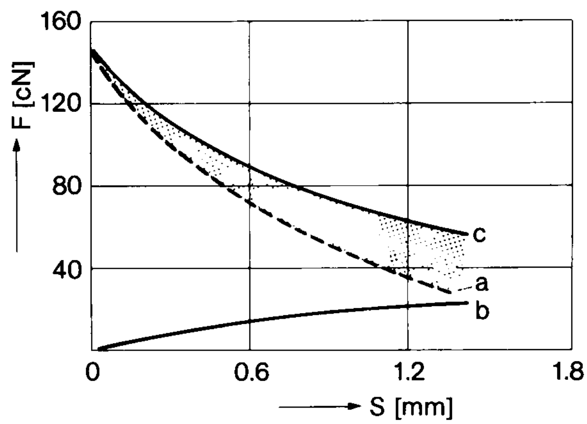


Fig. 97: Force/travel diagram of K-relay with 200 mW operating power c = a + b

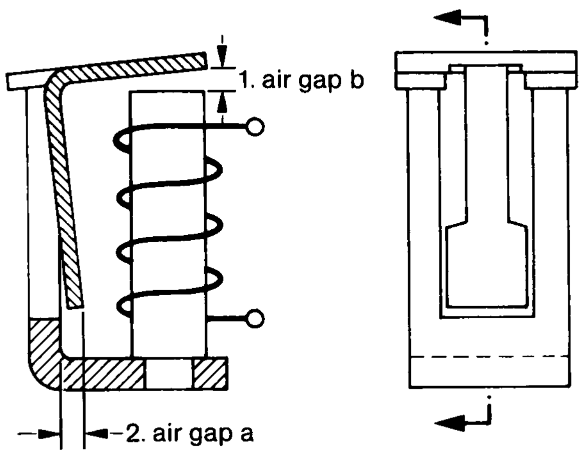


Fig. 96: Magnet system of the K-relay, → relay tables (fig. 306)

The force/travel course of this magnet system, measured at 200 mW energizing power, also shows that with just 1.4 mm actuating travel of the armature arm, that proportion of the actuating force 'a' of air gap 2 is already nearly as great as the proportion 'b' of air gap 1 and that, with the armature pulled in, there is no longer any influence from this second air gap (fig. 97). Curve 'c' shows the resulting course of the force/travel 'a' + 'b' [18]. Depending on the position of the armature arm, its maximum pull-in force can be applied to any point of the actuating travel or it can, in the pulled-in position, counteract the force direction in air gap 1.

A further possibility to meaningfully vary the course of force/travel with a polarized magnet system can be realized by inclining the pole faces relative to the pull-in direction.

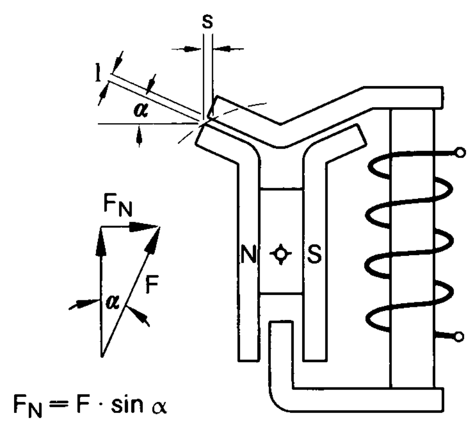


Fig. 98: Magnet system with polefaces inclined to the direction of pull

Deliberation: Leaving aside the saturation of the iron circuit, the pull-in force increases with the square of the reciprocal of the air gap 'l' width. If the pole faces are inclined relative to the pull-in direction, then the actuating force of the armature is reduced by one component, relative to the pull-in force. It is thus clear, that for every actuating travel or air gap, there must be an optimum angle of incline for the pole faces. The optimum angle of incline to produce the greatest actuating force of the armature travel needs to be established. This is calculated from:

$$\text{Sin}\ \alpha = \frac{\Sigma R_{Fe}}{\Sigma R_a} \quad \text{(fig. 98)}$$

R_{Fe} is the magnetic resistance in the iron circuit, R_a is the magnetic resistance in the air gap.

In a multiple air gap system, it is even possible to realize combinations of differing angles of incline of the pole faces involved, or to incline one and leave the other in the normal position relative to the pull-in direction (fig. 98).

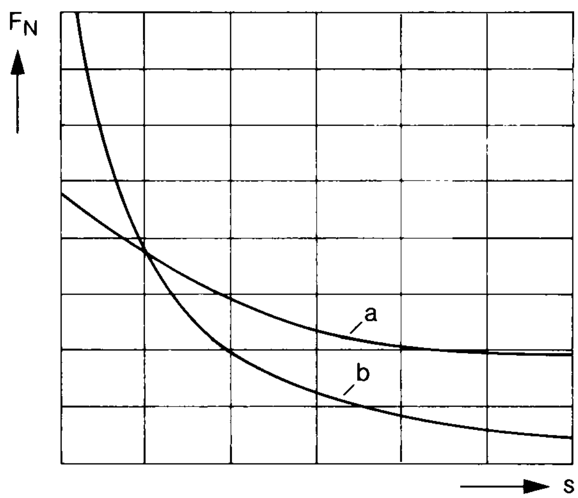


Fig. 99: Comparison of the force/travel diagram of magnet systems which have pole surfaces a) inclined and b) normal to the direction of pull

Inclined pole faces are particularly advantageous for systems with large travel of the armature. Fig. 99 shows the comparison of the force/travel course of a magnet system with pole faces:

a) inclined relative to the pull-in direction, and

b) normal to the pull-in direction

and the proportion which is gained with larger actuating travel, and lost with smaller travel.

<u>Comparison of equivalent magnet systems for modern reed change-over relays</u>

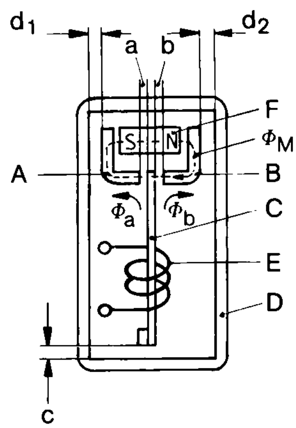


Fig. 100: Double pole magnet system with two pole magnets

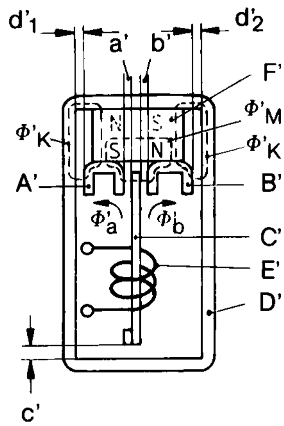


Fig. 101: Double pole magnet system with 4 pole magnets complying in principle with DE-PS 2723220

Magnet systems, as illustrated in fig. 100 and 101, are respectively described in patent specifications 2549039 [78] and 2723220. They demonstrate very clearly how "slight" design differences can have major effects on the characteristics and the *efficiency* of the relays. Both systems differ from conventional reed change-over relays (fig. 15), by the following features which they have in common:

- The free end of the contact reed, C or C′, is between the fixed contacts A, B or A′, B′, which are formed as pole shoes.
- The bobbin (fig. 16), holds the pole shoe-type fixed contacts A, B or A′, B′, and additionally serves as a protective tube for the contacts.
- The contact reed C or C′, is split in two at its free end and is adjustable within the magnetic field allocated to it.
- In the air gap a, b or a′, b′, electromagnetic fluxes Φ_a, Φ_b or Φ'_a, Φ'_b, are superimposed on the permanent magnet flux Φ_M or Φ'_M.
- The permanent magnet F or F′, can be activated into a *getter.*

- The ferromagnetic housing cap D or D′, serves as a magnetic shield and thus for the flux guidance.

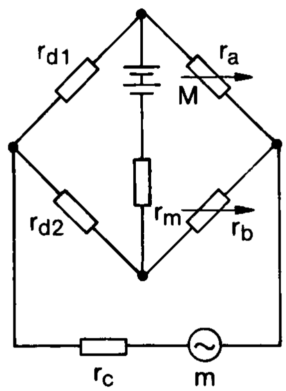


Fig. 102: Equivalent circuit of the magnet systems shown in figs. 100 and 101 [106] (unimportant leakage fluxes are not considered)

Fig. 102 clarifies the physical identity of both systems, in which:

r_a, r_b = magnetic resistance of the variable air gap a, b (a′, b′).

r_{d1}, r_{s2} = magnetic resistance between the pole shoes A, B (A′, B′), and the housing D (D′)!

r_c = magnetic resistance between the contact reeds C (C′) and housing D (D′).

r_m = magnetic resistance of the magnet F (F′).

M = magnetomotive force of the magnet F (F′).

m = magnetomotive force of the energized coil E (E′).

It has been emphasized in several publications that the system shown in fig. 101 is a four-pole magnet system. The German Patent Specification, DE-PS 2723220 also refers in the preamble to a "four-pole permanent magnet arrangement" although it reveals only a two-pole arrangement with its pole shoes, A′, B′, (Fig. 101).

As a rule, four-pole permanent magnet arrangements will have four effective poles or poleshoes, for example, as shown in figs. 9 and 98.

In accordance with the German Patent Specification 2723220, the advantage of a magnet system such as that illustrated in fig. 101, is said — in accordance to the invention — to exist in the fact that the pole shoes A′ and B′ lie against the ferromagnetic housing cap. (Az. 1 Ni 10/79 of the German Federal Patent Tribunal). Regrettably however, pole shoes A′, B′ which lie against a ferromagnetic housing cap, will in effect reduce the resistances r_{d1}, r_{d2}, illustrated in fig. 102, to insignificant values, and consequently will also similarly affect the magnetomotive force M. How such problems can be solved on paper, is shown by the Federal High Court of Justice in the proceedings X ZR/80, according to which, "lying against", is to be understood as, "facing at a certain distance" Why then these defined separations d_1', d_2' are not evaluated, or are evaluated differently; from the known separations d_1, d_2 [106], fig. 100, which were established through calculation, is still a mystery.

B. Philberth [107] concerns himself with such barely comprehensible approaches. They rest rather frequently on "opinions" which interpret disclosures into the opposite, and judge that which was not yet disclosed [55, 111].

The practical differences of 1.7 cm^3 relays with a magnet system as in fig. 101, and alleged optimum separations d_1', d_2', compared with a magnet system as in fig. 100 are, among other things, that;

a) the 4-pole magnet F′ is approximately 4 times larger and 4 times more expensive;
b) for each cN of contact force, approximately 80% more operating power is required;
c) longer pull-in and bounce times are caused, and therefore;
d) the relays can have only a reduced range of application.

Magnetic Field: → Magnet System, → Magnetism.

Magnetic Flux: The product of the number of turns and the current strength. It is known as the *ampere turns.*

Magnetic Force (Lorentz Force): occurs when electrically charged particles are moved in a magnetic field and the speed component, vertical to the magnetic field lines, differs from zero. The acting force, K, is proportional to the vector product of the speed, v and induction, B, i.e. it is vertical on both (fig. 103).

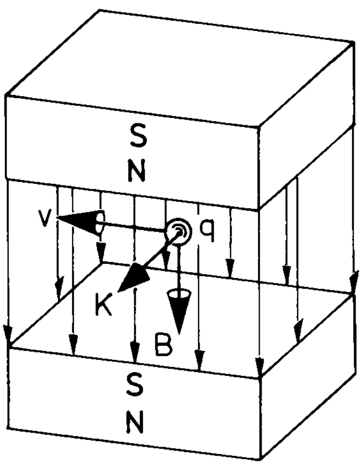


Fig. 103: Force of a magnetic field on a moving positive charge q

Magnetic Materials: Usually ferromagnetic materials which, dependent on the form of their *hysteresis,* are divided into hard and soft magnetic materials.

a) Soft magnetic materials are used if, assisted by an external magnetic field (mainly through an electric current), high inductions (corresponding to the direction of the energizing field) are to be produced. (→ Electromagnetic relays). The properties required include: high relative *permeability* μ_r (with low temperature dependence), high *saturation* magnetization B_s and small remanence B_r, as well as coercive field H_c (→ Hysteresis), low hysteresis losses and a good machinability. These materials thus have a steep hysteresis curve with diminutive area. Several important soft magnetic materials are listed in table 24.

b) Hard magnetic materials are used when, without an external magnetic field, or after its switch-off, permanent magnetic properties are required. (→ Polarized relays, → Energy storage). They are therefore noted for a high remanence and coercive field (→ Hysteresis), a large energy product $(B \cdot H)_{max}$, as well as low sensitivity towards stray fields, mechanical and thermal influences.

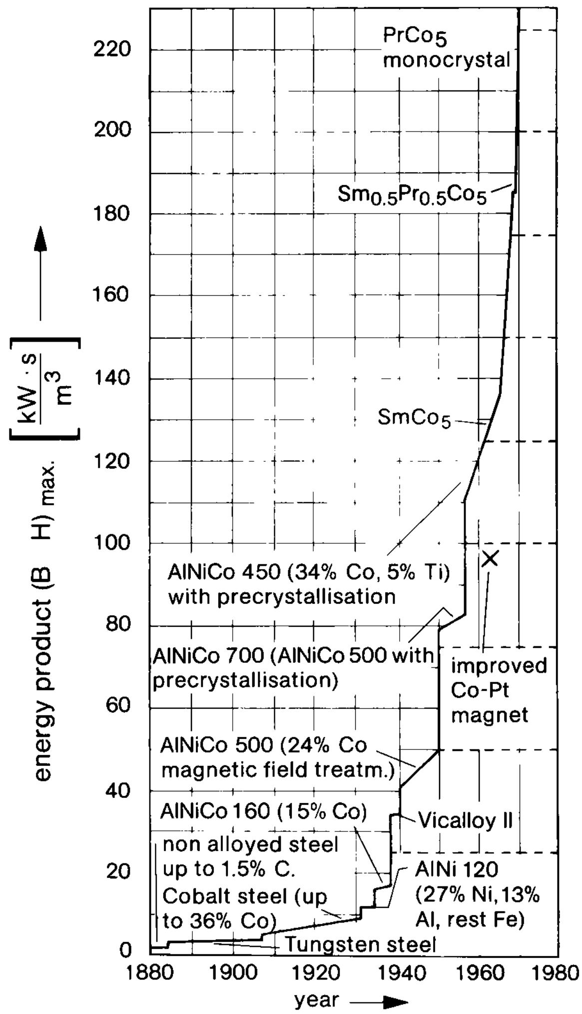


Fig. 104: Increase in permanent magnetic values $(B \cdot H)_{max}$ since the development of magnets began in 1880 [69] (in 1984 this value is already about $350 \frac{kWs}{m^3}$)

Consequently, they show hysteresis curves of large areas since, to achieve this property, a material state of high stress is demanded in which the setting

Type	Composition	B_S in T	B_r in T	H_C in A cm^{-1}	$\mu_r \cdot 10^{-3}$
Iron	99,9 % Fe	2,0	1,2	0,008	3,5 ... 20
Dynamo sheet	0,7 ... 4,3 % Si, 0,08 % C, <0,3 % Mn, Rest Fe	≈1,95	1,2 ... 1,4	0,45 ... 0,72	4 ... 9,5
Textured sheet (Goss-sheet)	≈3,25 % Si, Rest Fe	2,0	≈1,7	0,12	60
Permalloy	21,5 % Fe, 78,5 % Ni	1,1	0,4	0,024	140
Muniperm	23,5 % Fe, 76 % Ni, 0,5 % Cr and Cu	0,8	0,4	0,04	45 ... 60
Supermalloy	15 % Fe, 79,5 % Ni, 5 % Mo, 0,5 % Mn	0,79	0,32	0,003	1200
Mu-metal	18 % Fe, 75 % Ni, 2 % Cr, 5 % Cu	0,8	—	0,24	250
Perminvar	30 % Fe, 45 % Ni, 25 % Co	1,55	—	—	2
Nifemax	50 % Fe, 50 % Ni	1,50	0,8	0,02 ... 0,12	25 ... 80
Normaperm	60 ... 65 % Fe, 35 ... 40 % Ni	1,3	0,6	0,24	10 ... 15
Compenthern	70 % Fe, 30 % Ni	0,025 ... 0,6	—	0,16	—
Fecosat	50 ... 85 % Fe, 15 ... 50 % Co	2,25 ... 2,4	—	0,8 ... 2,0	—
Manifer 110 ... 194	MnZn-ferrite	0,34	—	0,1 ... 2,4	—
Manifer 270	NiZn-ferrite	0,3	—	1,5	—
Manifer 320 ... 360	NiZnCo-ferrite	—	—	<1	—

Table 24: Soft magnetic materials [out of 35]

Type	Composition	B_r in T	H_C in A cm^{-1}	$(B \cdot H)_{max}$ in 10^3 Ws/m^3
Steel	99 % Fe, 1 % C	1 ... 1,2	20 ... 28	1,2
Steel	61 % Fe, 38 % Co, 1 % C	1	190	7,8
AlNi G 10	13 % Al, 25 ... 28 % Ni, 2 ... 4 % Cu, Rest: Fe	0,58	504	8,8
AlNiCo G 28	7 % Al, 15 % Ni, 32 % Co, 4 % Cu, 6 % Ti, Rest: Fe	0,84	880	26,2
AlNiCo S 16	6 % Al, 17 % Ni, 26 % Co, 4 % Cu, 6 % Ti, Rest: Fe	0,58	720	14,4
Vicalloy Aurodur	52 % Co, 14 % V, Rest: Fe	1	410	28
Sintered pure iron (powdered magnet)	100 % Fe	0,5 ... 0,75	446 ... 270	7 ... 9
Heusler alloy (powdered magnet)	10 % Al, 15 % Mn, 75 % Cu	0,54	3000	28
Maniperm 820	$BaO \cdot 6Fe_2O_3$ (isotrop)	0,18 ... 0,23	1200 ... 1580	6,4 ... 8,7
Maniperm 860	$BaO \cdot 6Fe_2O_3$ (anisotrop)	0,37 ... 0,41	1600 ... 2400	25,6 ... 32
Samarium-cobalt	$SmCo_5$	0,75 ... 0,9	6000 ... 7100	130 ... 160

Table 25: Hard magnetic materials [out of 35]

of specified magnetic values through heat treatment with (anisotropic) or without (isotropic) an external magnetic field plays an important role, and is of vital importance to the manufacturing process. Fig. 104 shows how, over the past 100 years, new hard magnetic materials with an ever increasing energy density have been developed. Extraordinarily hard permanent magnets have resulted, in particular from magnetic materials with rare earth components, either as a natural mixture or with individual elements like samarium (Sm) or praesodym (Pr) [69]. A small selection of hard magnetic materials, still in use, is shown in table 25.

Considering the revolutionary improvements permanent magnetic properties have presented to relay technology, (→ Polarized relays, → Energy storage, → Temperature compensation, → Gettering), it would be interesting to pose the question: "What further surprises will the future hold?"

- What would be the effect of combining a selenium cobalt (SeCo) magnet with a AlNiCo magnet, (both of which have such differing demagnitization curves) fig. 105, for use in a polarized magnet system?
- How do the differing temperature coefficients behave in parallel or series arrangements?
- How well could the new magnet materials be used for "gettering"?

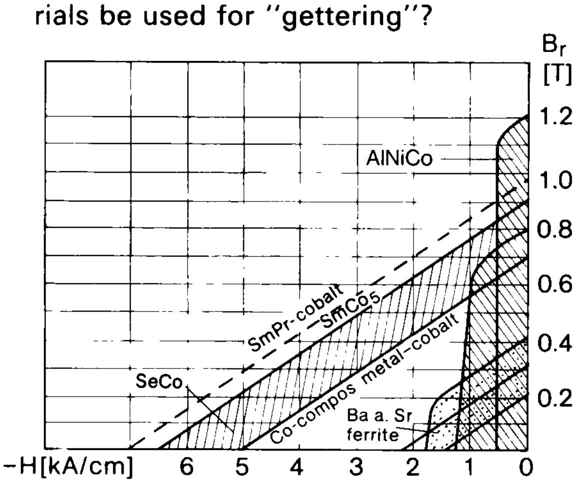


Fig. 105: Demagnetization curves for rare earth and cobalt magnets compared to AlNiCo and ferrites

Magnetic Shielding: As is generally known, there is no material with zero permeability with the exception of *superconductors.* Consequently, there is no magnetic insulator at normal temperatures. However, in order to keep the influence of external magnetic fields as low as possible (for example on relays, or conversely, the influence of relay magnetic fields on nearby components), the space to be shielded is surrounded by a soft-iron cap with as high a permeability as possible, so that, due to the good magnetic conductivity of the material, practically all the interference fields will be contained.

In the case of relays, care must be taken to ensure that such shielding causes as few magnetic shunts as possible.
However, the metal cap is also to conduct the electromagnetic flux, for example in the R relay (→ Relay table). Since, with polarized relays, the superimposition of electromagnetic flux onto the permanent magnetic flux in the air gap corresponds to a multiplication of the fluxes, with regard to the armature holding force, the separation between the pole shoes (fixed contacts) and the cap must be so optimized that:

a) the stray flux in the permanent magnetic circuit is as small as possible;
b) the electromagnetic circuit shows magnetic resistance (air gap) as low as possible;
c) external magnetic influence is minimal.

If the above stated factors are optimized, the application of a soft iron cap will not only reduce the magnetic effects on the relay, but will also increase the *efficiency.*

Magnetism: is characterised by a force effect which occurs as a result of a magnetic field. Magnetic fields are caused by moving electric charges or so-called molecular magnets (elementary dipoles).

Type o. magnetism	Alignment of elemental dipole
Diamagnetism	Induced dipole opposing external field direction
Paramagnetism	
Ferromagnetism	

Fig. 106: Types of magnetism [as per 35]

The following defines the magnetic characteristics of materials depending on their behaviour in a magnetic field:

a) **Diamagnetism:** an external magnetic field when applied to such a material induces elementary dipoles which oppose the applied field, i.e.

$\mu_r < 1$ and constant (→ 2.3 Formulae of Electro Technology). Diamagnetic materials are thus so-called "magnetic non conductors". The following are typical diamagnetic materials: Cu, Zn, Ag, Cd, In, Au, Hg.

b) **Paramagnetism:** in an externally applied magnetic field, elementary dipoles within the material align themselves in the same direction as the applied field, i.e. $\mu_r > 1$. The alignment is only very weak and is temperature dependent. Complete *saturation* cannot be achieved. *Hysteresis* is linear.
Paramagnetic materials display only weak magnetic conduction properties. Paramagnetic materials are Al, Cr, Rh, Pd, Sn as well as rare earth metals which partly display ferromagnetic characteristics at low temperature.

c) **Ferromagnetism:** in the material there are minute areas (→ Weiss domains) in which elementary dipoles lie parallel to one another. Under the influence of a magnetic field these areas are increased in size and lie in the direction of the applied field. Thus $\mu_r \gg 1$ and is a function of the field strength $\mu_r = \mu_r$ (H). As a consequence the *hysteresis* is non linear (→ Magnetic materials).
Ferromagnetic metals are the elements Fe, Co, Ni (ignoring certain rare earth metals). Above the Curie temperature (table 26) ferromagnetic materials become mostly paramagnetic.

Material	Curie temperature [°C]
Iron	770
Cobalt	1123
Nickel	358
Bariumferrite (Maniperm)	450
AlNiCo	700–850
Co_5Sm	730

Table 26: Curie temperature of commonly used ferromagetic materials

Make Before Break: → mbb.

Make Contact: (also called normally open or form A contact), is closed in the actuated state (active position), and open in the non-actuated state. → Contact Types.

Making Capacity: → Inrush current.

Material Migration: occurs with every d.c. load, between the points of operation of make or break contacts. Distinction is made between coarse and fine migration. In simpler terms, this means that below the arc limiting curve shown in fig. 24 *fine migration* occurs, i.e. the contact material migrates from the anode to the cathode; above the arc limiting curve, coarse migration occurs, i.e. the contact material migrates from the cathode to the anode.

Maximum Permeability: The maximum *permeability* value which is achieved along the new curve. (→ Hysteresis). It is of importance to the design of magnet systems and relays.

mbb (make before break): is required of a change-over contact in some special applications. For example, interruption of a telephone connection to another circuit during the course of a call is prevented by such change-over switching. → Sequence action change-over contact.

Measuring Relays: monitor given circuit parameters. On exceeding or falling short of a certain preset value, contacts are actuated with (or without) time delay. Measuring relays are divided into *monitoring relays* and *protective relays* (in accordance with VDE 0435)

Mercury Relays: are usually clapper-type relays which have a mercury contact tube instead of or in addition to the spring contacts. They are suitable for the switching of high current loads. → Mercury Wetted Relays.

Mercury Wetted Relays: are relays having a protective envelope for the contacts (→ Reed relays), with mercury wetted contacts (utilizing capillary action). They display virtually no contact bounce, low constant contact resistances, and therefore have long life with high reliability. There is a possibility of problems arising, due to their being position dependent when there is plenty of mercury, or due to a break in the mercury film or the forming of an amalgam in the case of insufficient mercury and arcing. The max. permissible temperature range is −37 °C to +107 °C.

Meter Relays: or pulse counters, have continuous switching mechanism cipher wheels, numbered from 0 to 9, arranged side by side and each displaying a decade.
There are summatory meters, adding or subtracting set-pulse and differential pulse counters with pulse counter combinations having readout counted in decades, either with or without electrical and/or mechanical reset. "Readout" in this context means that the counter can be interrogated or "read-out" during actual operation, (e.g. in long-range transmission or telemetering technology). Set-pulse counters, on reaching a preset value, will emit a signal, (e.g. for switching machines) on and off, for selecting predetermined quantities etc.). Summation set-pulse counters will always display the cumulative number of pulses, whereas subtracting set-pulse counters always display the number of pulses remaining before the signal is activated.

Mho: The expression for the unit of electrical conductance. 1 Mho = 1 S.

Microprocessor: → MP

Miniature Relay: Characterised merely by its small construction, without there being any clear definition. That is why it is possible for some firms to call their small relays, microminiature relays, even though, in some cases, these are larger than those known as miniature relays.

Mini Contactor (MC): The collective description used by the SDS company for a large relay (or small contactor) for loads of 10 to 20 A/220 to 380 V, having three or four contact elements each of which can be specified as NO or NC. Conventional or polarized systems can be used for magnet systems.
Mini contactors utilizing a polarized magnet system can be designed to have two stable switching states (either bistable or monostable), as well as three stable switching positions, (center-stable or tristable). → Three-Position Contactor.

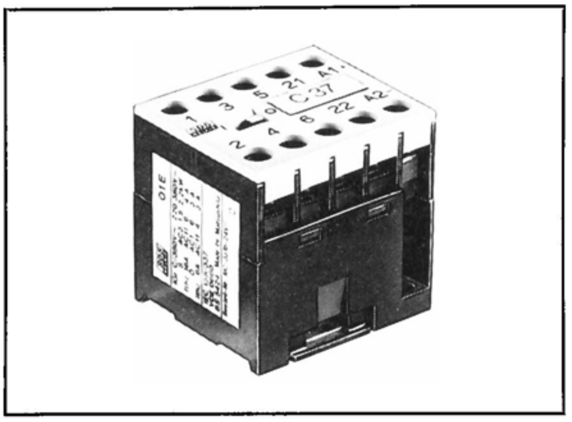


Fig. 107: Mini contactor type MC for 16 A load, with screw terminals. Fixing alternatively with 2 M 3.5 screws or on DIN EN 50022 35 mm mounting rail

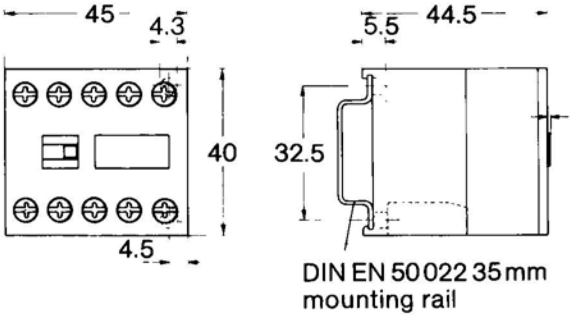


Fig. 108: Dimension of mini contactor as illustrated in fig. 107

MNOS: Metal nitride oxide semiconductor; semiconductor component which, as opposed to the *MOS,* has an additional nitride layer between the metal and the oxide layers. The insulating nitride and oxide layers allow a characteristic charge distribution. MNOS can thus be used in non-volatile semiconductor memories.

Monitor: *Protective relay* which opens or closes a circuit when preset limits are exceeded (or not attained).

Monitoring Relay: → Protective relay.

Monostable Relay: assumes a defined off-position in the non-energized state. (→ Relay times). In the case of a change-over contact (or a normally open and normally closed contact), the NC contact is closed in the absence of energization. By using a *C-switching circuit* (figs. 43 and 44), it is possible to operate a bistable relay as a monostable relay, so that the operating costs are reduced by 99.9%.

MOS: Metal oxide semiconductor. This technology gives the highest integration density for integrated circuits and can be used to produce active elements (e.g. *FETs*), as well as passive elements (resistances, capacitances). By comparison to bipolar technology, fewer manufacturing steps are required, with a simultaneous increase in reliability.

Motor Protection Switch: Adjustable, current dependent, delayed over-current trip or *over-current relay* to supervise all current phases.
For intermittent operation or special applications the requirement for all-phase monitoring may be waived.
The protection may be via thermal, or magnetic trips, or relays (VDE 0660).
Protection switches are designed to protect motors against damage due to non-starting, overload, mains voltage drop, and, in the case of three phase current, phase failure.

Motor Starter Switch: For motor switching. To have a switching capacity corresponding to the starting current of the motor being switched (VDE 0660). → Utilization Categories.

Moving Coil Relay: The coil and core are designed as an armature, and are mounted at the center-of-gravity. Relays of this type of construction are highly sensitive, but due to their relatively large mass and armature movement, they require long pull-in and drop-out times.

MP (μP, MPU): Microprocessor. A central processing unit (CPU), accommodated on one or two microchips. The MP is a module for the control and processing of data. The principal components are:

1. A control section with instruction register, decoder and control for decoding and monitoring of instruction execution.
2. An arithmetic unit which processes the data. The arithmetic unit usually contains an intermediate register, status bits (flags), and an arithmetic logic unit (ALU).
3. A main memory for data transport and intermediate data storage. It consists of an instruction counter which indicates the location of the next instruction, registers, and possibly an index register and stack indicator.
4. An instruction set which indicates which instructions can be executed by the microprocessor.

MTBF: Mean Time Between Failure is the expected period of operation, i.e. the mean time of operation in serviceable systems. In relay technology, components cannot usually receive preventative maintenance against failure or breakdown, therefore the *reliability* is expressed by the *MTTF* value.

MTTF: Mean Time To Failure is the mean life expectancy in non-serviceable systems (e.g. relays). → Failure rate.

Multivibrator: Circuit for generating two defined initial states (e.g. 0 or 1). The basic principle of operation of a multivibrator consists of two opposed back-to-back RC amplifiers. Depending on the type of back-to-back coupling, distinction is made as follows:

a) astable multivibrator: An oscillator which generates square waves. It is used, for example, in clock generators and signal generators.
b) monostable multivibrator (monoflop): A circuit which, with the occurrence of a trigger pulse, flips for a predetermined period of time, from a stable to an instable state. It serves for pulse forming, and is often used for the suppression of contact bounce. → Bounce, → Schmitt Trigger.
c) bistable multivibrator (flip-flop): It has two stable initial states and hence serves as a storage element in the processing of logic variables. → Stepper relays.

Mumetal: High permeable FeNiCu alloy with very low *coercive field.* The magnetic values are very sensitive towards mechanical stress. → Magnetic materials.

Mutual Inductance: The inductance M, with which two coils with inductances L_1 and L_2 are coupled. $M = k\sqrt{L_1 \cdot L_2}$. Mutual inductance must be taken into account, in particular with sensitive two coil polarized relays.

Mutual Permeability: The permeability of a magnet system with air gap or with differing materials. → Shearing.

Negative Logic: The allocation between the logic conditions 0 and 1, and the voltage potential conditions LOW (condition with a more negative potential) and HIGH (condition with a more positive potential) so that; 0 ≙ HIGH, and 1 ≙ LOW.
The advantage over positive *logic* lies in the fact that the generally active HIGH condition is more easily and more clearly achieved, particularly with unstable voltage levels and long conductor runs. Such logic is used, for example, with C3-relays. → Relay Table.

Neutral Relay: A relay in which the pull-in direction of the armature is independent of the current direction in the coil, i.e. in contrast to *polarized relays;* when connecting the relay, there is no need to note the polarity of the connections to the coil.

Nipple: A contact actuating mechanism consisting of insulating material and attached directly to the armature or to the contact springs.

Noise (or noise voltage): Interference voltages in amplifier circuits (e.g. in telephone equipment). Interference voltages can be caused by:
a) Thermal noise (lattice vibration of the metal atoms).
b) Thermo-electric potentials at the touching point of a contact.
c) Resistance changes at a contact point = *contact noise* or contact vibration [24].

Nominal Conductor Cross Section: The diagrams 1 and 2 are intended as an

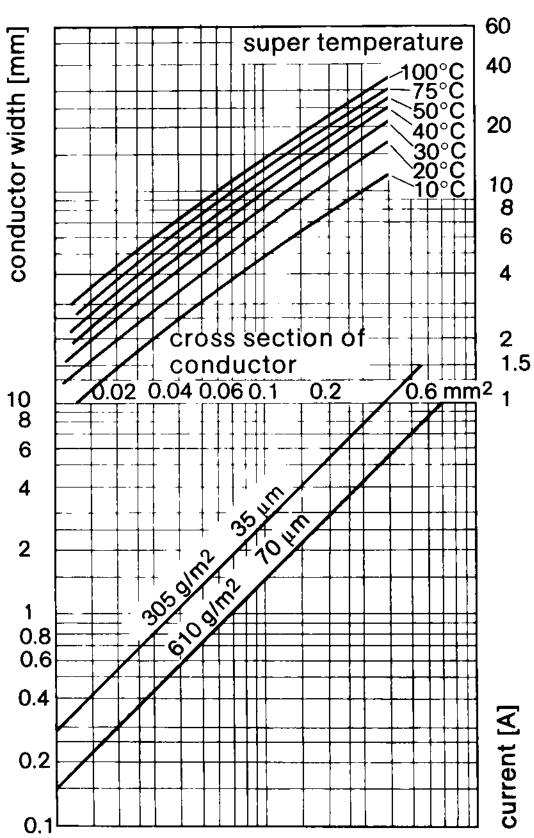


Fig. 109: Loading by conductor cross section on copper laminated base material (p.c.b.) [76]

aid for estimating the excess temperature with regard to the current strength for various cross-sections (fig. 109, 110).

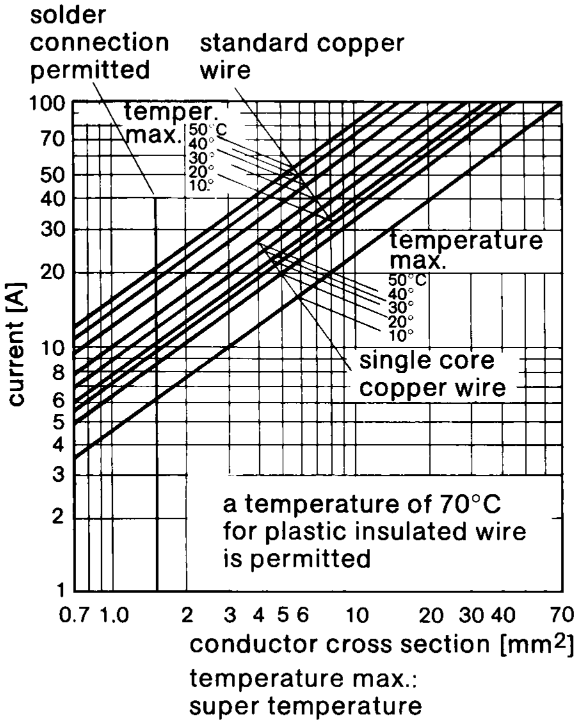


Fig. 110: Loading by conductor cross section of single core and multi stranded wires

Nominal Data: Relay data at nominal power. → Nominal value.

Nominal Power: Lies above the pull-in power consumption by a safety factor which takes into account environmental influences, wear phenomenon and tolerances. Other factors which assist in determining the magnitude of the safety factor are: pull-in time (high speed relays), or the contact force required to ensure reliable contact make, if this force is directly dependent on energization.

Nominal Switching Capacity: or nominal make/break switching capability data stated by the manufacturer. → Switching capacity.

Nominal Value (rated voltage, -current, -energization, -power): The variable to which other characteristics of a relay are specified or referred. For example, the pull-in time is not stated for the pull-in voltage, but for the rated voltage. As a rule, the nominal value corresponds to the operational value. With alternating voltage, RMS values apply.
In accordance with VDE 0660, the nominal values of any switchgear must be rated so that, in normal atmosphere, the equipment will not exceed its limit temperature with occasional switching.
In practice, however, it is advisable that the condition should apply not to normal atmosphere, but to the permissible ambient temperature range stated in the data sheet.

The following ratings are commonly used for d.c. or a.c.

0.1	0.16	0.25	0.4	0.63 A
1	1.6	2.5	4	6.3 A
10	16	25	40	63 ... A

for d.c. voltage:
3, 5, 6, 9, 12, 16, 24, (26), 35, 48, 60, 110, 220, 440, 600 V
for a.c. voltage:
6, 12, 24, 42, 115, 127, 220, 240, 380, 500 V.

Nominal Voltage: The energizing voltage at which the relay performs to the relevant ratings as stipulated for its operation.

Non-Inductive Coil: → Bifilar Winding.

Non-Operate Current: The highest current in a relay coil at which the contacts will not be actuated.

Normally Open Contact: → Make contact.

NTC Resistor (Negative Temperature Coefficient Resistor): *Thermistor.* A resistor whose value decreases with rising temperature.

Operating Temperature: The temperature which a relay attains during operation when thermal equilibrium is reached.

Operational Data: The data required for the safe operation of a relay or other components, taking into account the permissible environmental conditions.

Optocoupler: Optoelectronic coupling element (optoelectronic isolator); made up of a luminescence diode (gallium arsenide) as a transmitter, and a phototransistor (silicon) as a receiver.
The signal transmission from transmitter to receiver takes place optically. Input and output are electrically isolated. In addition to their use in rapid response switches, optocouplers can also be used as transmitters for digital or analogue signals from a frequency of 0 up to several MHz. It should be noted that the *contact resistance* of approx. 100 Ω is some 10^5 times greather than that of a relay contact.

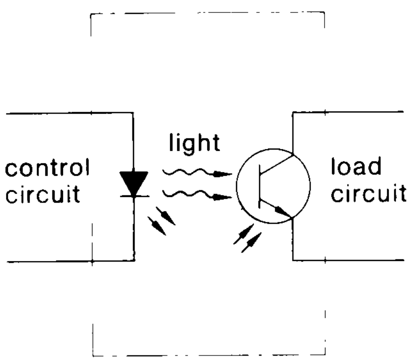


Fig. 111: Optocoupler circuit

Overcurrent Relay (also measuring relay for protection against thermal overload or, motor protection relay): in accordance with the definition of IEC 255 part 8 (VDE 0435/82 part 3011, draft 1), an electrical relay with specified time delay charateristics which protects electrical equipment from thermal damage due to electrical causes, (→ Protective relay), by monitoring the current flowing in the protected equipment.

Overvoltage Relay: also referred to as a voltage dependent relay; the relay responds when the applied voltage reaches, or exceeds a defined threshold value.

Paramagnetism: → Magnetism.

Parasitic Oscillations: External oscillations which adversely affect equipment. They are usually a broad band mixture of frequencies, with differing energies in the various frequency ranges.

Passivation Bath: produces a thin protective layer on metals, (e. g. silver), to prevent tarnish. Solderability and contact making capability remain unaffected.

Peltier Effect: Reversal of the *Seebeck effect.* By applying a voltage, a temperature drop occurs between two contact points. Application is with Peltier elements in which semiconducting materials (e. g. bismuth telluride) are electrically arranged in series, and are thermally parallel between two plates (electric heat pump).

Performance Standard (German: Güteklasse): This is specified in accordance with DIN and states tolerance ranges of certain component characteristics or of measuring instruments. The lower the standard number, the higher the performance.

Permanent Magnets: Magnetized materials which, after one magnetic alignment — even without external energization — generate magnetic fields. Permanent magnets are used in polarized relays. → Magnetic Materials.

Permeability: Magnitude of the magnetic field (→ Magnetism).

a) The absolute permeability, μ, is the proportionality factor between the magnetic induction B, and the magnetic field strength H. It is a measure of the magnetic conductance (→ 2.3 Formulae of Electro Technology). In ferromagnetic materials, μ is not constant within wide ranges, but is dependent on the previous history of the material and on the external magnetic field.

The absolute permeability of a vacuum is called the permeability, μ_0, or universal or magnetic constant.

b) The relative permeability μ_r is μ/μ_0. → Magnetic Materials.

Permeability (μ_0): → 2.2 Units of Measurement, → 2.3 Formulae of Electro Technology.

Permissible Ambient Temperature: Together with maximum contact and coil temperature increases at 100% duty cycle sum up to the *limit temperature.* → 3.1, pos. 20.

Phase Angle φ: The reactances of an a.c. circuit give rise to a phase difference between voltage and current. In the vector diagram, U and I form the phase angle φ (fig. 112).

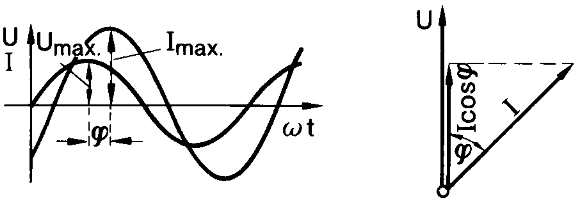


Fig. 112: Phase angle between voltage and current in AC circuits

For calculation of the active power, only the product of voltage and active current (current component in voltage direction) is of importance.

If P = active power,
I = effective current strength,
U = effective voltage,
φ = phase angle,
then $P = U\,I\cos\varphi$.

→ 2.3 Formulae of Electro Technology.

Phase-Failure Relay: → Phase Sensitive Relay.

Phase Sensitive Relays: these protect three phase motors, transformers etc., against the hazards of operating on only two phase in the event of failure of the third supply phase. This is illustrated in fig. 113. When connected to a three phase supply, the relay is always pulled in and the contact between 2 and 3 is closed. If one or more phases fail, the relay will drop out, and the contact changes over.

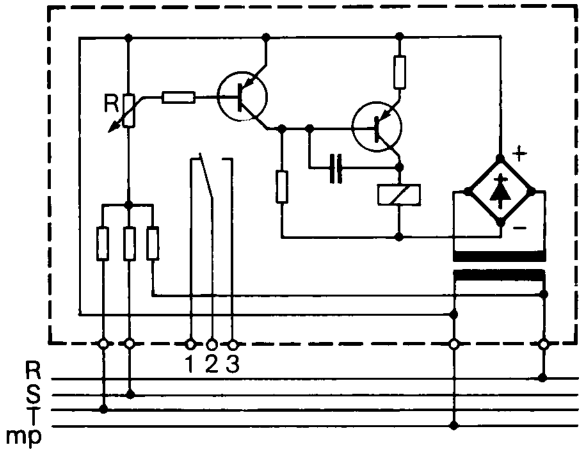


Fig. 113: Phase supervisiory circuit

On re-establishment of all three phases, the relay will again pull in. By the use of potentiometer R, the relay can be adapted to non-symmetrical mains.
The phase-sensitive relay PT10 from SDS, for example, features such a circuit. Its use in conjunction with a mini-contactor is described under *protective relays.*

Phase Shift: The temporary shift of an oscillation relative to a reference oscillation of equal frequency.

Photodiode: A semiconductor component which drastically changes its current-blocking behaviour under the influence of light. Interposing a photodiode in a relay coil control circuit will enable the relay to be controlled by the action of light.

Photoelectric Relays: are relays which are controlled by a photocell. → Photodiode, → Optocoupler.

Pick-up: The action in which the contacts of a relay move from an initial position into an active position.

Piezoelectric Effect:

a) direct piezoelectric effect: The creation of electrical surface charges by mechanical compression or tension of a suitable crystal (e.g. quartz) or a ceramic, in a prescribed direction relative to the crystal axes.

b) reciprocal piezoelectric effect: The extension or contraction of a crystal (e.g. quartz), or a ceramic, by imposing electrical charges on the surface (electrostriction). → Quartz.

Piezoelectric Relays: utilize the *piezoelectric effect.* A piezoceramic material is used in place of an electric coil. When a voltage is applied to the bonded piezoceramic, it lengthens or bends in a similar way to a bi-metal strip and operates the contact springs. Patents for piezoelectric relays have been applied for, but to date of publication series production has not begun.

PLA (Programmable Logic Array): Integrated circuit which, to the user's specification, is mask-programmed by the manufacturer, and permits the logic operation of binary input values.

Plunger Relays: also called soleniods, utilize the magnetic flux density of the coil center. They are generally used for generating high magnetic pull-in forces with relatively large armature travel.

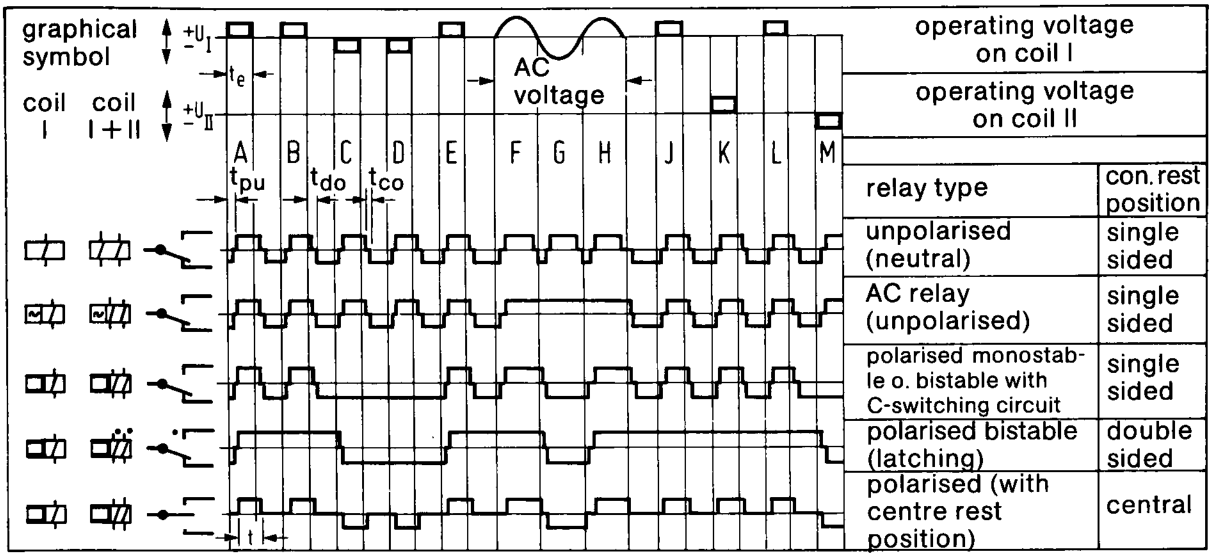
Polarized Relays: have a permanent magnetic flux which is superimposed on the energizing magnetic flux in the air gap, (fig. 9). With suitable arrangement of the two fluxes, significant advantages over non-polarized relays can result (fig. 8):

1. Much higher efficiency, because the armature actuating force is effectively realized by the product of the energizing and permanent magnetic fluxes. The best method of obtaining maximum contact force but with minimum operating power consumption, has proved to be the use of a polarized magnetic system, as shown in fig. 9. This has a contact arrangement the force/travel vectors of which counteract the actuating force of the armature in regard to magnitude and direction, so that only sufficient power to provide for the required stability, vibration resistance etc. is consumed (figs. 13, 14). However, since all systems require such safety margins, this method in effect means that no control power needs to be consumed to provide contact forces, regardless of the number of contact springs required (table 1).

2. Compensation for the effects which fluctuating ambient or operating temperatures have on the pull-in voltage. If, for instance, a relay is required to operate within a temperature range of $-55\,^{\circ}C$ to $+125\,^{\circ}C$, the coil resistance will vary, due to the temperature coefficient of the copper coil wire (0.39%/°C), by $0.39 \times 180 = 70.2\%$, which in turn leads to an increase in the control power consumption. This otherwise wasted energy is not required due to *temperature compensation.*

3. Universal possibilities of control, result as a consequence of the dependence of the polarity on the energizing voltage and the position of the armature. As shown in fig. 114, polarized monostable relays operate like normal unpolarized relays (with unidirectional polarity-energizing pulses A, B, E, F, H, J, K, L). On reversal of the polarity, the contact remains non-actuated. Bistable polarized relays (latching type relays) change the contact position only with change of the energizing voltage polarity (energizing pulses C, E, G, H, M), and retain it even with interruption of the energizing voltage. Applications: amplifiers, vibrators, conversion of sine pulses into square pulses. Since the switching of polarized bistable relays requires control pulses of no more than a few ms (often less than 1 ms, as for example, with R- and DR-relays → Relay table), They permit savings of approximately 99.9% in power consumption over monostable relays.

Most control systems however, require relays with single-sided, monostable con-



t = contact time, t_{do} = dropout time, t_e = exitation time, t_{pu} = pick up time, t_{co} = changeover time, → relay times.

Fig. 114: Operating function of different types of relay with the same control voltage

tact rest position. For these, similar savings in power consumption of up to 99.9% can be achieved by using the *C-switching circuit* [14, 40] (figs. 43 and 44). → Efficiency.

4. Faster switching and much less contact bounce of correctly designed, polarized relays result in increased operational life, since arcing, contact heating and contact wear are reduced. *Radio interference* due to a bounce duration of less than 0.2 ms is barely discernible.

5. The negligible self-heating of the coil, (as a consequence of the 99.9% saving in power consumption), increases the permissible ambient temperature range. It increases the *reliability* as well as the life, and reduces the stress on other components located in the immediate vicinity.

6. Contact reliability is approximately 100 times higher due to the possibility of gettering with sealed relays and results in an appropriate reduction in maintenance costs. → Getters.

7. Miniaturization without loss of reliability (fig. 73).

Considering that this extensive list of technical and economic achievements of polarized relays stems from a magnet which costs only approximately $2\frac{1}{2}$ pence, but which offers savings in operating costs, — throughout the life of the relay — amounting to many times the purchase price of the relay, it is easy to understand that polarized relays are rapidly finding increasing use in new applications. → Relay Evolution (Part 1.2).

Pole Areas: Opposing areas in the air gap of a magnetic circuit. If the surfaces are of different size, the dimension of the smaller surface only, can be used for the approximation calculation.

Power Factor: → cos φ, → Phase Angle, → 2.3 Formulae of Electro Technology.

Power Ratio of Relay Coil: The ratio of permissible continuous load to pull-in power requirement.

Power Relay (German: Starkstrom Relais): This description is still in occasional use for contact loads >10 A/240 V~, but is not in accordance with existing IEC and VDE specifications.

In the VDE 0435/10.81 part 120 or DIN IEC 255 part 0-20, respectively, contact classes for relays are stipulated in accordance with table 27. Relays of class III

Class	Voltage	Current	Use of relay	Principal voltage and current range
I	<0,02 V	<0,1 A	Low level loads, special low loads, internal NO and NC contacts in electronic equipment	The range 0.02 V and between 0.1 and 100 A is not subject of the specifications
II	0,02 to 250 V	<1 A	A) Telecommunications Data processing	6 to 60 V <0,2 A
			B) Measuring relays Domestic equipment Regulation and control systems Signal systems	24 to 250 V <1 A
III	0,02 to 600 V	<100 A	A) Switching relays, e.g. for general use Trips	24 to 600 V 0,1 to 100 A
			B) Industry Railway systems Heavy duty	24 to 600 V 1 to 100 A

Table 27: Contact classes for relays to DIN IEC 255 part 0-20/VDE 0435 part 120

can therefore have a maximum contact load of 100 A/600 V.
It may perhaps be expedient to classify such relays as *contactor relays* or *contactors.* (For distinction between relay and contactor, see *switching relay*).

Power Source: → EMF.

Primary Circuit: The controlling circuit. → Relay Energizing Side.

Protection Classes: For protection against excessive shock-hazard voltages when using electrical appliances, several *protective measures* are possible. These are arranged in protection classes. The use of equipment classified under 0 and 01 is not permitted in Germany.

Class I Equipment: Shock hazard protection is not only dependent on the earth insulation, it also depends on additional protective measures which are provided by the connection of accessible parts to a protective conductor (neutral) of the supply, so that following any breakdown of earth insulation, these accessible parts cannot receive any contact hazard voltage.

Class II Equipment: Shock hazard protection depends not only on earth insulation, but also on additional protective measures. This consists of a double or reinforced insulation. No provision exists for the connection of a protective conductor, and no reliance is placed on the condition of the insulation.

Class III Equipment: Protection from electric shock is provided by connection to extra-low, safe voltage. Voltages which are above this safe voltage are not permitted in this equipment class.

Protection Measures: against excessively high shock hazard voltage, with or without protective earth.
Without protective earth:
a) Protective insulation as an additional operational insulation;

b) Site insulation, applicable only with permanently installed equipment;
c) Limit the contact potential to 24 V or 42 V via a safety transformer;
d) Protective isolation, whereby increased protection from contact voltage is obtained.

With safety ground:
a) Protective grounding with single ground wire. The maximum ground resistance must not exceed 50 V divided by the switch-off current (the switch-off current is 3.5 times that of the rated current of the nearest fuse). Can be economically produced only with small fuse ratings.
b) Grounding, with the grounded neutral conductor being used as a fault return line.
c) A combination of a) and b), which is common in a normal domestic installation.
d) Monitoring the fault voltage via a *leakage current circuit breaker.*

Protective Earthing (grounding): → Protective Measures.

Protective Gas: A filling in hermetically sealed relays. Suitable fillings are inert gases, nitrogen and, in particular, purified air with a relative humidity of approximately 24%. When selecting the protective gas, the contact material must be taken into account (→ Brown-powder effect).

Protective Relay: *Measuring relay* or the combination of various measuring and *switching relays* into a composite unit with a definite protective function, (in accordance with VDE 0435). Protective relays are also described as monitors.
The electronic protective relay, PT 10 from SDS (fig. 115), consists of a phase-failure monitor, an asymmetry monitor and an overcurrent monitor. It has a switch position indicator and an operating knob for manual reset to the rest position after a safety trip action.

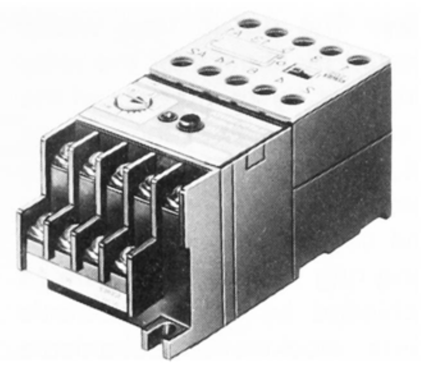


Fig. 115: Electronic overload relay PT10 mounted on to a mini contactor

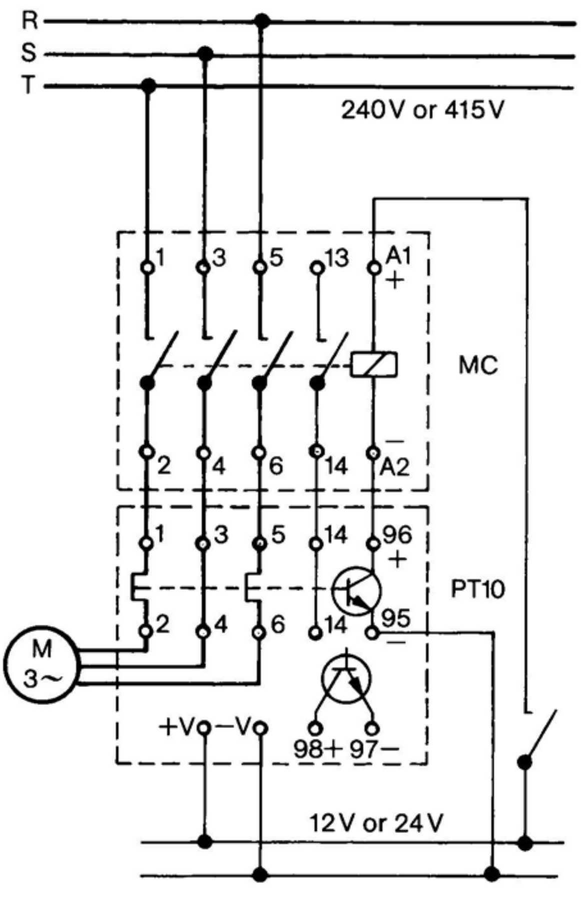


Fig. 116: Circuit diagram example of a PT10 overload relay used in a motor starter circuit

Protective Switch: → Leakage Current Circuit Breaker.

PTC Resistor: Component with positive temperature coefficient of electrical resistance.

Pull-In Delay: The pull-in time which may be extended by change of the relay time constant, (e.g. by an increase of the armature or contact travel of the masses to be moved, or by use of an opposing low self-induction coil). (Short circuiting of the second coil on two-coil relays, or short-circuiting ring.) Greater delay times are often achieved by using electronic times elements, clockwork mechanisms or through bimetal systems. → Time Delay Relay, → Delay Winding.

Pull-In/Drop-Out Ratio: Ratio of pull-in to drop-out voltage (or current). It is influenced by the residual air gap, the magnetic force/travel curve and the characteristics of reset and contact springs. The pull-in/drop-out ratio is of magnitude 8 (approx.). When using the *C-switching circuit* it is usually in the range 1.2 to 1.4.

Pull-In Excitation: The minimum number of ampere turns required for the pull-in of a relay.

Pull-In Lag: → Start-Up Time.

Pull-In Power: The power which is consumed within the energizing coil to cause a relay to pull-in. The relay must operate at the pull-in power specified in the *relay table.* This is specified at 25°C ambient temperature.

Pull-In Time:
a) For normally open contacts: The time from coil energization to the first contact make.
b) For normally closed contacts: The time from coil energization to the opening of the contact set.
c) For change-over contacts: The time from coil energization to the first contact make of the set.

Methods for varying the pull-in time are discussed under 3.12.

Pull-In Value: The value of the variable under consideration when pull-in occurs.

Pull-In Voltage: The smallest value of energizing voltage that a relay requires to pull in. For most relays, the ambient temperature and selfheating of the coil must also be taken into consideration, because the resistance of the copper winding will vary by approximately 0.4%/°C. → Temperature Compensation.

Pulsing Relay: Pulse-wise switching relay with adjustable pulse and pause periods. → Relay Table (figs. 378 and 379).

Quality: The sum total of properties and characteristics of a product which render it suitable for its intended use, (see DIN 55350). The time dependent component of quality is called *reliability.*
Just how comprehensive the concept of quality should be viewed, is illustrated by the so-called quality circle (fig. 117), from which the mutual influence of quality effective measures on the overal quality of the product can be seen.

Quality Control (QC): → AQL.

Quartz Crystal: A frequency determining component for filter and oscillator circuits having close frequency tolerance. Depending on geometry and electrode configuration, the frequency can be between 1 kHz and 150 MHz. Quartz crystals have very low self-damping, good chemical and physical resistance and, with balanced loading, a virtually unlimited life. The frequency tolerance is governed by:
- Quality of the ageing
- Manufacturing accuracy
- Frequency response within the operating temperature range
- Loading

Radio Interference: Unwanted high-frequency electrical occurrences in equipment, machine or plant, which can severely impair radio reception in the surrounding locality. Distinction is made between permanent interference, clicking noise, conductor associated interference (mainly between 150 kHz and 30 MHz), and random interference fields (30 MHz

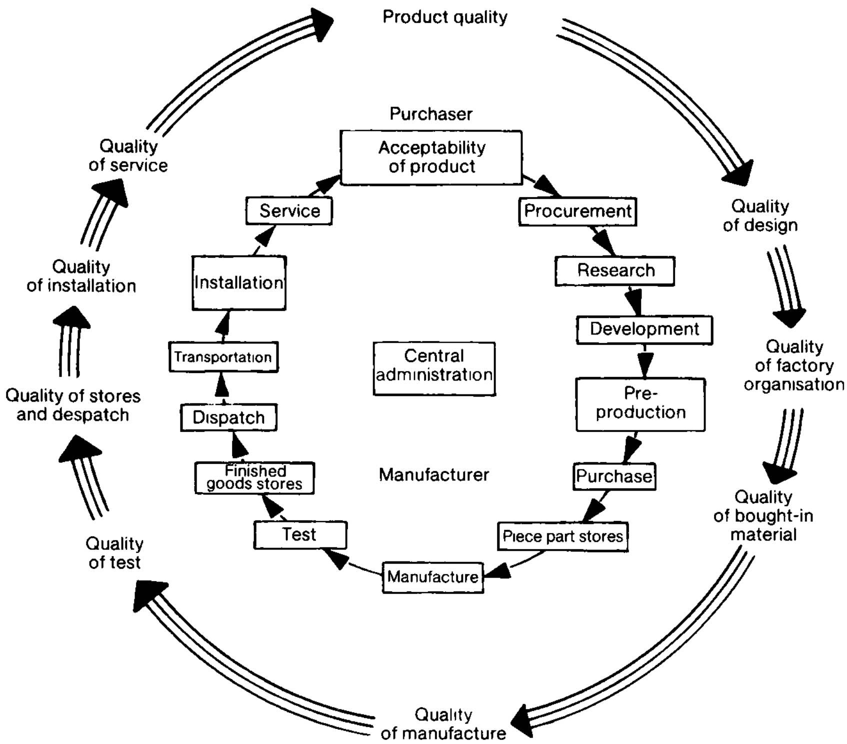


Fig. 117: Circle of quality [75]

to 300 MHz). VDE regulation 0875 distinguishes between four radio interference grades in equipment and, specifies their use in local areas, as:

Radio Interference Grade G (severe):
purely industrial areas.

Radio Interference Grade N (normal):
residential areas.

Radio Interference Grade K (small):
operation of equipment under stringent conditions of interference suppression.

Radio Interference Grade 0 (zero):
Interference free equipment.

The level of interference can be reduced through *radio interference suppression.*

Fig. 118: Radio suppression mark, degree of protection N to VDE 0875

Radio Interference Suppression: is the term used for all measures taken to reduce the *radio interference* caused by any electrical device, machine or equipment, to the permissible levels laid down in VDE 0875. Radio interference suppression can be achieved by screening the radio interference through a close meshed screen grid and by damping the noise signals which pass from the source into the lines, by connecting noise suppressing capacitors, (RC networks) and anti-interference inductors (LC components). Arc extinction on contacts or carbon brushes, through parallel connection of RC networks is often insufficient. One or more LC components would still be required (series connection).

Suitable interference filters are commercially available as filter elements in which capacitors and inductors are fully wired in a shielding container. These noise suppression devices are also built as complete mains connected units, combining the mains plug connection [37, 38, 39].

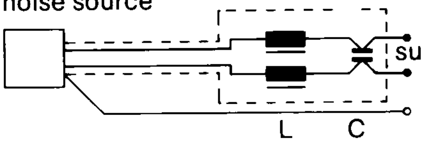


Fig. 119: Radio interference suppression diagram

L inductor
C capacitor

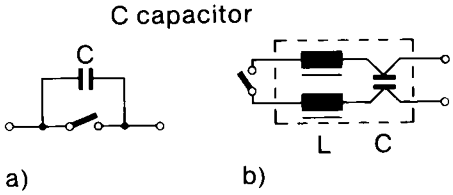


Fig. 120: Radioshield with suppression combination and shielded cables

a) Bridging with a capacitor, as in fig. 120a, provides little suppression.
b) Where the internal impedance of a contact is increased by use of inductors (fig. 120b) together with an anti-interference capacitor, good noise suppression will result.

Ratchet Relays: have a mechanical or magnetic latching facility through which the contact is held at the switched position. Releasing is either by hand or through a further control pulse.

Rated Current: The current which a relay can carry continuously under specified conditions without exceeding the permitted temperature rise.

Rated Current, Maximum: is limited mainly by the cross-section of the conductor (cross section of contact spring), and by the contact resistance.

Reactive Power (Result of the expression $I_{RMS} \cdot U_{RMS} \cdot \sin \varphi$, → 2.3 Formulae of Electro Technology): occurs with a.c. with a phase shift φ between current and voltage. It cannot be registered by a kWh meter, i.e. it is an idle load on the supply.

Recovery Time: The time which a thermo-electrical relay, delay relay or time-lag relay, requires to be operable again. → First-Cycle Effect.

Rectifier (Graetz): → Rectifier Circuits.

Rectifier Circuits: are used to convert single or multi-phase alternating current into direct current (table 28).

Reed Relays: were developed in the 'thirties' by the Bell Telephone Laboratories. Reeds literally mean, "thin, flat leaves or tongues" Distinction is made as follows:
- dry reeds: dry switching, ferromagnetic reed contacts, which have to date proved successful only as make contacts. With change-over or break contacts, the contact force is very low, the contact resistance is too high and manufacture not particularly economical.
- ferreeds: also have dry switching reed contacts, but these consist either of iron with a high remanence, or a permanent magnet flux is superimposed on them. If over-energized, the contact reed usually returns to its original position, severely limiting their range of application.
- reed change-over relays: in their polarized version, these have found a broad field of application. A relay of this type, the R-relay, which received an award from an international jury at the "Electronica 68" Exhibition in Munich, for its high technology, is illustrated in figs. 121 and 279.

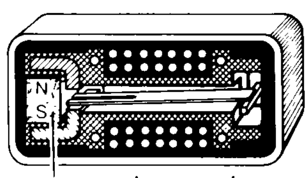


Fig. 121: Polarized reed changeover relay

In the intervening period extensive improvements have been carried out on the R-relay [20, 77, 78], such that contact re-

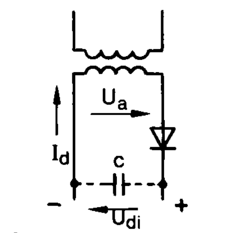
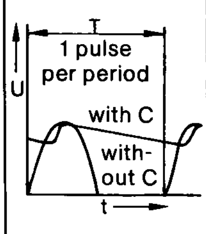
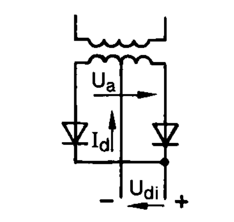
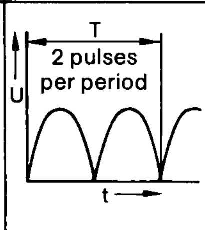
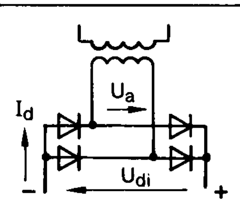
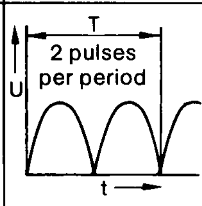
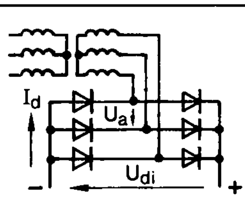
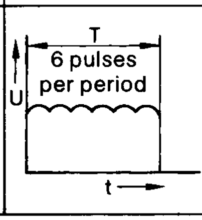
Description Short classification to DIN 41761	DC power supply diagramm U_a connected voltage U_{di} ideal no load DC voltage I_d DC current	Voltage curve T = periodic time duration of the system voltage	U_{di}/U_a	P_T/P_d P_d DC power P_T transform load	Current in branch I_Z	Notes
Single pulse centre point tapping **M1**			without C: $\frac{U_{di}}{U_a} = 0.45$ with C: $\frac{U_d}{U_a} = 1.41$	$\frac{P_T}{P_d} = 3.1$	I_d	When rectifying low level loads. C has the effect of smoothing. M3 (star connection) comprises three single-phase circuits connected to a three-phase transformer with centre tapping and then supplies a superimposed DC voltage.
Two pulse centre point tapping **M2**			$\frac{U_{di}}{U_a} = 0.45$	$\frac{P_T}{P_d} = 1.5$	$\frac{I_d}{2}$	
Two pulse bridge network **B2**			$\frac{U_{di}}{U_a} = 0.9$	$\frac{P_T}{P_d} = 1.23$	$\frac{I_d}{2}$	For loads of up to approx. 2kW (Graetz rectifier)
Six pulse bridge network **B6**			$\frac{U_{di}}{U_a} = 1.35$	$\frac{P_T}{P_d} = 1.1$	$\frac{I_d}{3}$	For loads > 2kW

Table 28: Common DC rectifier circuits

liability has been increased enormously. The R-relay has a permanent magnetic field which amplifies the energizing flux, generated by the coil, in the air gap, (contact gap), and thus gives rise to high contact force — without saturation effect. The power consumption is low. The *efficiency* of this polarized relay is approximately 50 times higher than that of non-polarized relays. That is why monostable R-relays are also polarized. In the bistable (latching) version, the influence of the ambient temperature on the pull-in voltage is largely compensated, and in all hermetically sealed versions the permanent magnet is now activated as a *getter*.

Because of their low inductance and capacitance, reed contacts are very suitable for switching HF circuits, provided the contact reed has a surface coating which

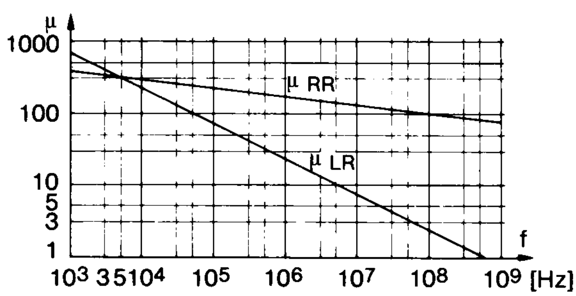


Fig. 122: Frequency dependance of real component μ_{LR} and imaginary component μ_{RR} of the complex permeability of NiFe wire (50/50)
l = 45 mm; d = 0.5 mm

takes the *skin effect* into account. Ulbricht [79] reported fully on this, and established frequency dependencies, as illustrated in figs. 122 and 123.

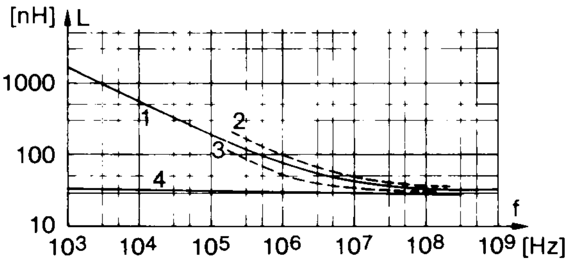


Fig. 123: Frequency dependance of inductance for miniature reed contact
1)* Calculated curve for a single strand NiFe (50/50) wire
l = 45 mm; d = 0.5 mm
2)* Measured curve — low frequency contact
l = 45 mm
3)* Measured curve — high frequency contact
l = 45 mm
4)* Calculated curve for a single strand copper wire
l = 45 mm; d = 0.5 mm
* Please check diagram carefully

Reed Resonance Relay: A relay with one or more reed shaped armatures which respond to certain frequencies.

Reflection Factor: A measure expressed as a percentage of the loss of HF energy in the antenna circuit of transmitting/receiving equipment. → HF Relays.

Relay, 400 Hz: operate on 400 Hz control voltage. The term 400 Hz relay has become common usage, because normal a.c. types are no longer suitable for this frequency, due to high eddy current and hysteresis losses. They are, above all, used in aircraft (airborne supply system ≙ 400 Hz). → SAC.

Relay Descriptions: depend on the relay application, and are thus distinguished as:
a.c. relay, antenna switching r., auxiliary r., break-in r., current r., *delay r., differential r.,* directional r., *frequency r., impulse r.,* nonsymmetry r., *overcurrent r., phase failure r.,* power r., printed circuit r., *protective r., pulsing r.,* rate-of-change r., regulating r., resistance r., *retentive type r., safety r., signal r., monitoring (= protective) r., telegraph r., telecommunication r., time-delay r., toggle r.,* voltage r. and *wiping relay.*
Or, the description depends on the construction, e.g.:
bistable (latching) *relay, center-stable r., change-over r., clapper-type r., electronic r., flat r.,* hermetically sealed r., *knife-edge r.,* make contact r., *mercury r., miniature r., monostable r., moving coil r., neutral r.,* oval r., *polarized r.,* precision r., *reed r., remanence r., rotating armature r., sealed r.,* sensitive r., *solid state r., stepping r., telephone* (round) *r., thermoelectric r.* and *universal relay* etc. It should be said, however, that round or oval relays, for example, are anything but round or oval, and many *flat*-type *relays* cannot rightly claim this description; several "miniature" relays offer sufficient unused space to house yet other *miniature relays* within. Never mind, though, since there are also such items as *"crystal can relays"* and "fifth dimension relays", which have neither a crystal can nor a fifth dimension. The problematical character lies in the entangled grouping which is subsequently reflected in statistical records. Thus it happens that relays can be found under controllers, electromagnetic switches, control equipment, amplifiers, auxiliary switching devices, time switches, selectors, solenoid-operated switches, *protective switches* etc. The servants of Parkinson's law even invented differing customs tariff classes for relays, although almost any relay can be perfectly legitimately listed in various classes. Maybe without classifications for one and the same relay, bureaucrats would lose some of their joy of life! → Relay Market.

Relay, Electric: In accordance with VDE 0435, these relays are devices which, with the influence of electrical variables (action quantities), operate other equipment via contact elements and auxiliary circuits. This can take place with or without delay. As a non-interacting, non-linear four-terminal network, the relay is one of the most important components in electrical and electronics technology.

Relay Energizing Side: Primary side, embracing all the parts of the relay which operate by receiving the electrical input information (coil) in order to operate the relay contacts (armature, nipple etc.).

Relay Market: Sales of relays are statistically very unsatisfactorily registered, especially since most of the relays can be accommodated in several groups (→ Relay Descriptions). If any relay, (e. g. a time delay relay), is sealed or used as a staircase light time switch, it presumably disappears from the statistics. Matters are made no easier when the most comprehensive statistics issued annually as an enclosure with the US magazine, "Electronics", include some absurdities. The results of the Mackintosh inquiries (table 29) represent a more useful picture.

Investigations of the ZVEI [81] brought the following results. West Germany's 1982 production values, totalling DM 634,109,000 are divided as shown in fig. 124.

	1981	1982
	Market / Prod	Market / Prod
D	TK 58 / 67 588 / 730	TK 60 / 70 611 / 770
GB	200 / 253	215 / 257
CH	42 / 33	44 / 35
S	204 / 88	215 / 92
E	55 / 15	55 / 15
N	26 / 11	29 / 11
NL	42 / 29	46 / 31
I	123 / 42	128 / 46
F	TK 46 / 37 158 / 136	TK 46 / 37 165 / 145
SF	29 / 31	31 / 35
DK	TK 11 24 / 2	TK 11 26 / 2
B	57 / 94	59 / 101
A	66 / 64	75 / 68
Total	1729 /1632	1816 /1715

US $ = 2.2 DM
TK = telecommunication relay

Table 29: Relay market/Production in DM millions, Mackintosh 1982 [80]

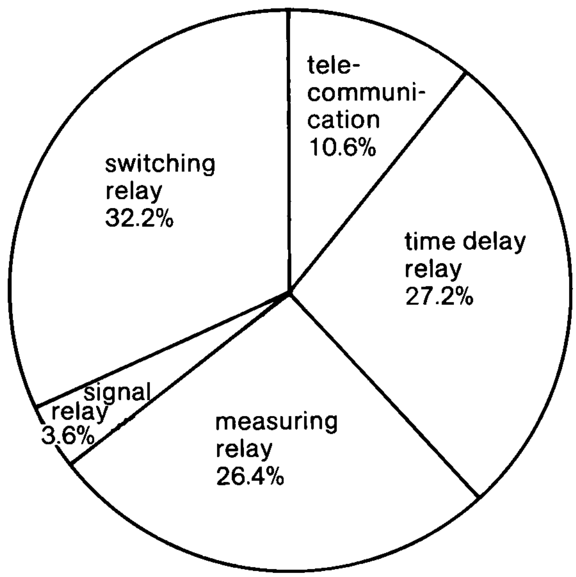


Fig. 124: Breakdown by production value of relay types in 1982 in West Germany [81]

Sales figures are shown in the graph below (fig. 125).

On the basis of extensive evaluations of various statistics, and inquiries made of suppliers and customers, the market in Europe appeared as follows:

"Relay Market in Europe 1982" (excluding contactors), in Million DM:

Federal Republic of Germany	700
Switzerland	45
Austria	65
Great Britain	300
France	250
Italy	150
Spain	40
Holland	50
Belgium	50
Sweden	200
Norway	30
Finland	30
Denmark	40
	1,950

The increase in 1983 was about 4 to 5%. For 1984, a growth rate of 7 to 8% is anticipated.

The Japanese market is roughly comparable to the German market. Measured against the export volume, however, the prodution figures are about double those of the Federal Republic of Germany.

The American market is roughly equal to the European market.

The further development of the relay market will largely depend on the adaptability of relays to modern electronics. Looking at the possibilities given in the section on *polarized relays, getters, time-delay relays* and *reliability,* the conclusion can be drawn that the benefits which relays can offer, should bring about an increase in their application (fig. 1).

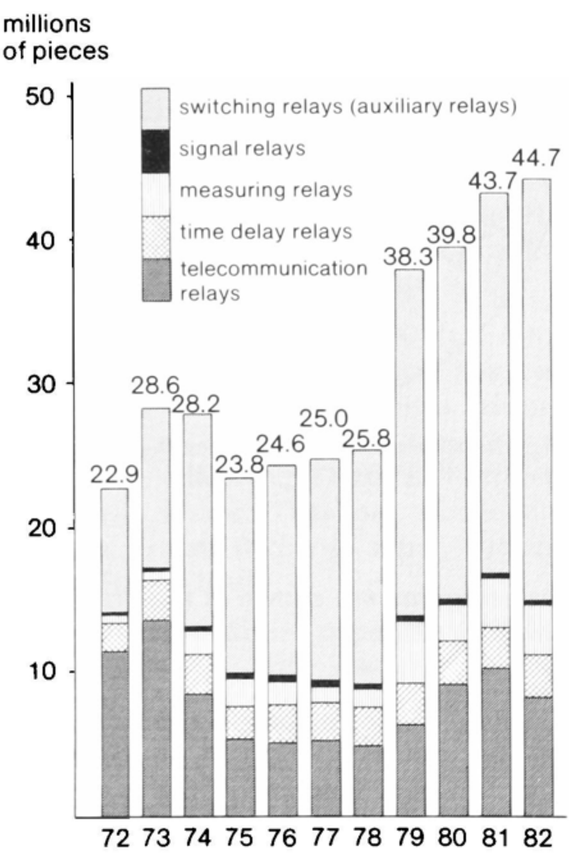
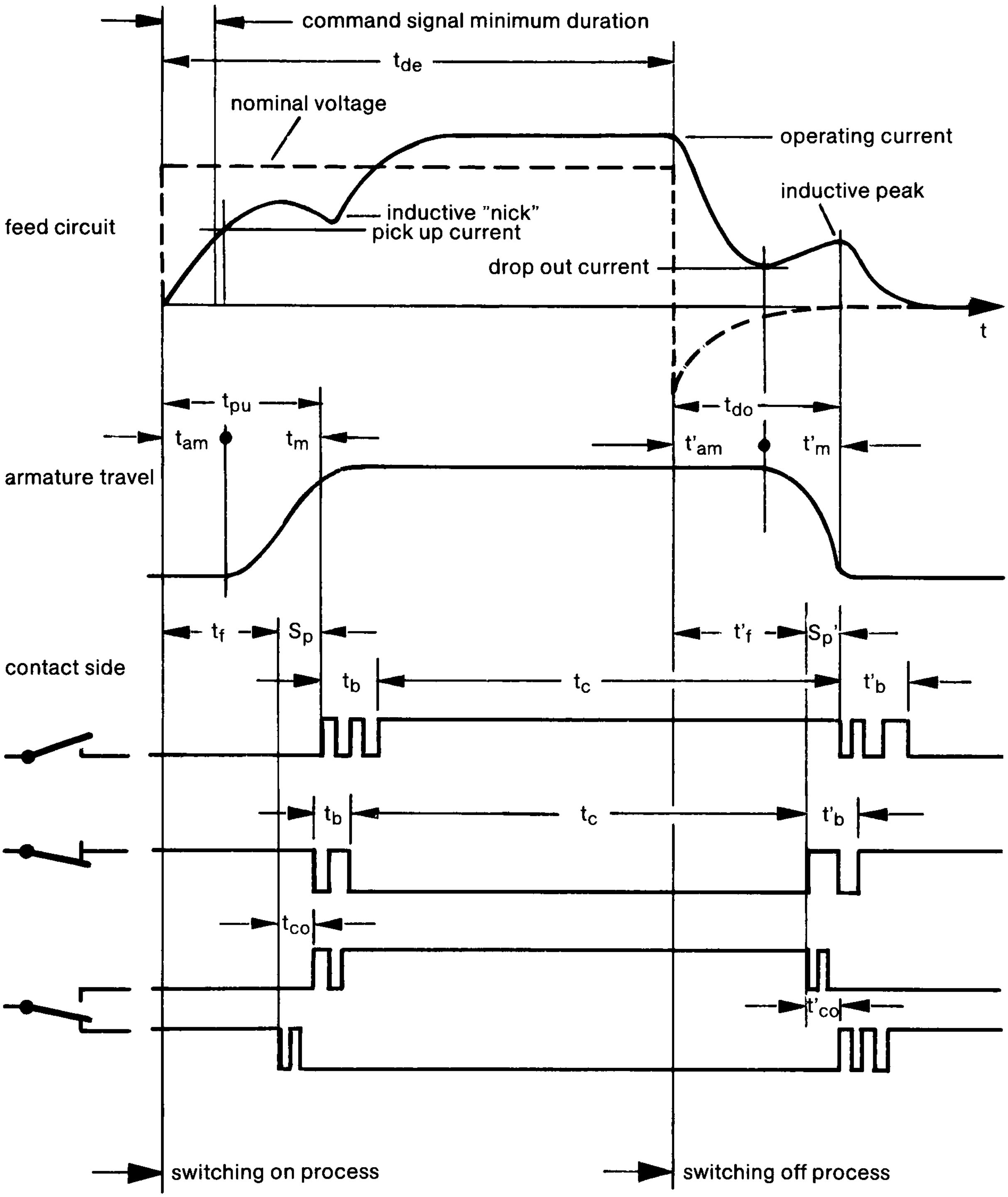


Fig. 125: West German relay market 1972 to 1982 (quantities) [81]

Relay Times: The switching times given in a switching action, are conditioned by the relay construction. They are principally governed by the electrical and mechanical time constant of the relay on energization. Although the electrical time constant $\tau_e = L/R$ can easily be calculated, the mechanical time constant τ_m, which is conditioned by mass and armature travel, is more easily established by experiment. Fig. 126 illustrates the relay times with ON/OFF switching of a monostable relay, (i. e. includes the energizing side, the armature travel, and the contact side for different contact types). The relay time data is generally related to rated energization (→ Relay Table).

An important parameter of bistable relays is the minimum duration of the command signal which will guarantee reliable operation. Command signal periods which are too short can not only cause the relay to return to its initial position, but can also switch the relay into an undefined intermediate position (unstable equilibrium), in which, for example, all relay contacts are open. What is particularly critical, is a frequently employed method of driving the relay via one of its own NC contacts, in order to reduce the power consumption or switching effort, (so called "cut throat switching"). The relay's response is, in many cases, so rapid that the coil current is interrupted at a moment when the kinetic energy absorbed by the arma-



t_{pu} = pick up time
t_{do} = drop out time
t_{de} = duration of energisation
t_c = time contacts are made

t_{am}, t'_{am} = delay in armature movement
t_m, t'_m = armature travel time
t_f, t'_f = first contact operation
t_b, t'_b = bounce time

t_{co}, t'_{co} = changeover time
S_p, S_p' = inequal contact make/break

Fig. 126: Monostable relay switching times (to DIN 41215)

ture is not quite sufficient to ensure that the effective position is safely reached, and therefore, a mid or intermediate position is adopted (possibly supported by friction).
A reliable and energy saving solution is often provided by the use of the *C-switching circuit.*
The comparison of operating methods of different relays is shown in fig. 114 (→ Polarized relays).

Release Time:

a) For normally open contacts: The time from switching off the coil energization to the opening of the contact.
b) For normally closed contacts: The time from switching off the coil energization to the instant of contact make (excluding bounce time).
c) For change-over contacts: The time from switching off the coil energization to the first contact make of the contact opposite.

The release time will be shorter, the lower the coil inductance, the lower the mass of the actuating members, the greater the restoring force and, the shorter the actuating travel. → Relay Times.

Reliability: The time dependent component of *quality.* It states the probability with which a product is capable of fulfilling certain requirements during a specified period of time, or of performing a stipulated number of operations (see also DIN 40041).
Since the profitability of a given piece of equipment begins from a certain point of reliability, and again, since excessive demands of reliability are usually uneconomic, the success of an undertaking begins with correctly balanced requirements of reliability and its control. The objective therefore is to make the characteristics of relay reliability readily recognizable and assessible. To this end, the following conditions must be taken into particular consideration:

1. Environmental conditions, such as temperature range, shock and vibration stresses, the atmosphere, humidity, sulphur and salt content etc., to which relays are exposed.

2. The type of contact loading, e.g. the magnitude of the inductance or capacitance of a switched load, the excessive inrush current of a lamp load, the switching frequency and the requirements then made of the life expectancy, quality and stability ratings. Particularly relevant among these are contact force, the contact resistance, the type of contact make, the contact protection, appropriate contact materials and the type of gettering of the contact chamber. Reliability is also often influenced by the characteristics about which there are no stipulations. For instance, the effects which the noise of a clapper-type armature, (→ White noise), the gas emissions of plastics or soldering residues, etc., have on the contacts, cannot always be compensated for by increased contact force.

An internationally, commonly applied method of evaluating the reliability of relays by means of the *failure rate* from experimental values is described in MIL-HDBK-217D for use also in commercial applications. In this document, the failure rate λ_P is established as the product of differing factors of influence:

$$\lambda_P = \lambda_B(\pi_E \cdot \pi_C \cdot \pi_{CYC} \cdot \pi_F) \left[\frac{\text{Failures}}{10^6 \text{ hrs}}\right]$$

in which λ_B as basic failure rate $\lambda_B = \lambda_T \pi_L$, with λ_T and π_L being variables which are exponentially dependent on the temperature and the contact load. An extract of individual factors is listed in the table below.

λ_T as temperature dependent failure rate

T (°C)	Relay temperature rating	
	85°C	125°C
25	0,0060	0,0059
30	0,0061	0,0060
40	0,0065	0,0063
50	0,0072	0,0066
60	0,0085	0,0071
70	0,0110	0,0079
75	0,0130	0,0084
80	0,0160	0,0090
85	0,0210	0,0097
90		0,0110
95		0,0120
100		0,0130
105		0,0150
110		0,0180
115		0,0210
120		0,0250
125		0,0310

Table 30: Failure rate λ_T versus ambient temperature

π_L as load dependent factor

S	Load type		
	resistive	inductive	lamp load
0,05	1,00	1,02	1,06
0,10	1,02	1,06	1,28
0,20	1,06	1,28	2,72
0,30	1,15	1,76	9,49
0,40	1,28	2,72	54,6
0,50	1,48	4,77	
0,60	1,76	9,49	
0,70	2,15	21,4	
0,80	2,72		
0,90	3,55		
1,00	4,77		
$S = \frac{\text{load current}}{\text{rated current}}$			

Table 31: π_L stress factor versus load type

π_E, so-called environmental mode

Environment	π_E
Stationary, in climatically controlled rooms, laboratories and test equipment, medical equipment and computer equipment	2
Stationary, in non climatically controlled and unheated rooms	4,6
Mobile, in wheeled and tracked vehicles	25
Mobile, in portable electronic equipment	63

Table 32: Environmental mode factor π_E

π_C as the contact form factor (see table 33 and *contact types*) which takes into account the number and type of load carrying contacts

Contact form	π_C
1, 2 (NO, NC) 21 (CO)	1,00 1,75

Table 33: π_C contact form factor (valid for load carrying contacts)

π_{CYC} as a factor which takes into account the number of switching operations per hour

Cycle Rate (cycles per hour)	π_{CYC}
>1000	$\left(\frac{\text{cycles per hour}}{100}\right)^2$
10–1000	$\frac{\text{cycles per hour}}{10}$
<10	1,0

Table 34: Cycle rate factor π_{CYC}

π_F as a factor which takes into account design features with differing load cases

Contact load	Application	Construction	π_F
Signal current (mV, mA)	Dry load	Armature (long) dry reed mercury wetted magnetically bistable balanced armature	8 18 3 8 14
0–5 A	General	Armature (long) balanced armature	6 10
	Sensitive (0–100 mW)	Armature (long and short) mercury wetted magnetically bistable balanced armature	 10 6 12 20
5–20 A	Medium load	Armature (long and short) mercury wetted magnetically bistable mechanically bistable balanced armature	 6 3 6 6 6

Table 35: Failure rate factor π_F referred to application range and construction

Supported by the *failure rate,* it is possible to make a very crude, albeit in most cases inadequate, assessment of the reliability of a relay in a specified application. However, if the effects of design details on the contact reliabilty are to be more precisely taken into account (i.e. collecting knowledge of importance to both user and designer), then the above listed influences must be more closely examined. It has been shown, for example, that with small and medium-sized loads, the use of bifurcated contacts results in a reliability rate approximately 50 times higher than when single contacts are used.

Where new production techniques are employed, it is almost impossible to avoid errors of a type not previously encountered. For example, fig. 19 illustrates that the initial failure rate of a new type of relay was 2.1%, even when great care was taken during manufacture. Over a period of 4 years this was reduced to 0.5%, and for a while remained at that level, until a new type of gettering brought a further (approx: 100-fold) quality improvement. The relay incorporating the new feature had an initial failure rate of 2%, despite the experience gained with this manufacturing technique, and that an additional getter was being used. However, within 2 years, the failure rate was reduced to 0.003%. Imitators of new technologies often underestimate the requirements of production know-how and will therefore seldom maintain a significant position in the market. This is another reason why knowledge of the start of production is advantageous. In section 4 line 3, the relay table lists the commencement of production of the individual relays.

In the laboratories of MEW [1], MSR [104] and SDS, the most diverse influences on the reliability of a very wide variety of types of relays are studied. Presently it is not possible to make any broad judgement, in spite of extensive tests having been carried out. By adding to these tests similar results which other companies have collected over many years of experience, by drawing the mean values and compiling the results from these, provides the list (table 36), of evaluation factors for the ratings and reliability characteristics concerned in the various load ranges. The application is explained in the example in table 37.

However, this estimation is correct only if the relay is used in a clean environment. The example shows that the evaluation factors must be based on considerations which include operational and environmental conditions.

Table 36 can, therefore, merely suggest that certain ratings should be seen in connection with the individual application, and meaningful evaluation factors set with regard to this. Further tests need to be carried out and other parameters taken into account, before the evaluation method suggested here, becomes more universally applicable.

Characteristics			Contact load range				
			Dry circuit up to 80 mV	Low level loads 80...150 mV, <20 mA	Intermediate level loads 0,15...12 V, <1 A	High level loads 12...60 V, 1...2 A	High power loads 60...380 V, >5 A
			Value factor corresponding to characteristics				
Contact force	cN	5/10/25	0,7/3/8	1/3/8	1/3/8	0,8/1,5/4	0,1/0,6/1,2
Contact bounce	ms	2/1/0,2	1/1,5/3	1/2/3	1/2/3	1/2/4	1/3/7
Contact resistance	mΩ	50/25/10	0,3/0,8/6	1/2/5	1/2/4	0,8/1,5/4	*
Coil heating	°C	50/20/10/0	0,5/1,5/3/5	1/2/3/4	1/2/3/4	1/2/3/4	0,3/1/2,5/4
Single-/bifurcated contact			0,2/10	0,5/8	1/6	*	*
Bifurcated linear contact (fig. 3)			10	12	15	5	*
Forced contact opening			1,5	1,5	2	5	6
With dust cover			0,6	1	1,2	1,2	1,2
Hermetically sealed in protective gas			3	3	2	2	1,5
Hermetically sealed contact chamber separated from the coil			4	4	3	2	*
Gettered contact chamber→ getter			20	10	5	*	*
Year of production		<1/2/>2	0,3/0,6/1,5	0,4/0,8/1,5	0,5/1/1,5	0,5/1/1,5	0,5/1/1,5

* No measured value

Table 36: Evaluation factors which largely affect the reliability of relays

Characteristics	Relay A	Value factor	Relay B	Value factor
Contact force	5 cN	1	10 cN	3
Contact bounce	1 ms	2	2 ms	1
Contact resistance	25 mΩ	2	10 mΩ	5
Coil heating	10°C	3	50°C	1
Type of contact	Single contact	0,5	Bifurcated contact	8
	forced opening	1,5	Opening by spring force	1
Type of protection	Hermetically sealed	3	Dust tight cover	1
	gettered	10	ungettered	1
No. of years of production	3	1,5	1	0,8
Quality figure	1·2·2·3·0,5·1,5·3·10·1,5=405		3·1·5·1·8·1·1·1·0,8=96	

Table 37: Example of a quality profile based on table 36 for switching a low load.
If relay A had been ungettered it would have had a quality figure of only 40.5 and in spite of being hermetically sealed would have thus been less suitable then relay B

This will include the following aspects:

1. Sliding movements of the contacts against each other so as to rub away contamination layers from the contact area, at least with ungettered relays.
2. Contact overtravel must be greater than the anticipated amount of contact wear.
3. Conductor cross-sections, e.g. 0.1 mm^2/A (min) with a CuBe *contact spring.*

4. Ratio of max. permissible coil power at 100% duty cycle, to the operating power. This provides information on the reliability of the energizing circuit, the coil heating, and the stress on the insulation of the coil wire as well as the thermal stress on components in the immediate vicinity. A coil which is exposed to frequent intensive temperature fluctuations, will "wear itself out". The coil insulation and other plastic materials will de-gas. The consequences of this are changes in the insulation values and, at least with ungettered relays, contact faults.
5. The ratio of energizing power/contact force, (the efficiency of a relay) is not just a question of reliability but also of operating costs.

If the characteristics of two relays, A and B, are compared and the allocated evaluation factors from table 36 are multiplied, the relay with the larger product (quality figure), probably offers correspondingly higher reliability (table 37).
In evaluating the influences of the getter on contact resistance, it must be remembered that the contact resistance is greatly influenced by the quality of the getter, and that the evaluation factor also takes into account the long-term effect of the getter on the contact resistance.
The best method to date of obtaining indications as to the reliability of a relay of a certain design, in a specific circuit, under definite operational conditions, is illustrated by use of the *Weibull diagram.* This provides not only for the life expectancy to be read from the position on the straight line, and the number of different failure causes from the number of curve sections; but also, above all, the breadth of the distribution, from the rise of the curve. Weibull curves with a steep rise, therefore, characterize very narrow distributions and thus reflect a high reliability of the relay, up to the beginning of the curve (fig. 167).

Reliability Characteristics in relays: are very difficult to recognize, even for the expert, and they are rarely mentioned in the data sheet. An example of this is illustrated in fig. 127 in a simple relay illustrating 15 characteristics.

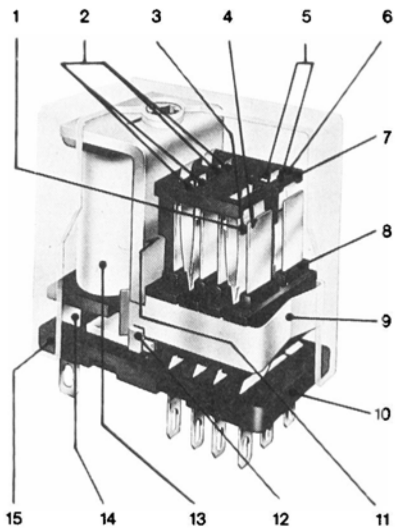


Fig. 127: Features for reliability (e.g. K-relay) → relay table

How these features affect the reliability at various loads in terms of numbers, is shown in table 38 in a comparison of the types I, II, III, IV and V for single contact relays of the same size as the K-relay. In spite of the higher contact force and energizing power of versions I and II, the K-relay (→ Relay Table) even after elimination of the contact load without faulty switching and taking all faulty switching actions into account, is still 108 times more reliable in arithmetic average. This does not include hermetically sealed 'K' relays.

1. The bifurcated contacts are semi-cylinders (fig. 3), they provide linear contact make and short-circuit protection of 120 A/0.8 ms.
2. NO and NC contacts are mechanically independent of each other, loaded only unilaterally, and, therefore, of high durability.

	No. of samples tested	Pick up power mW	Contact resistance mΩ NO*)	Contact resistance mΩ NC*)	Relationship max./min.	Contact bounce time ms max. NO*)	Contact bounce time ms max. NC*)	Contact bounce time ms min. NO*)	Contact bounce time ms min. NC*)	Contact force cN NO*)	Contact force cN NC*)
Bifurcated contact relay (type K)	24	182	27	24	2,25	0,14	0,03	0	0	13,5	14,2
Single contact relay Type I	10	255	10	9,5	2	0,38	0	0,2	0	19,6	14,9
II	10	360	19	16,7	6,6	0,67	1,3	0	0		
III	4	210	12	15	6,6	0,27	0,42	0	0,2		
IV	6	160	62	13	11	1	0,4	0,2	0	7	7
V	6	265	12	12	2	0,3	0,37	0,1	0		
Average value		243	30	14	5,6	0,52	0,5	0,1	0,04		

*) NO = Normally open contact
NO = Normally closed contact

Contact loading	10 µA, 30 mV limit value 100 Ω			10 mA, 10 V limit value 40 Ω with 4 contacts in series			100 mA, 30 V limit value 10 Ω		Relay type	
	1st failed switching operation	No. of switching operations	Total of faulty switching operations	1st failed switching operation	No. of switching operations	Total of faulty switching operations	No. of switching operations	Total of faulty switching operations	No. of switching operations	Total of faulty switching operations
K4-24V-1	–	2 318 400	0	8 850 450	8 861 050	1	1 560 000	0		
K4-24V-1	1 627 200	2 318 400	108	5 355 570	6 044 370	11				
K4-24V-1				6 830 610	7 462 290	21				
K4-60-1				7 950 240	9 696 240	16	1 560 000	0	322 600	0
K4-60-1				6 479 520	6 688 320	15			322 600	0
K4-60-1				3 636 480	9 095 620	5				
Average value		2 318 400	54	6 382 145	7 984 581	11,5	1 560 000	0	322 600	0
I		336 400	0	111 040	150 720	10	302 800	0	273 300	1
I	4800	336 400	295	65 280	70 560	13	1 560 000	15	260 600	0
II				1 493 700	1 518 270	25	1 560 000	1	260 600	0
II				262 860	269 490	24	1 560 000	7	273 300	0
III				45 120	45 130	11			203 000	0
III				556 320	557 280	11			203 000	84
IV				96	145 440	36			16 800	1
IV				528	1 872	16			16 800	0
V				48	12 096	22			18 900	0
V				36 000	36 960	16			18 900	0
Average value		336 400	147	257 099	280 782	18,4	1 270 700	5,75	154 460	8,6

Table 38: Resulting reliability of contact make with 6 relay types of same design

3. A 20 µm gold foil is rolled onto the silver center contacts, which not only increases the corrosion protection, but also guarantees reliable operation in applications for dry as well as power circuits, with low and almost constant contact resistance.
4. The Ag fixed contacts are rolled onto corrosion-proof German silver.
5. Bilateral, forced contact opening, reduces contact sticking possibility.
6. Bilateral contact make is only at armature speed and, therefore, is almost free from bounce.
7. Actuating comb of abrasion-proof polyamide prevents formation of dust.
8. A stable contact spring set embedded in polyamide guarantees stable ratings and high insulation stability.
9. Retaining spring ensures permanent preloading of the spring set, and stable ratings over many years, because no loss of insulating material can result in a loosening of the contact spring set.
10. The baseplate is connected only with the cover: There is, therefore, no thermal or mechanical influence on the characteristics.
11. An additional armature air gap increases the efficiency of the *magnet system* by approx. 30% and allows higher contact forces.
12. The yoke carries all the relay parts virtually free from play and tolerances.
13. The coil is wound without kinks, over a plastic covered, oval soft-iron core, with heat-resistant polyurethane-insulated Cu wire.
14. Coil connections are embedded in the bobbin.
15. Special designs in hermetically sealed, transparent housings, with approx. 20% protective gas loss over 10 years, afford additional reliability under the most severe environmental conditions. → Sealed relays.

Remanence: also called remanent induction, is the induction which remains in a ferromagnetic relay after the external magnetic field has been switched off. Distinction is made between true remanence (completely closed iron circuit), and apparent remanence (not completely closed iron circuit). In relays, it is usually the apparent remanence that must be reckoned with. → Magnetism.

Remanence Relay: Relays which due to the remanence of the iron circuit remain in the operated condition, even when the energizing power is missing or is subjected to large fluctuations. In order to keep this residual magnetism as large as possible, the magnetic iron circuit, or parts of it, are manufactured from carbon steel or permanent magnets. The drop-out of the relay is triggered by a counter-excitation (polarity reversal), which has to be much weaker than the pull-in energization. By contrast to the *polarized relay,* the permanent magnetic flux in the remanence relay lies in the electro-magnetic circuit (figs. 128 and 129).

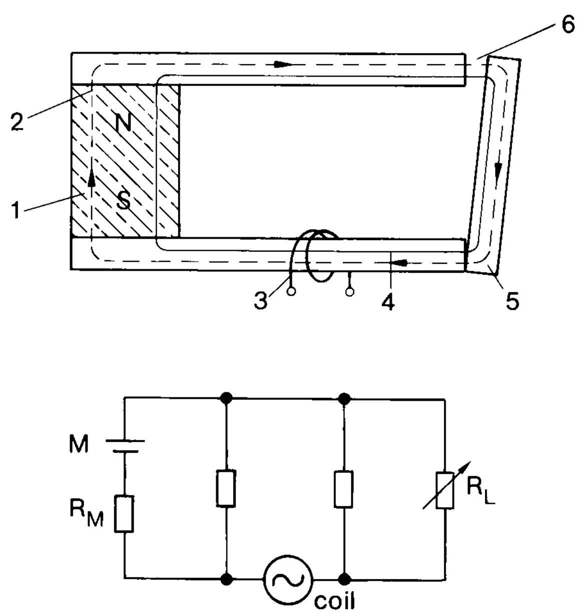


Fig. 128: Magnet system of a remanence magnet relay and its equivalent circuit

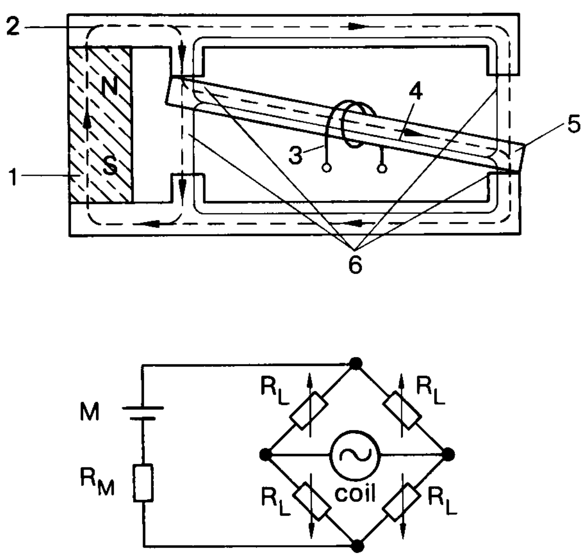


Fig. 129: Magnet system of a polarized bistable (latching) relay and its equivalent circuit

Applications:

1. Relays which are to remain in the operated condition for a long period.
2. Relays which must remain in the operated condition, even when the power fails in the control circuit, e.g. air-raid warning equipment and emergency standby units.
3. Relays for which only one control pulse (capacitor kick) is available for the energization, and which must remain operated until a counteracting pulse occurs.

In principle, a polarized relay fulfils all these conditions with lower power consumption and more reliability. Remanence relays are less reliable because, with a drop-out energization of similar magnitude to that of the pull-in energization, the armature may pull-in again after a brief drop-out. Furthermore, the time-related operating characteristics, especially under the influence of heat, and the vibration resistance, are more difficult to control than with polarized relays.

Reset Spring: effects the resetting of the armature into its position of rest. It is advantageous to arrange for the spring force to be variable so that the drop-out, pull-in and holding values can be set as required.

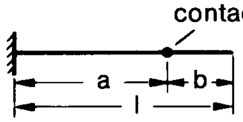
Reset Time: → Release Time.

Residual Air Gap: is the description for the air gap which remains at the armature end position, between the armature and the core/yoke. Since the magnet forces generally rise very steeply with the approach of the armature to the core, a definite air gap prevents "armature sticking", (→ Sticking) and influences (stabilizes) drop-out, holding and pull-in values.

Residual Ripple: is the a.c. voltage which remains after smoothing, and is superimposed on the d.c. voltage. Rectified voltage is smoothed by filters.

Resonance: describes the phenomenon in an oscillatory structure which manifests itself when, on being excited by a multiple of the natural frequency (→ Resonance frequency), it begins to oscillate in sympathy, and in this process, the amplitude of oscillation can become very large, (dependant on the damping).
The individual components of a relay also show resonance at certain frequencies. In the fully assembled relay, numerous resonance frequencies can additionally occur, which, even with low energizing power, can lead to destruction of the component.

Resonance Frequency: The frequency which is inherent in an oscillating system. The magnification or build-up of the amplitude which occurs on excitation with this frequency depends on the self-damping. The mechanical resonance frequency of a contact spring is given in fig. 130.



$$\omega = \sqrt{\frac{12E\,Jl^3}{a^3 b^2 (3l + b)\,m}}$$

Fig. 130: Resonance frequency of a contact spring

The parameters used are explained as follows:
E = elasticity module [N/mm^2]
J = 2nd moment of inertia [mm^4]
m = mass of oscillating body [kg]
The resonance frequency of an electrical resonant circuit is calculated from:

$$\omega = \sqrt{\frac{1}{LC}}$$

→ 2.3 Formulae of Electro Technology.

Resonance Relay: as a rule, operates with the inherent frequency of the armature and contact spring mass, which is matched to the frequency of the control current. Rauch and Überschuß have published interesting findings on this [82].

Resonant Circuits, Electrical: Circuits which contain an inductance and a capacitance, coupled either in series or in parallel. On switching of these circuits, oscillations occur (i. e. the build-up of electrical and magnetic fields which periodically alternate), but due to the presence of resistances, these oscillations are always damped. The oscillations can represent an additional electrical stress for a switching contact.

Rest Position: The position of the armature and contacts of a monostable relay in the non-energized state.

Retentive Type Relay: A relay in which the armature is held in the open position by a permanent magnet. → Polarized Relays.

Return Loss: occurs when a line is not terminated with its characteristic impedance, or when lines with differing characteristic impedance are coupled. At the location of the mismatch, a wave which returns to the beginning of the line is created due to reflection.

Ripple: The percentage ratio of the effective value of the a. c. voltage portion of a rectified voltage to the mean value of this d. c. voltage.

Rotating Armature Relay: A relay with a center-of-gravity supported armature which, together with the yoke legs or the magnet core, forms two or four air gaps. The armature may be equipped with a soft magnet or with permanent magnets.

SAC Coil: Sensitive Alternating Current Coil (with bifilar winding), without eddy current and demagnetization losses for a large frequency range. Energy saving up to 90% at 50 Hz, approx. 9% at 400 Hz and usable also in the kHz range [83]. At date of publication endurance tests were still being performed.

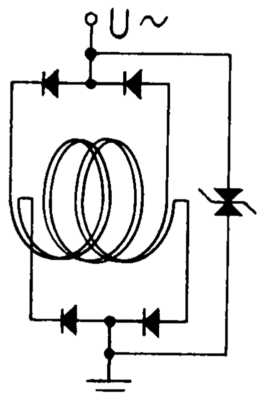


Fig. 131: SAC-coil circuit

Safety Relay: must comply with special safety regulations for controls on power operated presses (ZH1/457) or the conditions for rail signalling equipment (UIC Code), where *forced contacts* and minimum separations of contacts in the event of failure are prescribed (fig. 309).

Saturation, Magnetic: is that range of the magnetization curve in which, with high field strength H, the magnetic induction B, increases only proportionally to the field strength H.

Schmitt Trigger: Threshold switch (monostable *multivibrator*). Fig. 132 shows a common form of the circuit.
The threshold value of the input voltage U_e required for tripping is set on the potentiometer R_5. The transistor T_2 is conductive in the rest condition, since negative potential is applied to its base via re-

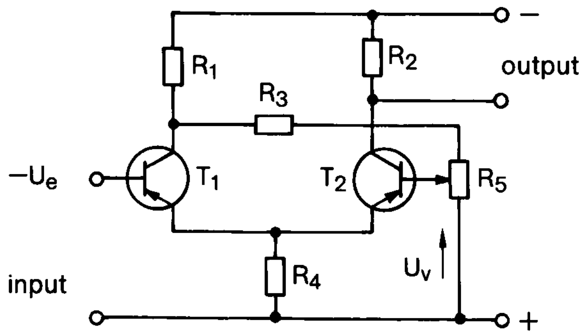


Fig. 132: Schmitt-Trigger circuit for low impedance input control signal

sistances R_1 and R_3. The collector/emitter current of transistor T_2 will assume such a high value that the voltage drop on resistor R_4 is smaller, by the value of the base voltage, than the reference voltage U_V, set by potentiometer R_5. For transistor T_1 to become conductive, to initiate the tripping action, it is necessary for the input voltage U_e to be larger than the sum of the voltage drop on resistor R_4 and the threshold value of the base voltage of T_1. This threshold value is similar to the base voltage of transistor T_2. The voltage U_V is therefore approximately as large as the threshold value of the input voltage for releasing the trigger action. With pnp transistors this voltage must always be negative relative to the emitter or, in this case, the positive pole of the battery. As soon as an input voltage of the required size occurs, transistor T_1 becomes conductive. The potential on its collector changes against positive values. This change of potential is transmitted via resistor R_3, to the base of transistor T_2, which then shuts off. There is a corresponding jump at the output. The trigger remains in this position until the input voltage disappears or falls below the threshold value.

Sealed Relay: A collective term for relays which are hermetically encapsulated in a housing. Originally, the potting consisted of a metal cover and a metal baseplate, which housed glass-to-metal sealed connections for contacts and coil. The cover and baseplate were soldered together. The housing was provided with an opening which, after evacuation and filling with protective gas, was sealed by soldering. It was difficult to prevent soldering vapours or flux residues from entering the relay interior and contaminating the protective gas or the contacts. These problems were largely eliminated by modern welding processes.

A much more economical method of encapsulation is the sealing of the plastic cap and baseplate by means of other plastics [20]. For a long time it was believed that adequate gas tightness could not be achieved with plastics. Tests showed, however, that with normal fluctuations of the atmosospheric pressure, protective gas losses could be held to as low as 10% by such encapsulation, over a period of 10 years, which meant that they also satisfied the test specified by MIL STD-883A. There was a problem at first to effectively seal the connections through the baseplate, but eventually, several practical solutions were found [19]. → Reliability.

Fig. 133 shows the contact resistance change of three relay types which were exposed to an H_2S atmosphere in both dust protected and plastic encapsulated versions, for up to 5000 hours. The differing contact resistance increase of the relays having only dust protection covers is based on the following data:

Relay type:	K	NF	HC
Contact form according to figure:	3	3	2
Contact force cN:	11	8	15
Contact material:	Au/Ag	Au/Ag	AgCdO gold plated

Whereas the K-relay, thanks to the reliability of its contact operation (bifurcated linear contacts, 11 cN) is still functional even in an H_2S atmosphere, a reduction of 3 cN in contact force is sufficient in the

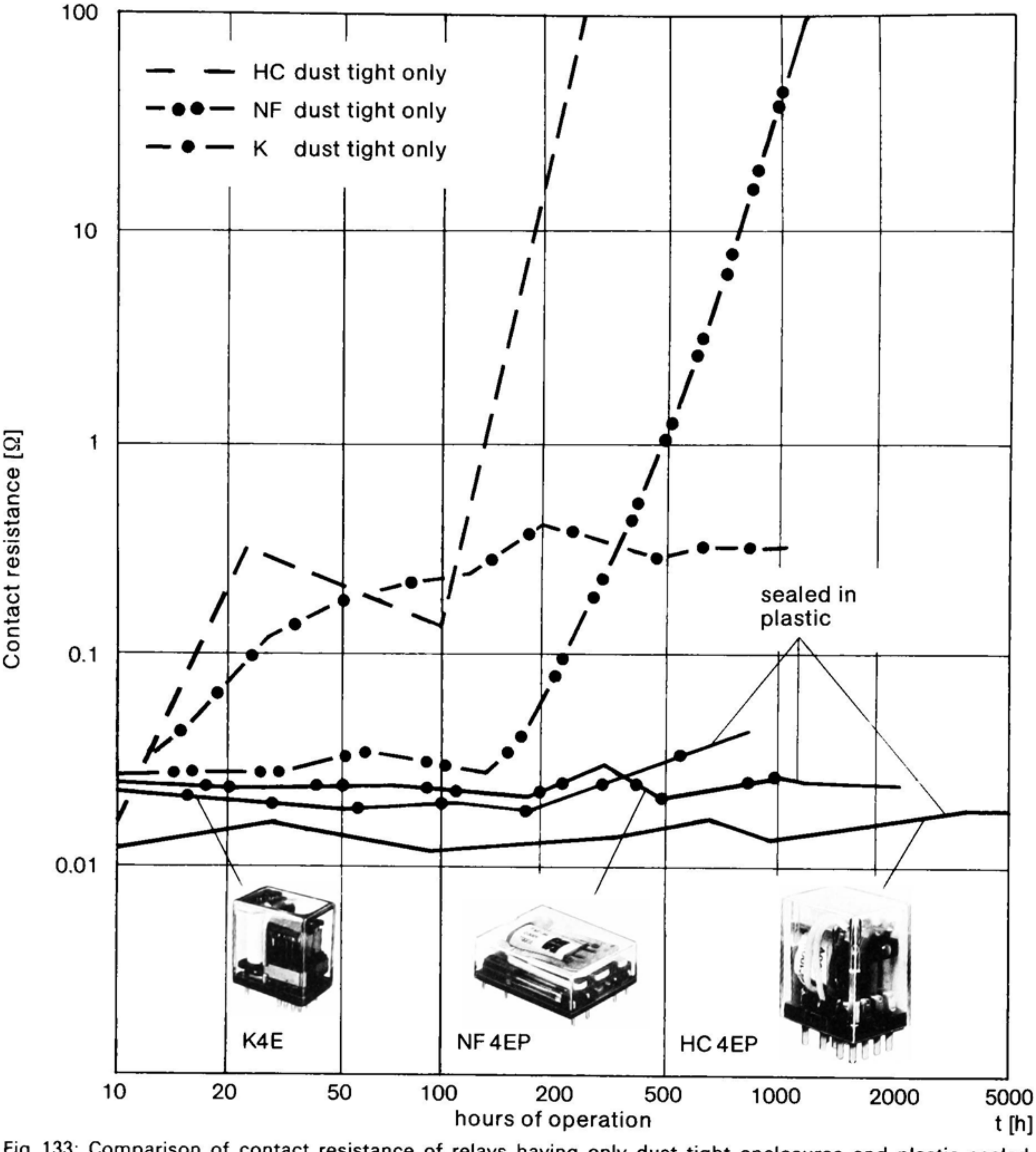


Fig. 133: Comparison of contact resistance of relays having only dust tight enclosures and plastic sealed relays in H_2S atmosphere

NF-relay to result in a contact resistance increase to more than 1 ohm after only 500 hours. The reason for the rapid contact failure in the HC-relay, in spite of the higher contact force, results from the relay having a single non-bifurcated, riveted contact with gold plating of only 1 μm thickness. In the plastic encapsulated versions, the contact resistance behaves as if no H_2S atmosphere existed.

Seebeck Effect: is one of the *thermo-electrial effects* and is the cause of *thermo-electromotive force.*

If two different metals touch, electrons will pass from the metal with the lower electron affinity to the metal with the higher electron affinity, until the *contact voltage* which results, blocks the electron flow. This contact voltage depends on the

metals used and their temperature, (thermo-electromotive force).
If the two metals are connected to form an electrical circuit and if both contact points are heated to different temperatures, the contact voltages (thermo-electromotive forces) no longer compensate each other, and a thermo-electric current flows, which draws its energy from the heat source. → Thermocouples.

Selector Switches: are used for the manual selection of circuits.

Self-Cleaning Contacts: rub against each other during contact make. → Contact resistance, → Tribology of electrical contacts.

Self Heating: Temperature increase of a device due to the power loss which occurs in the device during operation, (e.g. of the coil and the contacts in a relay).

Self Inductance: The property of a coil, if a current change is forced upon it, to generate a voltage which counteracts this change.

Self Inductance Coefficient: also called the A_L value; it is used to calculate the coil inductance. The A_L value is a measure for the inductance of a winding. The product of the A_L value and the square of the number of turns, will give the coil inductance.

Sensitivity of a relay: is the property to operate with low power consumption, (i.e. to pull in or drop out). Very sensitive relays are, *polarized relays* and *moving-coil relays.*

Sensor: A component for the recognition and detection of physical conditions. Distinction is made between:
pressure sensors,
humidity sensors,
light sensors,
temperature sensors,
magnetic field sensors,
infra-red sensors, etc.,
and combinations of these.

Separating Height: The separation of the residual air gap given by the separator.

Separator: Separating pin, also called anti-freeze pin. With pulled-in armature, it effects a magnetic residual air gap, either to ensure safe drop-out of the armature after energization, or to bring the drop-out value nearer to the pull-in value.

Sequence Action Change-Over Contacts: Sequenced make — break contact (F.NO.NC) → Contact types.

Sequencers: Microprocessor controlled circuitry, or stored programmable instructions, with electromechanical and/or electronic outputs. They are now used instead of *step-by-step switches*, for measuring, controlling and regulating tasks of the more complex type (see DIN 19237/19239).

Fig. 134: PL40 sequencer from SDS

Shearing: Dislocation of the *working point* of a magnet system, closer to the *coercive field* H_C, by increasing the working air gap or increasing the magnetic resistance of the magnetic circuit.

Shielding: Elimination of effects of electrical or magnetic fields on electrical, electronic or magnetic components. A soft-iron shielding cover is generally sufficient for shielding relays. → Magnetic Shielding, → Radio Interference Suppression.

Shock Resistance: This denotes an acceleration in g (force due to gravity), the duration of which is specified in IEC 68-2-27 or NARM Std. RS401-A. There must be no contact interruption of more than 10 μs duration and no damage.

Short-Circuit Ring: (shading ring) is usually of copper, and embraces either part of the core or of the armature at the pole faces. It extends the relay times and prevents humming in a. c. relays. → Delay Winding.

Short-Circuit Withstand: The withstandability of any switchgear in the operated condition, or any of its components (e. g. tripping device), against the electrodynamic and thermal stresses occurring in the event of short-circuiting. The determining parameters of the short-circuit withstandability are:
- for dynamic loading, the *surge current* as the highest momentary value of the short-circuit current;
- for thermal stress, the *short time current* as the root-mean-square value of the short-circuit current over its duration.

Short Time Current: In accordance with DIN IEC 255, part 0-20 or VDE 0435, part 120, the short time current of relay contacts must be carried for 1 sec., without any damage resulting to the contact and its environs.

Signal Relay: A switching relay for the transmission and indication of messages (in accordance with VDE 0435).

Skin Effect: The resistance increase of an electrical conductor in which eddy currents occur caused by alternating magnetic fields penetrating the conductor. The eddy currents cause an irregular current distribution over the conductor's cross-section (current displacement) and, thus, reduce the effective conductor cross-section with increasing frequency. The higher the frequency, the more the current flow into the "skin" (→ Contact resistance). For this reason, HF conductors consist of several individually insulated stranded wires, or thin-walled tubes.

Snap-Action Switches: have a spring action mechanism which is actuated by means of a specified force over a specified distance of travel. In the resulting indirect switching action, the switching speed is largely independent of the actuating speed (fig. 80). The contact opening travel is usually smaller than 3 mm.

Snap-In Systems: Generally, these are snap-in fastening systems in which dismantling is possible only with tools.
Fig. 135 shows a *snap-action switch* which is inserted into an adaptor and held by two lateral spring loaded "fingers" All that is necessary for its removal is to spread the "fingers" clear with a screwdriver.

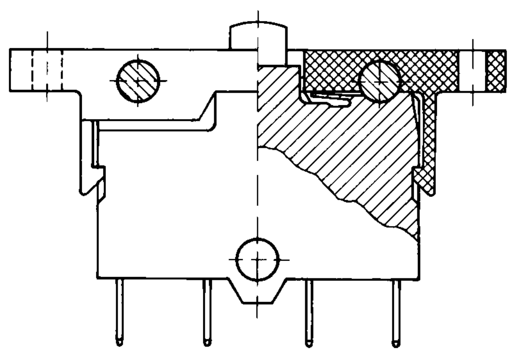


Fig. 135: Section of a snap action switch which can be screw or adaptor mounted

Snap-in systems are also used in relay sockets. The S-NS socket, (fig. 136) for the S-relay, (→ Relay Table) even has snap-in facility for chassis mounting with differing wall thicknesses.

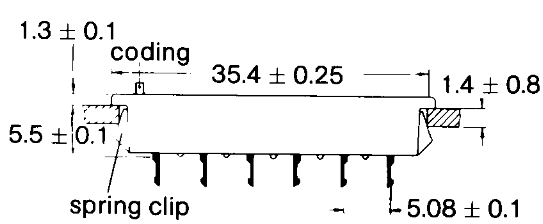


Fig. 136: S-NS plug-in socket from SDS with spring clip

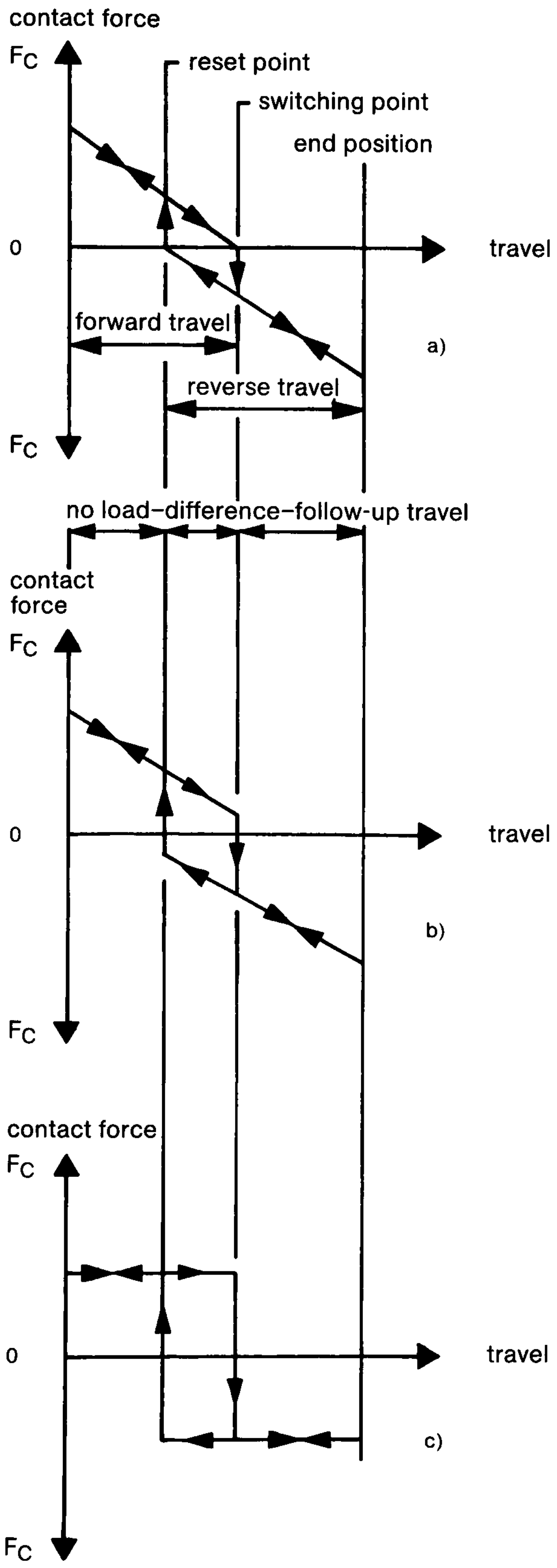


Fig. 137: Contact force shown in relationship to travel (→ snap system of a snap action switch)

Snap-System of a snap-action switch: The contact force in *snap-action switches* is largely independent of the actuation. With very slow actuation, (i.e. with very low operating speed), an influence of the snap system on the contact force is noticeable. The differences are shown in fig. 137. The terms used in the diagrams are defined in DIN 41635. Distinction is made between single snap-action systems with or without friction influence and double-snap action systems.

a) Single snap system:
   The contact force drops to zero until change-over.
b) Single snap system:
   The contact force is determined by the friction in the system before change-over.
c) Double-snap system:
   The contact pressure is almost fully maintained until change-over.

Socket: A connecting element with plug-in and wiring sides. The volume resistance of a good plug-type connection is between 1 and 4 mΩ. Its use is justified, if:

a) during the life of the unit the replacement of a relay is to be anticipated, or
b) during soldering either too high a temperature or soldering vapours can affect the operability of the relay.

Due to multi-cone configuration of the connection side of the plug-in contact springs (fig. 138), sockets have become safer in operation, more economical with regard to storage, as well as more convenient and time saving for wiring.
The conical form of the sprung plug-in flanks ensures smooth insertion of the wire into the lug (approx. 30% time saving over lugs which do not have this conical form for insertion).
Another conical form of the actual lug allows the sprung plug flanks (fig. 138) to exert a contact force on the conducting wire located within, thereby ensuring that

a possibly bad soldered joint ("cold soldered joint") will not disturb the function of the component plugged in.
Conically shaped ends form a guiding tip, which facilitates insertion into printed circuit boards.

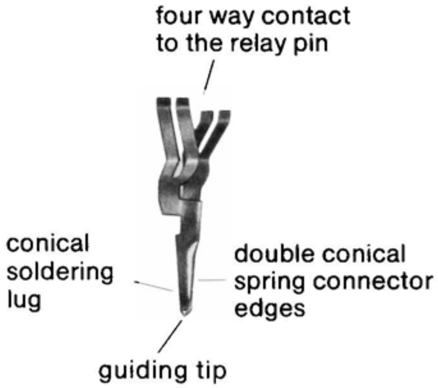


Fig. 138: Multi concial socket contact spring [92] with the same advantages whether used for conventional wiring or p.c.b.

When used in plated-through-hole PCBs, contact make occurs even before soldering, due to the double-conical, sprung plug-in flanks.
A socket for the K-relay (→ Relay Table) with multi-conical contact springs, as illustrated in fig. 138, is shown in fig. 139.

Fig. 139: Plug-in socket, type K4-S (SDS) with 10, 14 or 20 socket springs as shown in fig. 138

Softening Voltage: → Contact Resistance.

Soldering: The joining of metals by means of a melted metal additive (solder), with the application of a flux.
The melting temperature of the solder is lower than the melting temperature of the metal parts to be joined.
Soft soldering means soldering at a temperature below 450°C. Hard soldering is soldering at a temperature above 450°C.
The media for the soft soldering process mainly used in the electrical industry (flame, soldering iron or dip soldering) are largely specified in DIN 1707 (soft solder for heavy metals) and DIN 8511 (flux for soldering of metallic materials).
According to DIN 8511, abbreviated symbol F-SW 31/32 (F = Flux, S = Heavy Metal, W = Soft Soldering), the majority of applications use flux composed on the basis of natural or modified natural resins without additives, or with organic, halide free activators. These fluxes are available as powders, fluids, or as a filler in the soldering wire (resin cored solder). Although flux residues may be left on the soldered area without risk of corrosion, it is advisable to remove any brittle remnants of resin, since these particles could cause mechanical failures. There are numerous solvents available on the market for efficient and rapid cleaning in conjunction with a steam bath or an ultrasonic bath.
The properties required of the soldered areas necessitated the development of a multitude of alloying systems whose temperature behaviour is different from that of the base metals. Soft solders represent the simplest case because they concern mainly two-component alloys.
It is clear from the Lead/Tin diagram (fig. 140), that, for example, an alloy with 40%

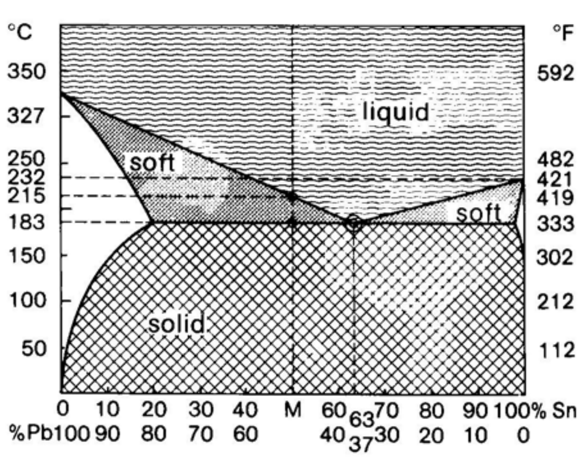


Fig. 140: State diagram of lead — tin alloy

tin, changes to a soft state as the temperature increases above 183°C. Solid and molten components exist side by side. Of particular interest is the eutectic composition with 63% tin and 37% lead. In this case, the alloy transforms directly from the solid to the liquid state, without passing through the soft phase.
This eutectic solder melts and solidifies the quickest, and it is the best to work with, provided there is no contamination. Fig. 141 shows the soldering process in detail.

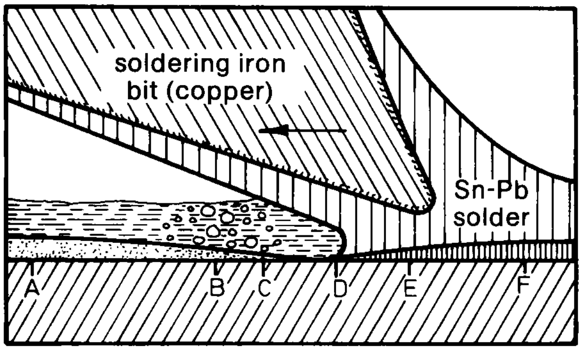


Fig. 141: Displacement of flux during soldering

Solenoid: → Plunger Relay.

Solid State Relay (SSR): Contactless, pure electronic relays, e.g. electronic switches with transistors or thyristors. The electrical separation between input and output is usually effected with the aid of an optocoupler (→ Relay Tables).

Space Factor: percentage proportion of copper on the winding cross-section of a coil. It depends on the type of winding, the tension of the wire during winding, the insulation and the wire dimensions.

Springs: → Contact Springs.

SSR: → Solid State Relay.

Stability of permanent magnets: is the capability of *magnetic materials* to retain their magnetic properties, unchanged, over a specified period of time. Any changes which occur are generally divided into:

a) reversible, time-dependent magnetization changes: They are logarithmically time dependent [89]. As a rough approximation, the inductive drop of the first 10 hours is equal to that of the following year, and then of the next 1,000 years [90]. In most cases, these changes are smaller than 1% and, in practical application, are allowed for by virtue of a definite weakening (in the alternating magnetic field), after remagnetization.
b) reversible magnetization changes due to temperature influence: permanent magnets change their magnetic condition in relation to temperature, (→ Temperature Compensation). After regaining the original temperature (where changes are not too great, → Curie temperature), the initial magnetic condition is re-established.
c) irreversible changes of structure: These occur when materialspecific temperatures are exceeded, sometimes under mechanical influences, and cannot be remedied by remagnetization [91].

Standards and Specifications: In the widest sense, standards may be regarded as rules of a game, to which the manufacturers of products submit voluntarily in order to simplify the use of the products for the users, e.g. interchangeability.
Specifications however, stipulate a lower limit for safety requirements, e.g. creepage and clearance distances, which are very frequently covered by legislation.
Many countries permit the use of electrotechnical products which are produced in accordance with applicable specifications, under the manufacturer's own responsibility, but several countries have made approval compulsory (Table 39).
With the increasing influence of the IEC specifications, national requirements are receding into the background, with the exception of the USA and Canada. In Germany, the VDE specifications rule ex-

tensively. The VDE specifications complex can be divided into the following groups:

Group 1.
Specifications for Power Installations.
Relays and mini-contactors are governed by VDE 0110/11.72.
"Specifications for clearances and creepage distances in electrical equipment"

Group 2.
Cables and Flexible Cords for Power Systems.

Group 3.
Insulating Materials.

Group 4.
Measuring and Testing.
Applicable to relays in this group: VDE 0435/9.62 and 0435a/9.72
"Rules for electrical relays in power plants"

Group 5.
Machines, Transformers, Conventors.

Group 6.
Installation Material, Switchgear and High-Voltage Apparatus.
Applicable to contactors in this group: VDE 0660/9.82, part 102 and part 203. "Contactors" and "Additional requirements for contactor relays"

Group 7.
Current-Consumer Appliances.
e.g. VDE 0700/2.81 part 1, "Safety of house-hold and similar electrical appliances"

Group 8.
Communication and Broadcasting Installations.
e.g. VDE 0806/8.81 "Safety of electrically energized office machines"

In addition to the industrial standards and specifications, there are special specifications for military applications. The most important of these specifications — regarded worldwide — is still the MIL-R-5757 (Relays, Electrical, for Electronic and Communications Type Equipment). Most of the other specifications for military applications of relays are based on the essential passages of this "basic specification" MIL-R-5757. Alongside this, the specification MIL-R-39016 (Relays, Electromagnetic, Established Reliability), has become important in recent years. It differs from MIL-R-5757 by virtue of definite reliability classes and requirements for repeat tests. The reliability class L of the MIL-R-39016, corresponds to the level of MIL-R-5757. There is a possibilty of MIL R-5757 being replaced by MIL-R-39016. This would mean that relay manufacturers incur higher testing costs, since considerably more life-test facilities would be required. The testing process itself, as specified in MIL-R-39016, is simpler than the one specified under MIL-R-5757. The Federal Republic of Germany has a specification, VG 0095302 (Basic Specifications, Electromagnetic Relays), which is based on the requirements of MIL-R-5757. The requirements of MIL-R-39016 form the basis for the requirements of the GfW (Gesellschaft für Weltraumforschung = Society for Space Research). In this, SR 100 (Group Specification, Relays), a part of the costly destructive testing which is required by MIL-R-39016, has been replaced by monitoring steps during the relay manufacture.

Start-Up Time:
a) On switch-on: The time from the beginning of coil energization to the commencement of armature movement.
b) On switch-off of monostable relays: The time from the end of coil energization to the commencement of armature movement.

→ Relay Times.

Static Measuring Relays (SMR): Electronic relays which fulfil their measuring task through electronic, magnetic or other means — without mechanically

Country	Name of Approval Society	Identification mark	Identification liability	Scope of approval
Switzerland	Schweizerischer Elektrotechnischer Verein (SEV)		Yes	Equipment up to 200 A rated or continuous current
Canada	Canadian Standards Association (CSA)		Yes	Unlimited for equipment enclosures and complete controls
USA	Underwriters Laboratories (UL)		Yes	
Belgium	Comité Electrotechnique Belge Belgisch Elektrotechnisch Comité (CEBEC)		Yes	For equipment in systems which are connected to the public low voltage supply network
Holland	Naamloze Vennootschap tot Keuring van Electrotechnische Materialen (KEMA)		No	Exclusively for fuses
Finland	Sâhkôtarkastuslaitos		No	Equipment up to 63 A rated or continuous current
Norway	Norges Elektriske Materiellkontroll (NEMKO)		Yes	
Denmark	Danmarks Elektriske Materielkontrol (DEMKO)		Yes for approved equipment, no for registered equipment	
Sweden	Svenska Elektriska Materielkontrollanstalten (SEMKO)		No	Only for domestic equipment and in special cases

Table 39: Summary of the most common foreign approval marks

moved parts (definition in accordance with VDE 0435 part 303, draft June 1982).

Station Protective Switch: A relay which, with the occurrence of a specified current in the neutral conductor and/or a certain fault voltage, trips with a delay.

Steatite: A ceramic insulator, especially for HF insulating parts, with low dielectric losses.

Step-By-Step Switches (cam-operated switches): operate contacts, frequently *snap-action switches,* in accordance with a definite switching programme, usually through control pulses. Every control pulse causes a movement of a camshaft by one "step". Two to sixty steps per revolution are common.
Where the camshaft is driven by a motor, many more contacts can be operated than with a pawl and ratchet action via a rotary magnet. Motorized step-by-step switches can usually be designed for forward and reverse motion, with reciprocal locking or with automatic return to the initial position, after reaching a certain position.
Cam-operated switches are increasingly being replaced by sequencers.

Stepper Relay: According to VDE 0435, this is a relay with two or more rest positions and which can change its switching position via identical switch impulses and then remains in that switched position until the next impulse.
Until recently, this switching behaviour for two stable positions was achievable only by elaborate mechanical interlocks. It can now be simply achieved using the *VS-module* (electronic circuit for relay control from SDS, → 3.14) along with a two coil bistable relay. The superb, well known characteristics of polarized relays are not sacrificed. As can be seen from the basic circuit diagram of the VS-module (fig. 143), coils L1 and L2 are energized alternately, with one relay contact, K, providing the "reverse switching".

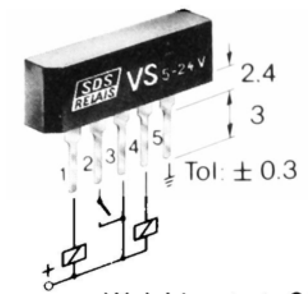


Fig. 142: VS-module

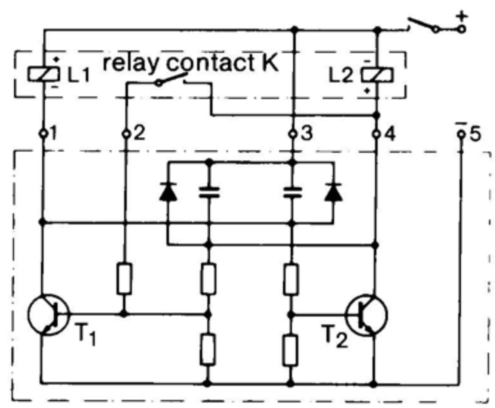


Fig. 143: Principle of operation of VS-module

Stepping Relay: also known as *toggle relay* or *stepper relay* (fig. 339), contains a switching mechanism which operates the contacts after every other control pulse or after several control pulses. Stepping relays are suitable for programme control switching.

Sticking: in monostable relays, means that the armature does not return to the rest position after the coil has been energized. The cause may be due to either insufficient reset force, or too high a remanence in the iron circuit. This effect can be counteracted by fitting a *separator* or an anti-freeze pin. → Contact Sticking.

Superconductor: Materials in which below a so-called "critical temperature" and a critical magnetic field strength, the electrical resistance is approximately zero, and magnetic fields are displaced from the material. An example of this is Nb_3Ge, with a critical temperature of 23 K. Superconductors are frequently used as windings for electromagnets with high field strengths for magnetic shielding and, at times, as switches, due to the great difference between the normal conductive state and the superconductive state [93].

Surface Test Methods: for the examination of contamination layers on contact surfaces. → AES.

Surge Current: occurs during switching of lamp or capacitive loads. With a lamp load, the surge current is approximately 10 times that of the rated current.

Survival Function: This describes the time-related reduction of an initial quantity of products. → Failure rate, → Reliability.

Switching Behaviour of Current and Voltage: The switch-on and switch-off peaks are of primary interest, particularly during closing and opening of electrical contacts. It is a fact that during the opening of an inductive circuit, a much higher voltage must often be interrupted than is supplied by the power source. Just as frequently, a peak occurs during the closing of a capacitive circuit, and this can easily destroy other components and weld the contacts. → Arc extinction, → 3.9

a) With an ohmic load (resistance R): The current I, and the voltage U, reach the operating value at the instant of switch-on, and drop to zero immediately on switch-off. This rarely happens in practice.

b) With an inductive load (inductance L): The current rises after switch-on, proportional to 1 — exp(-RT/L), to the operational value, and on switch-off, decays exponentially. The voltage reaches the operational value instantly, and at the instant of switch-off, forms a peak of opposite polarity which decays exponentially.

c) With a capacitive load (capacitance C): During switch-on and switch-off, a peak occurs with an exponential decay. The switch-off peak occurs only when the capacitive circuit is discharged. The voltage behaves in a similar way to the current in an inductive circuit.

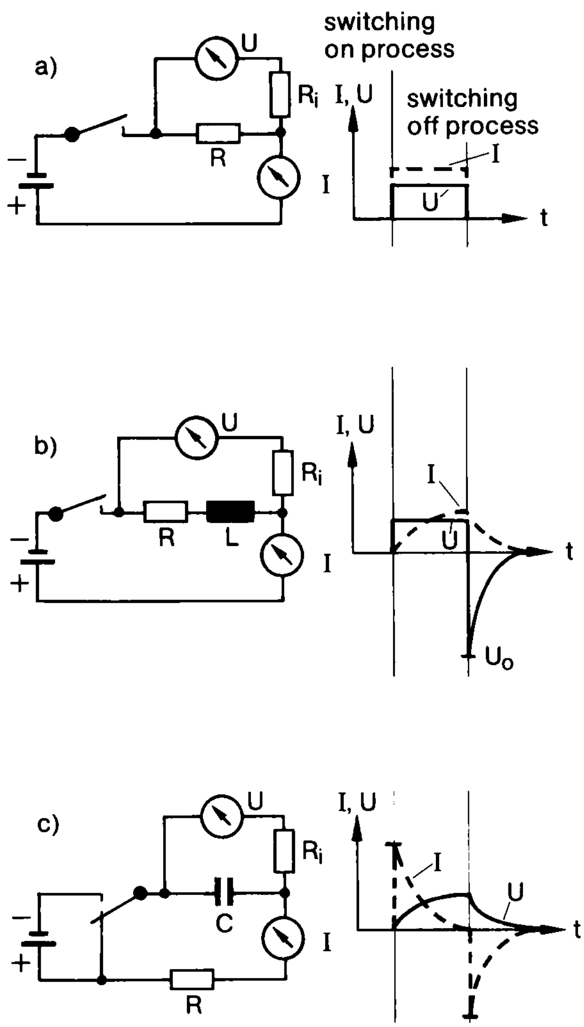


Fig. 144: Current and voltage characteristics with
a) resistive,
b) inductive,
c) capacitance contact loading

Switching Capacity:

a) In accordance with VDE 0435/10.81 part 120 or DIN IEC 255 part 0-20: The highest value of current which an output circuit — under specified conditions (voltage, number of switching operations, power factor, time constant etc.) — can successively switch on and off (= IEV 446-06-21).

b) In accordance with VDE 0660/09.82 part 200, differentiation is made between rated switch-on and rated switch-off capacity (→ Nominal switching capacity), depending upon the application, which can be found in the relevant specifications.
→ Utilization Categories.

Switching — Current, Voltage and Load Ranges: within which a relay contact can safely switch a given load not only in the new condition, but throughout the operational *life* of the relay. These ranges depended not only on the contact materials used, but also on the type of contact make, the contact form, the *contact bounce,* the contact cleanliness (→ Contact resistance, → Getter), and contact force. None of these parameters were considered in [54]. Since this publication concerns itself only with the technology of conventional relays, table 40 compares the switching capabilities of conventional small relays with those of a modern 5-layer bifurcated linear contact (figs. 3 and 4) [16], having the characteristics as shown by the S-relay (fig. 298).
It is observed that the switching load range of the modern relay with the 5-layer bifurcated linear contact (figs. 3 and 4) is 200,000 times larger than the largest switching load range (10^{-6} to 50 VA), of a conventional relay, as listed in table 40.
It should be noted that 5 µm gold plating on a bifurcated linear contact (fig. 4) displays a resistance to wear which is 2.5 times higher than that of a 10 µm gold layer on a contact which has point-form make only. The S-relay which is fitted with bifurcated linear contacts (fig. 298) is still suitable for switching *dry circuits,* even after 10^5 switching cycles of 2 A, 30 W. Publications [84] which state that, for switching loads of ≤0.1 V and ≤1 mW, the data sheet mechanical life expectancy, can still be anticipated when

Type of relay	Traditional relays							S-relay (fig. 298)
Contact material	Ag	AgCu	AgCdO10	AuAg8	AuNi5	AgPd30	AgPd30 +10 µm Au	5 layered linear bifurcated contacts
Switching voltage V	12–100	12–100	24–250	10^{-6}–24	0,1–24	1–60	10^{-3}–60	10^{-5}–250
Switching current A	0,05–2	0,1–4	0,5–4	10^{-6}–0,2	10^{-5}–0,5	10^{-4}–1	10^{-6}–1	10^{-7}–5
Switching load W(VA)	1–30	2–50	10–50	10^{-3}–5	10^{-5}–30(50)	10^{-4}–30(50)	10^{-6}–30(50)	10^{-10}–100(1000)

Table 40: Load range of various types of contact materials in traditional relays [54] as compared to the 5 layered linear bifurcated contacts (figs. 3 and 4) used in modern relays having characteristics as shown in fig. 298

the contact is sealed in protective gas, seem to contradict other conclusions (fig. 167). It is perfectly possible, however, to switch a load in a range from pW to kW, provided that very high contact forces with self-cleaning effect are available, or that the contact reliability and the life expectancy are of secondary importance. The significance of a wide switching load range [85, 86] is also economically relevant, since multiplicity of types and costs of storage are reduced, and the relay user is spared from having to decide which contact materials to select.

Switching Cycle: A single pull-in and drop-out operation, i.e. the action of switching a relay or switchgear on and off.

Switching Element: The usual description of the "contact set" in *contactors* and *relays.* It is that part of the device which comprises all parts directly concerned in contact operation. The fixed and movable contact with its associated springs, mounting and bearing parts.
A switching element is self-sprung if the current carrying parts also serve as springs. It is externally sprung when there are special springs which are not current carrying.

Switching Frequency: The number of *switching cycles* per second. The maximum achievable mechanical switching frequency depends on the energizing power, the contact travel, the mass to be moved, the reset force and the core cross-section. If arcing occurs during switching, then the switching frequency, taking heat dissipation into account, is limited to an appropriately lower value.

Switching Relays: or *power relays,* are used for the switching of auxiliary circuits or motor circuits (→ Circuits) and, with regard to their applications, overlap with those of *contactors.*
In accordance with VDE 0435/9.62, which was valid until September 1984, switching relays are defined as non-measuring relays which, when switched on or off, operate other equipment via one or more relay contacts and, if the application requires it, with a predetermined operating delay.
In more recent specifications, these relays are described as "all-or-nothing" relays.
Grouped according to their external characteristics, relays, switching relays and *contactors* are logically allocated as shown in table 41 (page 144) [26].
In the German translation of IEC 255, part 1-00, that is, VDE 0435/8.79 part 201, draft 1, switching relays are divided as: those without any specified time delay behaviour, which would be grouped as *auxiliary relays,* and those with a specified time behaviour, grouped as *time-delay relays.*

Symmetrical Windings: with the same number of turns have the same resistance. There are two possibilities of achieving this. One is to split the coil into two halves, with each half having the same number of turns. The other would be to divide the first winding into two halves, fully wind the second winding over the first half, and then wind on the second half of the first winding.

Synchronization: is producing in-step running of two periodically occurring processes, e.g. a self-hetrodyning time-base deflection and a periodic test voltage.

Telecommunications Relay: A relay suitable for the transmission of speech frequencies and signals.

Telegraph Relays: must switch rapidly and almost free from bounce, and their *distortion* must not exceed 3%. Most suitable for this application have been the small polarized relays of types V23062 and V23064 from Siemens which, due to their precise method of operation, allow switching frequencies up to 200 Hz, high contact loading, and virtually bounce free contact make. These types have won a worldwide reputation and set a high standard within teletype engineering.

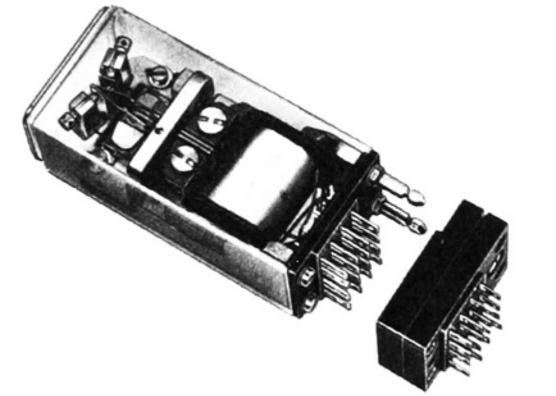


Fig. 145: Siemens type V22063...69 relay, dimensions L × B × H = 39 × 28 × 85.8 mm, weight approx. 170 g

Telephone Relay: usually a clapper-type relay or knife-edge relay, with a round coil core and a contact spring set which is laminated on. → Relay Descriptions.

Temperature: → Thermo-electrical effects, → Limit Temperature, → Thermal Resistance.

Temperature Compensation: With constant energizing voltage and increasing temperature, the magnetic flux generated by the relay coil drops in relation to the resistance change of the coil, (approx. 0.39%/K for Cu). If a permanent magnet is used which has a temperature coefficient which compensates for the temperature coefficient of the relay coil and is in unison with the change of *energy storage,* the temperature influence on the pull-in voltage of the relay over a wide temperature range can be ignored. (→ Part 1.2).

Temperature Scales: The Celsius or centigrade scale is the most commonly used scale. The temperature range is divided into 100 degrees between freezing point (0 °C), of water at 1013.2 m.bar (= 760 Torr).

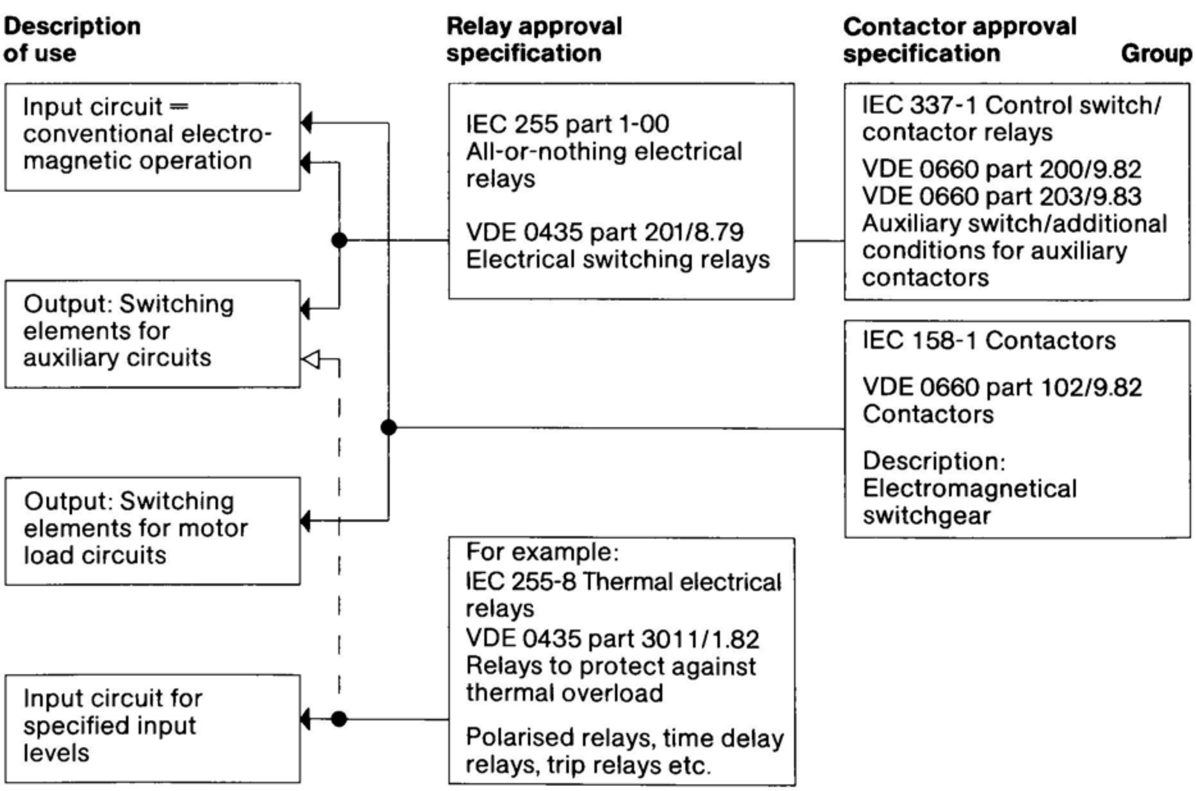


Table 41: Classification of relays and contactors according to description of use [26]

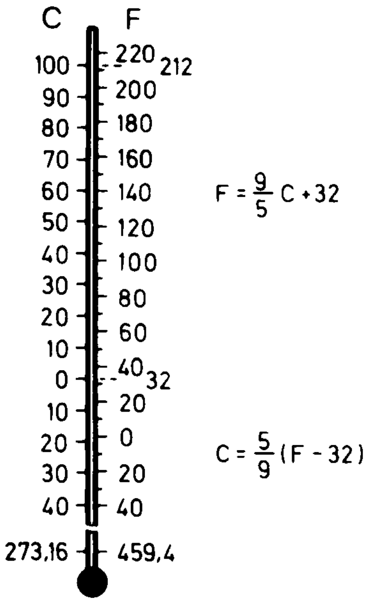


Fig. 146: Centigrade and Fahrenheit scales

English speaking countries use the Fahrenheit scale in which the range between freezing point (32°F), and boiling point (212°F), of water, is divided into 180 degrees.
A comparison of both scales is shown in fig. 146. → 2.2 Units of Measurement.

Ten-Degree Rule (10° Rule): It is known from physical chemistry that the reaction rate dM/dt of many processes of kinetic reaction shows an exponential dependence on the temperature, in accordance with the Arrhenius equation:

$$\frac{dM}{dt} = a \exp(-E/RT)$$

where, a, is a material-specific constant, E is the activating energy of the processes, R is the gas constant and T the absolute temperature.
Since a number of reactions which approximately satisfy the Arrhenius equation also occur in relays (e.g. diffusion processes), it is possible to assess the temperature influence on the life m ($dM/dt \triangleq m$, → Weibull) of a relay. In cases where mainly physio-chemical processes determine the failure, the "rule of thumb" is that a rise in ambient temperature of 10°C (in the range of approximately 40°C to 120°C), will reduce the life by about half.

Test Equipment for Life and Quality: Life test equipment for type testing and quality control is an essential and productive asset, not only for the relay manufacturer, but also in some instances for "goods inwards" quality control.
A universal test unit (fig. 147), manufactured by Transtechnik [42], measures the voltage drop at each closed contact for every relay tested. This is then compared with a preselected limit value.
The open contacts are monitored to determine whether a sticking fault is present (e.g. whether a contact has welded). At a preselected time after test coil energization or switch-off, measuring commences, thereby including inadmissible extensions of the switching times in the test. The switching frequency is also programmable. Since NO and NC contacts of test relays are often adjusted with different contact forces, the limit values of the voltage drop can be set separately. Should a fault occur, the unit will be stopped in the fault position and the fault will be indicated by a lamp, or the fault will be counted by a mechanical counter, with the test cycle continuing. (For each contact there is one counter for contact resistance faults and one counter for contact sticking faults.)
The actual value of the voltage drop is stored at each amplifier until the next reading. For every test contact, therefore, the continuous reading of the contact resistance is available and can be recorded on an X-Y plotter. An externally connected accessory unit gives the logarithm of the time axis to enable even early failure to be recorded with good resolution. Each test cabinet accepts up to five plug-in modules, each with 12 measuring points. It also contains the supply voltages for the test circuits and the variable supply voltages for the test coils, so that both polarized and neutral relays can be

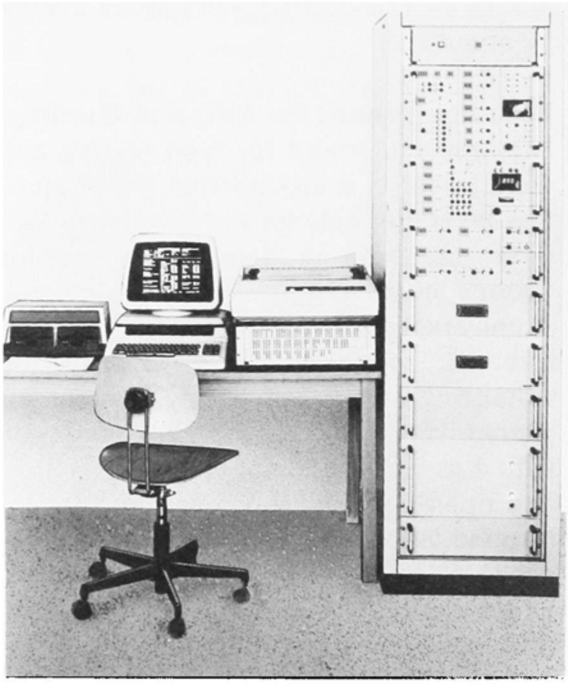


Fig. 147: Life test equipment

tested. To prevent erroneous measurements, the unit will automatically switch off if a supply voltage failure occurs.

High-Level Measurements: An additional mains cabinet contains the high voltage power supply equipment for the contact loads, in which d.c., and a.c. loads of max. 500 Hz can be handled. The load cabinet houses special, bank-wound slide resistors, which enable almost any likely load to be set. The test item adaptor is supplied via separate current and voltage circuits. The measuring cabinet contains the test and cycling circuits described above.

Low-Level Measurements: Since the current, for this type of measuring, is constant at 1 mA, 10 mA or 100 mA, programming can be carried out directly in mΩ. The voltage at the open contact is variable within the limits of 20 mV to 10 V. In addition, every measuring plug-in module contains the current generators. The tested items are also accommodated in the cabinet.

In order to eliminate any erroneous measuring due to thermo-electric voltages and humming influences, the measuring current is cycled at approximately 300 Hz, and the voltage drop on the tested item is amplified and then rectified using a rectifier.
A computer may be used for the documentation of the quality standards. With this computer, after a preselected number of switching cycles, all contact resistances, fault counters and completed measuring cycles can be interrogated and the values stored. The measured values can be printed out and can be stored on a floppy disc. In this way it is possible to undertake a statistical calculation for an entire test to the end of the test item's life. It is also possible to connect up just a printer, without a computer.

Test Equipment for Goods Inwards and Laboratory: For verification of the most important relay parameters, and for which due to small relay quantities the cost of an automatic test facility would not be appropriate, a mobile relay test desk (fig. 148) has been designed and manufactured by Transtechnik [42]. This permits the user to measure pull-in and drop-out voltage or current, coil resistance, contact resistance, dielectric strength and insulation resistance. Moreover, with the aid of a built-in multi-channel oscilloscope, it is possible to determine the dynamic contact behaviour (→ Fritting) and the switching times. The relay contact operated positions are indicated via an amplifier and signal lamps. All the above parameters can be measured for both monostable and bistable relays (with one or two coils).
The equipment is housed in a mobile console, and contains the following components:

1. Low Voltage Measurements: Power unit for the energization of the coil under test with direct and continuously variable current, which has a selecta-

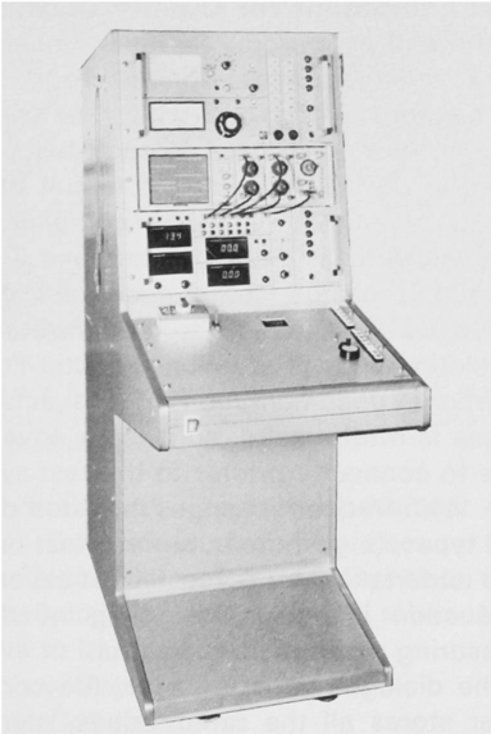


Fig. 148: Laboratory equipment for testing relays

ble polarity reversing and short-circuit resistance, power-pack. The set voltage and resulting current are indicated by digital instruments. Switching from one preset voltage to another can be effected by a changeover switch. Rapid monitoring of the predermined limit settings for the pull-in and drop-out values is easily accomplished.

Push Button Assembly: The stabilized voltage can be periodically switched on and off, or polarity changed for bistable relays, coil 1 and coil 2 can be energized alternately. Switch-on and switch-off duration are separately infinitely variable in two ranges. An amplifier is supplied for every changeover contact of the test sample relay. For low contact loading, an indicator lamp for the NO and NC positions is also provided. The switching conditions for a maximum of four changeover contacts can be seen on the oscilloscope. Thus, it is possible to monitor the time behaviour of all the contacts of the test relay simultaneously on the screen. In addition to the bounce and change-over times, the pull-in and drop-out times can also be read, since a pulse is superimposed on the oscillogram with every excitation of the test item.

Coil Resistance Measurement: The coil resistance can be read in three ranges on a digital instrument.

Contact Resistance: The contact resistance of the test relay is output on a digital instrument and may be selected for any contact. Measurements can be carried out using three different impressed current levels.

Operation: The individual control actions can be performed easily with the push buttons located adjacent to the test adaptor.

Adaptor: The adaptors can readily be changed over (by plugging in). Because of the requirement to measure contact resistance, the adaptor is provided with separate current and voltage paths.

2. High Voltage Measurement: Using a set of push buttons, every relay terminal can be set to housing potential (or high voltage) for insulation and dielectric strength test. Thus every terminal can be checked against every other terminal.

Dielectric Strength: By use of a variable transformer, the 50 Hz test voltage can be infinitely increased to a maximum of 3000 V and can be read off on an analogue instrument. If the fault current exceeds 1 mA, a fault signal is given, and the test voltage is switched off. For additional safety, the short-circuited current is limited to 5 mA in the event of a failure due to breakdown. A further safety measure is that the test voltage can be switched only when a transparent, protective cover has been placed over the test item.

Insulation Test: The insulation resistance can be measured using an analogue instrument for various d.c. voltages. Measuring ranges from $10^6\,\Omega$ to $10^{13}\,\Omega$ are possible. The change-over panel and the adaptor socket can be used for up to approximately $10^{10}\,\Omega$. For higher resistances, the relay must be connected direct, with special lines.

Adaptor: The socket for the high voltage adaptor is separate from the socket for the low voltage adaptor. However, up to a voltage of 2000 V, the same adaptor can be used for both high and low voltage testing.

The test equipment [42] described has proved its value to several relay manufacturers for the testing of small batches.

A compact, non portable mini-tester is shown in fig. 149. A portable test unit in a carrying case, particularly suitable for customer calls, is shown in fig. 150.

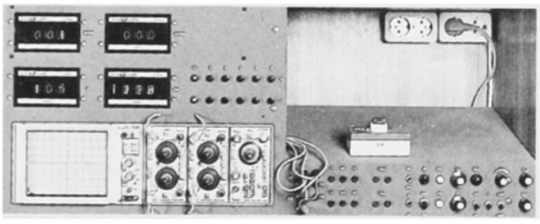


Fig. 149: Measurement station with small tester, digital voltmeter and oscilloscope

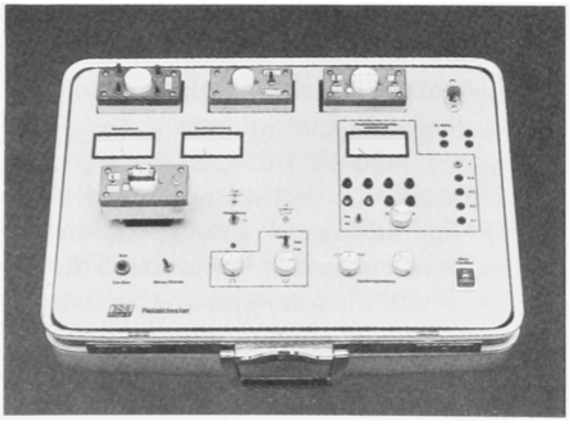


Fig. 150: Small portable relay tester [42]

Test Equipment for Quality Control: At the end of a production line, finished relays must be tested for adherence to the electrical parameters which are specified in the data sheets. In such tests, it must be possible to obtain a digital GO/NOGO statement regarding compliance with the permissible tolerances and also an output of the actual test data obtained, so as to be able to recognize any development in production defects. Furthermore, documentation of the actual values is often useful, so it is an advantage to connect a printer to the test system. With frequent changes in tested device types, (e.g. if the automatic test unit is to undertake the final testing of several production lines) programming of the measuring parameters is helpful.

In the dialogue with the user, the computer stores all the rated values, starts the automatic test unit and then evaluates the measured values. With automatic test equipment (fig. 151) it is practical to monitor only such parameters which are commonly required to be

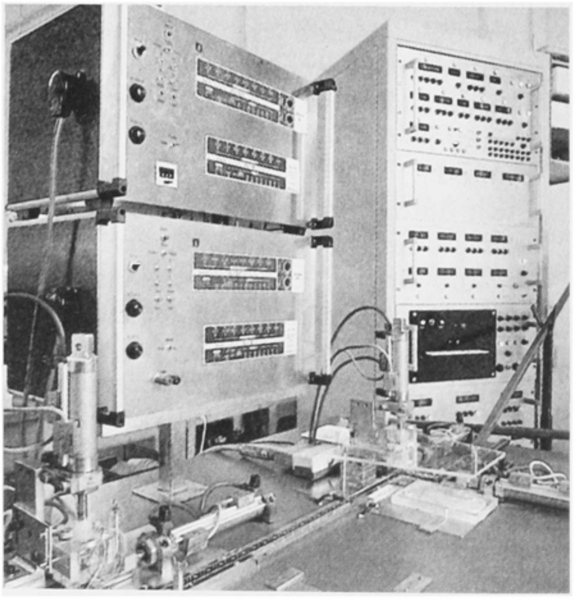


Fig. 151: Fully automatic relay test station from the MSR factory [104] working with transport and selection units controlled by sequencers as well as with a relay tester from Transtechnik [42]

Fig. 152: Computer (photo from MSR [104]) to monitor final product specifications and quality trends of the final assembled relay as it comes off the production line

checked in the majority of the test objects. Such measurements are set out below. Naturally, polarized relays with one or two coils, as well as neutral relays, also have to be measured:

a) Low Voltage Tests
   1. Coil resistance
   2. Pull-in and drop-out values
   3. Contact resistance
   4. Switching times
b) High Voltage Tests
   1. High voltage withstand
   2. Insulation resistance

In low voltage testing, it will be expedient to commence with measuring the coil resistance. Measuring is undertaken with an active tolerance measurement bridge, with separate preselectable set values and tolerances for two coils.

In measuring the pull-in and drop-out values, distinction is made between a measuring voltage of stepped form, when only the adherence to the limit values need to be monitored, (min. and max. pull-in values, max. drop-out value, min. holding value), and a ramp-shaped measuring voltage required to establish the actual values. In some cases it will be appropriate to test the holding values with both stepped and ramp functions, since some test relays show differences in the holding value, depending on the shape of the test voltage waveform applied. Normally, pull-in/drop-out measurements are best performed using a voltage waveform matched to the subsequent use of the test item. It is also possible to design the automatic test unit so that an impressed current facility is available via a change-over switch.

Contact resistance measurement is selectable, either with a current in the range of 100 mA to 2 A, with a no-load voltage of approximately 2 V, or under low level conditions of 10 mA, 20 mV. In order to be able to eliminate thermo-electric and hum voltages which occur in the measuring circuit, the measuring current is periodically switched. The voltage applied to the test device is amplified with an a.c. voltage amplifier, rectified with a synchronous rectifier and fed to the fault evaluation section. The voltage drop must, of course, be measured directly at the test relay itself (i.e. every test relay must have two pole contact).

The switching times are measured by a digital counter with 10 μs resolution. Normally, monitoring and display of pull-in, change-over and bounce time takes place and is similarly followed by the drop-out, associated change-over and bounce time.

The entire testing time of the low voltage tests amounts to approximately 0.6 secs. for the step function pull-in/drop-out measurements and approximately 1.2 secs. for the ramp-form measurements. A selector switch provides for each test step to be switched off individually, if some parameters are not to be measured.

The high voltage test can be significantly reduced through suitable, vectorial phase interlinking of the three-phase current, since then only a maximum of two test steps will be left for the complete measuring of all the test relay parts relative to each other. The tripping current is normally 1 mA, with a short-circuit limit of 5 mA. The test cycle is 1 sec, switchable to 10, 30 and 60 seconds. A protective cover on the test piece adaptor, combined with a safety interlock switch, pre-

vents the high voltage being applied in the event of the test relay being changed manually. The insulation resistance is measured at a voltage of 100 V or 500 V. The trip limit value is preselectable over a range of 10^6 to $10^{10}\,\Omega$. Higher resistance values can be handled in terms of measuring technology, but this would incur additional complication in the change-over panel and the adaptor. Testing time is preselectable between 1 and 60 sec.
As soon as the insulation resistance is found to be better than the set limit value, the test cycle is interrupted, and the relay is passed as satisfactory. The testing time of the high voltage part of the test is approximately 2.1 secs., with a pulse cycle time of 1 sec. for a good insulation resistance test.
To summarize, it can be said that automatic test equipment from Transtechnik [42] has been used by many relay manufacturers for several years, with trouble-free operation. Furthermore, it is important for the user to know that, in the event of failure of the automatic test unit, the servicing will be carried out reliably and bottlenecks will be prevented. → Test Equipment for Life and Quality.

Test Voltage: In order to judge the *dielectric strength* (voltage withstand) of components, the type and duration of influence of the test voltage must be precisely specified. The time dependence can be explained from the theories of heat and ionization. On the one hand, channels of higher conductivity (supported by contaminations in the materials) are formed over a period of time by mechanical forces of the electrical field and Joule heating in the insulating materials, on the other hand, a certain period of time will elapse until sufficient charge carriers (electrons) exist to build up a stationary discharge.
In general, the requirement for electromagnetic relays (see IEC 255) is that the specified test voltage is applied to the test object for 1 minute, with the voltage maximum being reached in 30 seconds, and, after a further 60 sec testing time, the voltage is reduced within 30 secs. In this process no currents >1 mA may flow (ANSI/EIA Standard RS-407-A-78). During quick testing (mass production), a voltage of magnitude 1.1 times is to be applied in a sudden burst for 1 second.

Thermal Instability Breakdown: Burning or melting of an electrical insulating material under electrical stress.

Thermal Limiting Current: → Short time current, → Short-circuit Withstand.

Thermal Resistance of a Relay: describes the temperature rise of a relay which is due to the power dissipation occurring in the coil and contacts. It is rated in Kelvin per Watt of leakage power. Since, as a rule, the coil power dissipation and the thermal resistance of a coil exceed by far the contact power dissipation, it is permissible in most cases to consider only the thermal resistance of the relay coil. → Relay Table.

Thermionic Relay: A cold cathode tube which is provided with an auxiliary anode and a main anode and is used for switching low level currents. The auxiliary anode permits a low ignition voltage. The tube is operable without warm-up.

Thermistor: NTC resistor (Negative Temperature Coefficient), semiconducting device, the resistance value of which drops with rising temperature (e.g. Fe_2O_3 with TiO_2 doping).

Thermocouples: Commonly used combinations for measuring purposes, see table 42. → Thermo-electromotive force.

Thermo-Electrical Effects: → Seebeck Effect, → Peltier Effect, → Thomson Effect, → Thermo-electromotive force.

Thermo-Electric Relays: show time delayed contact operation due to the influence of heat. This is usually effected by means of a bimetal and heating disc or

Temperature of hot point	100°C	500°C	1000°C	1500°C
Metal pair	Thermo-electric voltage in mV			
Iron-Constantan	5,37	27,84	—	—
Copper-Constantan	4,25	27,40	—	—
Nickel-Nickel chromium	4,04	20,64	41,32	—
Platinum-Platinum rhodium (10 %)	0,64	4,22	9,60	15,58

Table 42: Common thermo-elements and their thermo-electric voltages referred to $t_0 = 0°C$

Material	$\frac{U_{Th}}{mV}$	Material	$\frac{U_{Th}}{mV}$
Tellurium	+50	Manganese	+0,57 ... +0,82
Silicon	+44,8	Gold	+0,56 ... +0,8
Antimony	+4,7 ... +4,86	Tin	+0,41 ... +0,46
Nickel chromium	+2,2	Lead	+0,40 ... +0,44
Iron	+1,87 ... +1,89	Magnesium	+0,40 ... +0,43
Molybdenum	+1,16 ... +1,31	Aluminium	+0,37 ... +0,41
Cadmium	+0,85 ... +0,92	Platinum	±0,0
Copper	+0,72 ... +0,77	Sodium	−0,21
Silver	+0,67 ... +0,79	Potassium	−0,94
Tungsten	+0,65 ... +0,9	Nickel	−1,94 ... −1,2
Iridium	+0,65 ... +0,68	Cobalt	−1,99 ... −1,52
Rhodium	+0,65	Constantan	−3,47 ... −3,04
Zinc	+0,6 ... +0,79	Bismuth	−7

Table 43: Thermo-electric voltage series referred to platinum (reference temperature 0°C, temperature difference 100°C) [105]

heating coil. The delay range lies between approximately 0.5 and 500 sec.
Distinction is made between ambient temperature dependent types and ambient temperature independent thermoelectric relays, as well as those with slow operating or instantaneous contacts.

Thermo-Electromotive Force: is measured at the ends of an open electrical circuit which may be composed of different types of conducting materials, the junctions of which are at differing temperatures. It is dependent only on the temperatures at the junctions and on material-specific values (table 43). The thermo-electromotive force is caused by the *Seebeck effect.*

The effects of thermo-electromotive force are utilized in technology for temperature measuring (fig. 153), and for generating electrical energy from heat, (e.g. wrist watches, space probes etc).

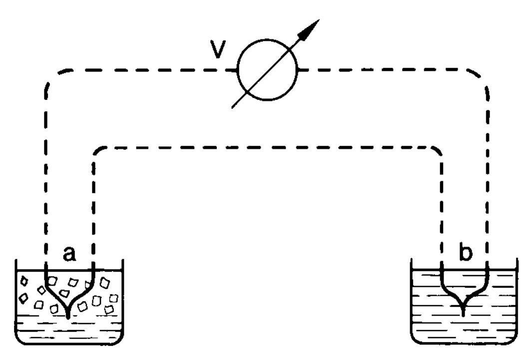


Fig. 153: Temperature measurement by using a thermo-element a) reference point, b) measurement point, V voltmeter

With metals, the thermo-electromotive force amounts to several µV/K, with suitable semiconductor combinations, it is several mV/K.

Thermo-electromotive force is frequently found to be an interference in measuring circuits, because the voltages to be measured are distorted due to the thermo-electromotive force generated when the junctions of the various conductor materials are brought to differing temperatures due to neighbouring heat generating components. Since, particularly at switching contacts, the current flows through various differing spring and contact materials, thermo-electromotive forces occur predominantly in monostable relays, since heat is generated following coil switch-on, and temperature differences build up along the current path through the contact spring set (warm-up time; fig. 154). The material selection of the current path determines the specific thermo-electromotive force. (Examples of relays soldered on to PCBs: R-relay with Rh contacts 14 μV/K, S-relay 0.1 μV/K).

The effective temperature differences on the material junctions in the current path depend largely on the relay design and on the connection geometry. They determine the temperature distribution within the relay. The interfering thermo-electromotive force generated by the temperature rise in the coil is eliminated by the use of bistable relays, or relays which utilize a *C-switching circuit,* since the coil has only a low *duty cycle* due to pulse type coil operation, and, therefore, only low heat levels are generated.

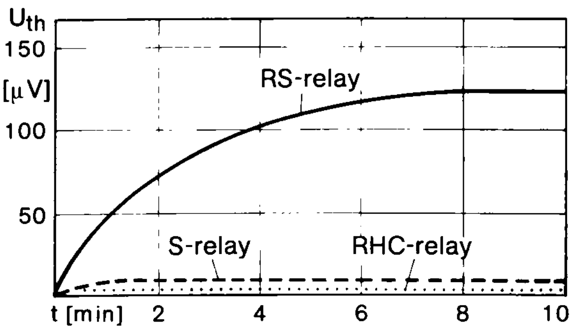


Fig. 154: Typical curve of thermo-electric voltage at a relay contact shown in dependance of duration of energization

Thirty Percent (30%) Rule: Laboratory examinations are expected to provide information in a short period of time as to how a test item will behave over longer periods of time. It is, therefore, necessary to test to standards more "stringent" than will be met with in practice. To that end, a rapid ageing effect is used as an aid for evaluation. The so-called 30% rule utilizes a 30% increase of operating parameters (a multiplication factor of 1.3). The application of this rule requires in-depth experience and a precise knowledge of physical and chemical data, so that only the time acceleration effect is utilized and no erroneous conclusions are drawn. The 30% rule has long been applied to test mechanical effects, but, with the limitations described, it can be used for ambient influences. However, no arbitrary increases beyond 30% should be considered. In space exploration, a factor of 1.5 or more is being applied.

The 30% stress increase does not provide information on test duration. This must be additionally specified.

Thomson Effect: belongs to the *thermo-electrical effects.* If charge carriers (e. g. electrons) move along a homogeneous conductor which has a temperature gradient imposed upon it, a continuous heat exchange occurs between the charge carriers and their environment, to set a thermal equilibrium. Charge carriers coming from a colder zone will, of course, cool down the warmer zone and vice versa.

Three Position Contactor: Has one rest position and two operated positions. Thus, it is possible, with so-called reverse motor starters, to replace two conventional interlocked contactors with one three-position contactor. Owing to the particular construction of the contacts, much of the previously necessary wiring is substantially reduced [26].

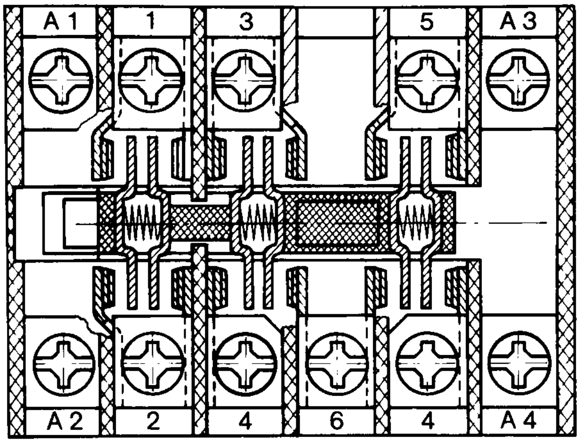


Fig. 155: Wiring diagram and contact arrangement of a three-position contactor

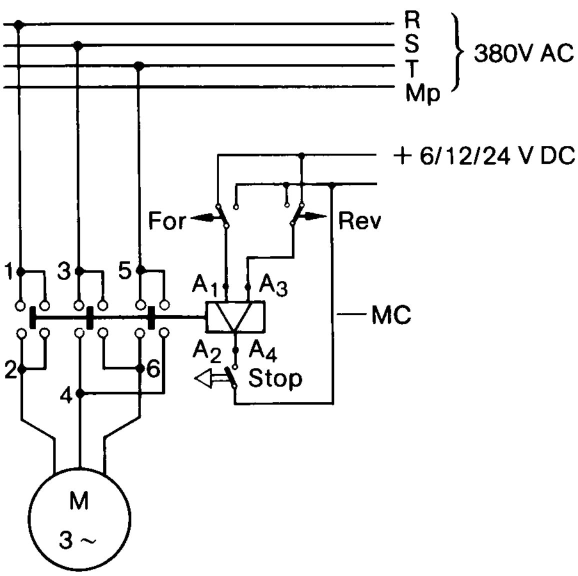


Fig. 156: Connection diagram for a 3-phase motor using a polarised three-position contactor having an operating coil split in two

Throw-Over Relay: A switching relay with two switching positions whereby on switch-off of the control parameter, the relay always remains in the last known position.

Thyristor: Controllable semiconductor rectifier. In the non-conducting state, (blocking condition) it is highly resistive in both directions. It will not be switched to the conducting (firing) state until a current is fed to the gate (→ Gate). The thyristor is often used as an electronic switch (Fig. 157).

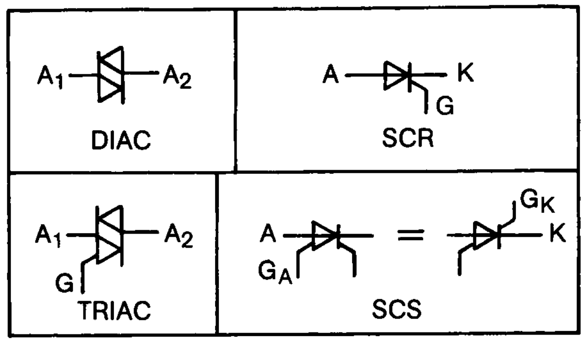


Fig. 157: Selected thyristor schematics (to IEC 117-7)

DIAC bidirectional diode thyristor
TRIAC bidirectional diode thyristor
SCR reverse blocking triode thyristor (may be controlled at the cathode)
SCS reverse blocking thyristor tetrode
A anode
G gate
K cathode

Time Constant: The time taken by a process with an exponential decay until the value 1/e of the initial quantity, or the value (1-1/e) of the final quantity, is reached. For relays, the electrical time constant is determined by the ratio L/R. The mechanical time constant, by contrast, is the mechanical starting time, conditioned by time lag and the armature travel.

Time-Delay Adjustment: Time adjustment in most *time-delay relays* is achieved by means of an adjusting knob. Where PCB mounted time-delay relays are concerned, a 45° inclined potentiometer with a screwdriver slot will be advantageous, since adjustment will be possible from above or, in the case of a slot-in PCB, adjustment can also be made from the side (fig. 158).

Time-Delay Relay: VDE 0435/9.62, which was valid until 9-30-1984, differentiated between delayed switching relays without a setting scale and delayed switching relays with a setting scale.
According to the new DIN IEC 255 part 1-00 or VDE 0435 part 201, time-delay relays are switching relays with a specified time

delay characteristic. Analog time delay behaviour can be achieved via a potentiometer (figs. 158 and 160). Digital time delay can be achieved via a coding switch (figs. 159 and 161).

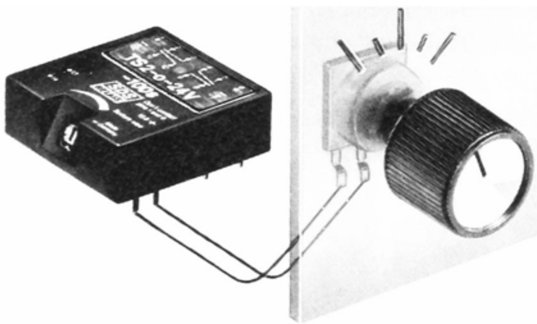


Fig. 158: SDS pcb type TS time-delay relay having an S-relay as output. Can be supplied as time-on or time-off delay (without need for auxiliary voltage), or as a pulse relay in three time ranges (10 s, 100 s, 800 s) pulse frequency 0.04 to 5 Hz → relay tables

Fig. 159: Quartz controlled QM48 time-delay relay from SDS. Digital setting of required time and digital display of the actual time. Three time ranges 0.01 s to 100 s, 1 s to 100 min, 1 min to 100 h → relay tables

The electronic time-delay relay from Schleicher [109], with analogue setting, is available in on-delay or off-delay versions, with auxilary control voltage. The shortest time which can be set is 0.05 sec., and the longest is 30 minutes. The switching condition at any particular time can be viewed on the front LED display.

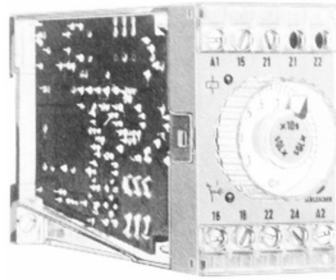


Fig. 160: Analogue time-delay relay type SZT3 (photo courtesy of Schleicher GmbH & Co.)

Two electrically isolated change-over contacts are available, with a maximum switching voltage of 250 V AC/300 V DC. In accordance with VDE 0106 part 100, the relays are suitable for snap-on top-hat rail mounting to DIN EN 50022-35. The housing measures 45 × 75 mm and is protected against accidental physical contact with live parts.

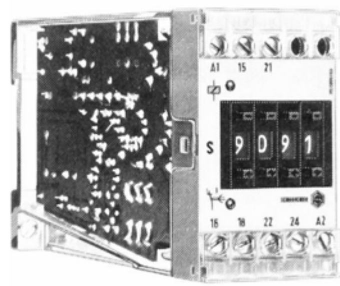


Fig. 161: Digital time-delay relay SZD3 (photo courtesy of Schleicher GmbH & Co.)

The digital time-delay relay from Schleicher [109], with digital setting, is available in on-delay or off-delay versions, with auxilary control voltage. Times can be set from 0.01 sec. up to 9.9 hrs. The longest time possible with a four-decade selector is 9999 minutes. The switched condition at any particular time can be viewed on the front-mounted LED display. Two electrically isolated change-over contacts are available, with a maximum switching voltage of 250 V AC/300 V DC. In accordance with VDE 0106 part 100, the relays may be snap-on mounted on a top-hat rail, DIN EN 50022-

35. The housing measures 45 × 75 mm and is protected against accidental physical contact with live parts.

Toggle (latching) Relay: → Stepper relay.

Top View: → Wiring diagram.

Townsend Discharge (leakage current): A non-self-maintained gas discharge with low current flow (dark preconduction current of µA magnitude) whose maintenance requires an external ionizer. → Discharge.

Transformation Ratio: Quotient of actuating travel and relay armature travel.

Transformer: Two or more inductively coupled windings which are used for the transformation of alternating current, the matching of resistances or for the electrical separation of two circuits.

Transistor: An amplifying semiconductor device with at least three connections (emitter, base and collector). The type of circuit (emitter, base or collector circuit) gives rise to basically differing characteristics. In relay technology, the main function of the transistor is that of current or power amplification, often in multi-step application.

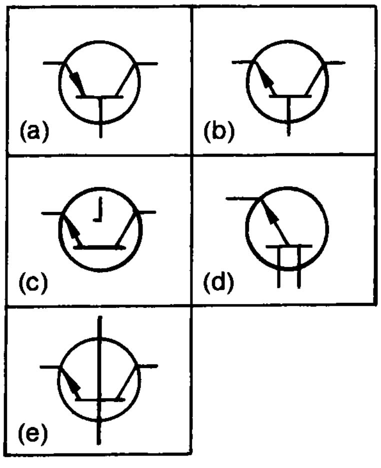


Fig. 162: Selected transistor (to IEC 117-7)
(a) pnp transistor
(b) npn transistor
(c) npn avalanche transistor
(d) unijunction transistor with p-type base
(e) npn transistor with transverse biased base

Transistor Relays: → Electronic Relays, → Solid State Relays, → Static Measuring Relays.

Transit Time: For a change-over contact, this is the time between the opening of one circuit and the closing of another, during which no contact current flows (→ Relay Times).
This definition applies to relays as well as to *snap-action switches.* Strictly speaking it applies only to snap-action switches with a double snap system (→ Snap system). In single-snap systems, the transit time begins from the instant in which the movement of the opening contact has become independent of the actuator travel and is thus irreversible.

Travel: The product of *armature travel* and *transformation ratio,* i.e. the travel for the actuation of the contact.

Travel Time: The time from the commencement of the armature movement to the closing of the armature. → Relay Times.

Tribology of Electrical Contacts: Surface contamination layers, which lead to increased contact resistance, adversely affect, above all, the functional reliability of low-level-current relay contacts. The contamination processes, which form the covering layer, are related to the chemistry of chemical solid state reactions. In many cases, such reactions require high activation energy. This can be supplied in the form of heat. However, solid state chemical reactions can also be triggered by kinetic energy. The accompanying phenomena, which may be observed, belong to the field of tribology. This term covers the science and technology of interacting surfaces in movement relative to each other and in associated processes. Tribology describes the physical and chemical effects of shock or friction on solids. Due to mechanical stress of solid surfaces, special energy conditions are created which can no longer be

described by the thermodynamics of reversible and isothermal processes. In the general systematics of chemical reactions, tribochemical processes, therefore, occupy a special position.
In rolling processes, for example, tarnishing layers occur on the surfaces of the iron rollers within a few minutes, which, but for the mechanical stress, would not occur until after the passage of some 10^{17} years. A multitude of experimental methods has been developed for the systematic examination of tribological processes. In the field of electrical contacts, equipment for the examination of frictional wear on plug-type connections is in the forefront. Tribological processes, however, can also be observed on relay contacts. They are best examined by using suitable relay models. Detailed representations will be found in engineering literature [88].

Triggering: The single or periodic release of a process through a command signal, e.g. with an oscilloscope, the release of a non-selfoscillating time-base deflection through the measuring voltage.

Tristable Relays: in addition to two switching positions, have a stable contactless center position of the armature or of the center contact. If energization is interrupted, the last switching position will be maintained. A reset to the center position requires much less control power than that required to reach an operated position.

TTL (Transistor-Transistor Logic): The use of *transistors* for logic operation and for amplification (offers a great number of possible logic functions).

Tunnel Effect: results from the uncertainty principle of quantum mechanics. It describes the "tunnelling through" of particles through potential walls whose height (potential energy) is greater than the energy of the particles moving towards it; i.e. in the understanding of classical physics, all particles would be reflected at this "barrier" However, due to the wave character of material particles, they possess, dependent on their kinetic energy and height and width of the potential wall, a certain probability of penetrating the potential wall. The tunnel effect is used, for example, in tunnel diodes [94].
In relay technology, the tunnel effect plays a role not to be underrated, as an influencing factor on skin resistance (→ Contact Resistance) [48].

TÜV Symbol: → VDE and TÜV symbols.

Two Step Relays: with increasing excitation, they switch in two or more steps.

UIC Code 736i/01.07.1974: Determines the characteristics for signal relays in railway installations (West Germany).
The requirements laid down for relays in this code are largely in agreement with the requirements stipulated by VDE 0831/6.83 (Regulation for Railway Signalling Installations). → Safety Relays, → Forced Contacts.

Ultra-Sound: Sound above the audible frequency range, i.e. f > 20 kHz. In conjuction with a liquid medium, ultra-sound is also used for cleaning relay contacts. Thermoplastics can be welded with ultrasound. → Contact Sticking, → 3.9 Advice on the Use of Relays.

Undercurrent Release: Triggering (or tripping) when current falls below a specified value.

Undervoltage Release: Triggering (or tripping) when voltage falls below a specified value.

Universal Relays: do not exist, since requirements of various areas of application differ too widely for them to be fulfilled by one relay. There are, however, relays available which cover a wide range of applications, such as the S-relay (→ Relay Table).

Utilization Category: Stipulates the application and the electrical stress of the *contact elements* of auxiliary current controllers and motor controllers in accordance with the scope of VDE 0660, where utilization categories are defined as in table 44.

Current type	Utilization category	Typical applications
AC	AC-1	Non-inductive or slightly inductive loads, resistance furnaces
	AC-2	Slip-ring motors: Starting, plugging[1]
	AC-3	Squirrel-cage motors: Starting, switching off motors during running
	AC-4	Squirrel-cage motors: Starting, plugging[1], inching[2]
	AC-11	Switching of AC electromagnets
DC	DC-1	Non-inductive or slightly inductive loads, resistance furnaces
	DC-2	Shunt-motors: Starting, switching off motors during running
	DC-3	Shunt-motors: Starting, plugging[1], inching[2]
	DC-4	Series-motors: Starting, switching off motors during running
	DC-5	Series-motors: Starting, plugging[1], inching[2]
	DC-11	Switching of DC electromagnets

[1] By plugging is understood stopping or reversing the motor rapidly by reversing motor primary connections while the motor is running.
[2] By inching (jogging) is understood energizing a motor once or repeatedly for short periods to obtain small movements of the driven mechanism.

Table 44: Utilization categories

Vacuum Relays: have one or more contacts in a vacuum of approximately 10^{-6} mbar. This enables voltages up to 50 kV to be switched with a contact air gap of 1 mm (fig. 25).

Varistor (VDR): Voltage dependent resistor whose conductance increases with increasing voltage.

VDE and TÜV Symbols: The meaning of the various symbols remains unclear in many minds, and this is further promoted by the competitive attitude of test centers authorized to carry out tests and award symbols of approval.
Furthermore, since the letter sequence "VDE" is a registered trademark, it is reserved exclusively for VDE test centers to award the VDE symbol. The consequence is that the "tested safety" is certificated by many differing symbols.
Working equipment which conforms to the laws on "technical working equipment", is marked by TÜV-Bayern (Bavaria) and by VDE as follows:

Switchgear conforming to VDE 0660, (e.g. the mini-contactor from SDS), are not even accepted for testing by the VDE. According to the VDE, the requirement for proof of conformity with the VDE 0660 is satisfied by a declaration of conformity in the meaning of article 10 of European Community for low-voltage devices of 19. 2. 1973.
By contrast, TÜV carries out tests and awards symbols to equipment passing the tests:

The situation in the case of relays is even more diverse. Since the use of VDE symbols

is intended for specific items — but not for relays — a special arrangement has been made. (The VDE specification 0024/12.81 lists the products for which the VDE symbols may be obtained).
Where relays are concerned, the VDE test centers will merely provide "expert assessment tests" or "expert assessment test with production control". In the former case, an expert's report is given, without entitlement to carry a symbol; in the latter case, a triangle, similar to the triangle used for the VDE symbol, may be used and a number (registration number of the VDE) entered within it:

In neither case is it permitted to offer or describe the product as: "VDE tested", "tested to VDE", "tested by VDE", "in accordance with VDE", "to VDE".
TÜV, however, permits a symbol (TÜV-Bayern, Bauart geprüft) to be carried on equipment which has passed the test, e.g. in accordance with VDE 0435 "Electrical Relays".

Vibration Resistance (→ Relay Table): describes the capability of a component (or equipment) to suffer no change of the switched condition (longer than 10 µs) and no damage (IEC 68) with sinusoidal acceleration of vibratory motion of definite magnitude in a specified frequency range. Where, for example, 10/2000 is quoted, it signifies that the item in question permits such an acceleration of 10 g up to a frequency of 2000 Hz.

Virgin Curve: The path of the magnetic induction with rising magnetic field strength on first excitation. → Hysteresis Loop, → Magnetism.

VMOS: *MOS* technology with V-shaped vertical semiconductor structure. Owing to the thus reduced conduction channel length, the switching times are significantly reduced and the switchable current is very much greater. Increased packing density is a further advantage.

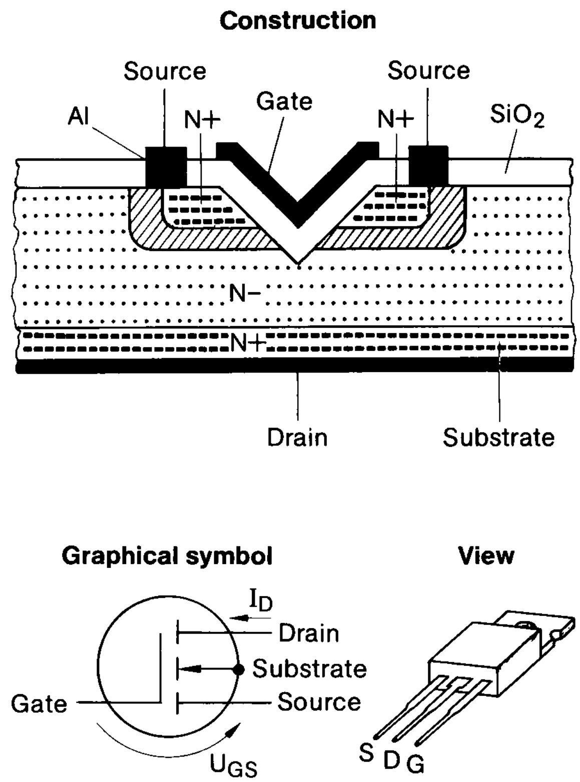


Fig. 163: Self-blocking FET (N^+ heavy N doping; N^- low N doping)

Voltage Breakdown: → Breakdown voltage.

Volume Resistance (R_D): is measured between the terminals of closed relay contacts. R_D = contact resistance + line resistance.

VS-Module: Electronic element connected in series which enables bistable (latching) two coil relays to be used as *stepper relays*. → 3.14.

V.S.W.R. (Voltage Standing Wave Ratio): The ratio of the voltage maximum to the voltage minimum of the reflected wave interferences caused by mismatching.

$$\text{V.S.W.R.} = \frac{|U|_{max.}}{|U|_{min.}}$$

The most favourable case: V.S.W.R. = 1, corresponds to the return loss = 0 dB.

WAGO Connection Technique: A non-threaded, non-soldered connecting system in which a "cage type spring" presses the connector lead against the terminal.

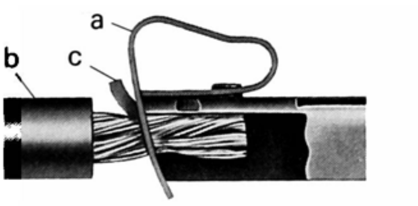


Fig. 164: Cage type spring with multistranded conductor

a) cage type spring
b) connector lead
c) terminal

Weibull Diagram, Weibull Distribution [97, 98]: This is generally usable in the statistical analysis of reliability and is particularly suitable for the examination of the life of components whose failure is due not only to accident, but mainly to wear (→ Bathtub Curve).
Based on the behaviour of a random sample over a limited period, assessments can be made in respect of fault characteristics of a batch throughout a longer period of time. In relay technology, it is used mainly to assess life and reliability for different contact loads.
The general form for the **failure probability** F(t) is:

$$F(t) = 1 - \exp\left\{-\left(\frac{t-t_0}{T-t_0}\right)^b\right\}$$

The complement $R(t) = 1 - F(t)$, is called **probability of survival,** in which:

- t = the **random variable** ($t \geq 0$), i.e. the number of switching cycles up to the time of observation (failure).
- t_0 = the **situation parameter,** i.e. the time from when failures can occur. As a rule, it is zero.
- T = the **characteristic life** (parameter of scale) ($T > 0$), frequently denoted by η, i.e. the number of switching cycles up to which 63.2% of failures occur ($F(T) = 1 - 1/e$).
- b = the **form parameter** which determines the curve form of the Weibull distribution (it is frequently represented by β [99, 100]).

The associated **failure density** (differential failure probability) $f(t) = d/dt$
$F(t)$ is calculated (for $t_0 = 0$) with

$$f(t) = \frac{b}{T}\left(\frac{t}{T}\right)^{b-1} \exp\left\{-\left(\frac{t}{T}\right)^b\right\}.$$

The *failure rate* contained therein

$$\lambda(t) = \frac{b}{T}\left(\frac{t}{T}\right)^{b-1}$$ shows that for

- $b < 1$ the failure rate diminishes as t increases and that the failures are early failures;
- $b = 1$ the failure rate is constant (random failures); the Weibull distribution transcends into the special case of the exponential distribution;
- $b > 1$ the failure rate increases with t (failures due to wear).

Fig. 165 shows examples of the functions named for differing b values [in accordance with 99].

Using the gamma function [101], the **mean life**

$$m = T\,\Gamma\left(1 + \frac{1}{b}\right); \; \left(m = \int_0^\infty t\,f(t)\,dt\right)$$

can then be calculated.

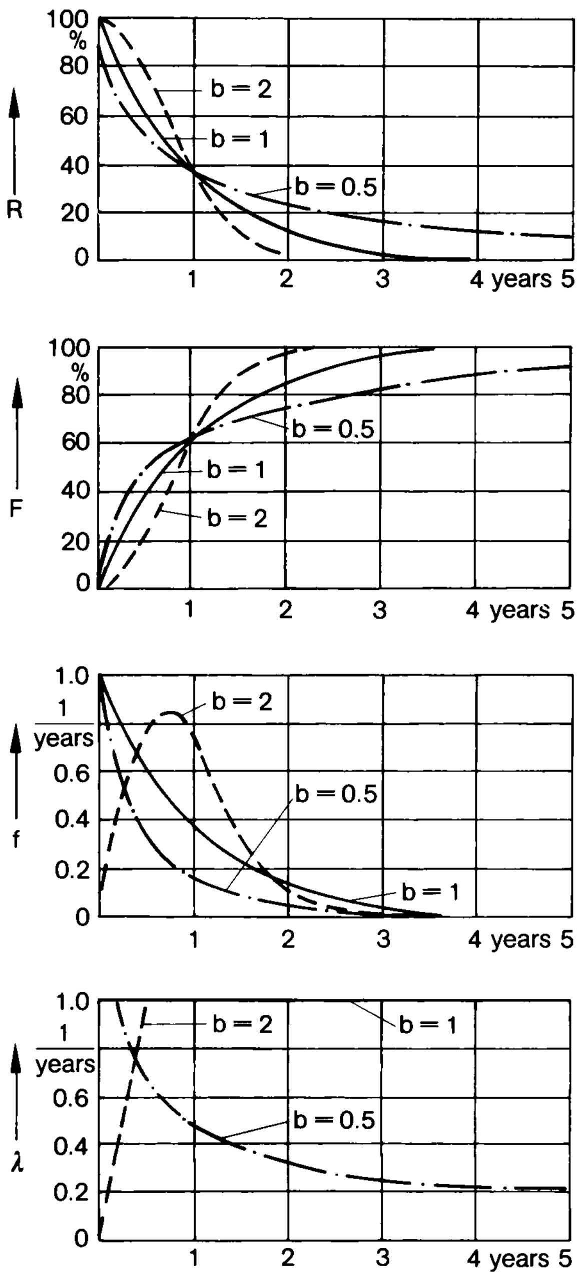


Fig. 165: Example of Weibull distribution with T = 1 and b = 0.5, 1, 2 (for $t_0 = 0$) [99]

In practice, the quoted parameters of distribution can be determined simply by using Weibull co-ordinate paper.

By conversion and taking the logarithm of the formula for the failure probability with

$$\ln \ln \frac{1}{1 - F(t)} = b \ln t - b \ln T$$

it will be seen that the distribution in co-ordinates with logarithmic abscissa and double logarithmic ordinate is represented by a straight line.

To give an example:

Let it be assumed that the quantity of the random sample is 5, and that the failures occur after 1.6×10^6; 2×10^6; 2.1×10^6; 2.4×10^6; and 2.5×10^6 switching operations.

Firstly, a mean ranking (i.e. a mean cumulative fault percentage) is allocated to each of the faults. This value, from the statistics thus describes the fault percentage to be anticipated for the entire batch (from which the sample originated), as calculated from the sample. Where no random sample is taken, but the complete batch is tested, the mean ranking is equal to the percentage failure; i.e. where, in a batch of 500 relays the number of failures is 30, the ranking of the 30th failure is 6%.

The appropriate formula for the mean ranking of the i^{th} failure with random sample figures $n \ll$ complete batch is:

$$mr = \frac{i - 0.3}{n + 0.4}$$

For the example, the values 13; 31.5; 50; 68.5; 87 result, which are then entered at the appropriate switching cycles on the Weibull paper (fig. 166).

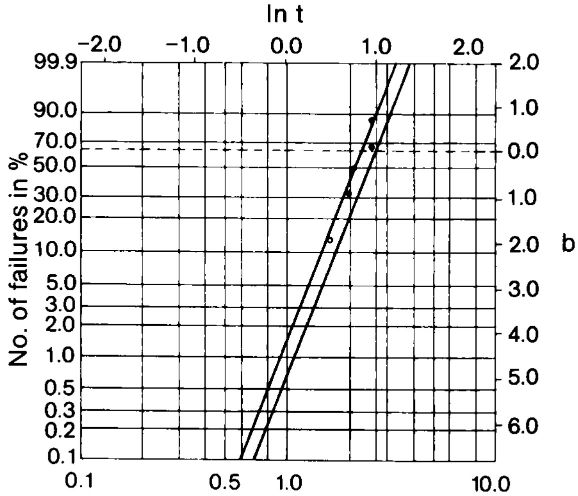


Fig. 166: Example of Weibull evaluation (explanation in text)

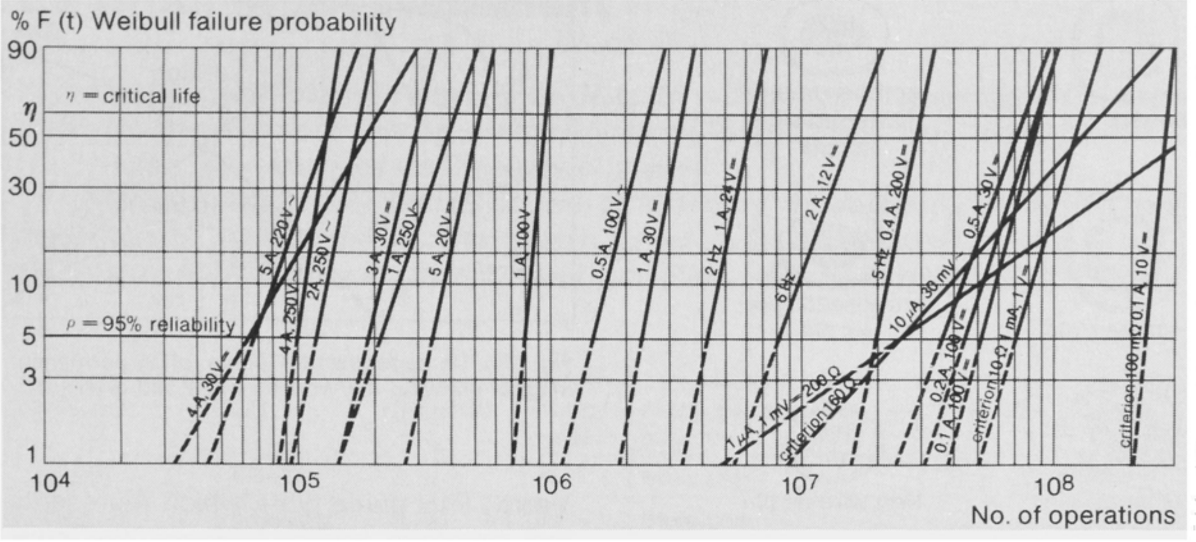


Fig. 167: Weibull reliability data of the S-relay (→ relay table) for various contact loadings with a failure criterion of 100 mΩ unless otherwise stated

If in certain cases it is not possible to establish a clear straight line through the points; but only several disjointed sections of straight lines, then we are dealing with a mixed distribution, i. e. the failures have widely differing causes.

In our example, the section of the straight line through the measuring points with the 63.2% line (broken line), results in the value $T = 2.3 \times 10^6$.

The section of the parallel through lnt = 1.0; b = 0.0 results in the b value of the distribution as a section of this straight line with lnt = 0 to b = 5.0. Thus, the cause of failure is wear.

A prediction as to the life of a relay should generally be made, as shown in the example for the S-relay (→ Relay Table) in fig. 167, using the Weibull diagram/distribution, in which the failure criteria must not be omitted.

Weiss Domains: Areas in ferromagnetic materials within which the elementary dipoles are aligned parallel. → Magnetism.

White Noise: also referred to as random noise, is a sound with statistically distributed zero-axis crossings and amplitudes of sound vibrations with uniform spectral energy distribution in the frequency band concerned. It can cause contact interference through generating resonance vibrations.

Wide Band Capacitor: A low-inductance, noise suppressing capacitor which is effective in the USW to Long Wave range; i. e. it has no self resonance in this range. → Radio Interference Suppression.

Winding: → Coil.

Wiping Relays: operate a contact only briefly during a coil switch-on or switch-off action.

Wire Wrapping: A non-soldered connection technique. Solid round wires are wrapped around angular pins. This connection technique has high reliability and can be fully automated. Terminal boards of high packing density can be produced very economically with the wire wrap method.

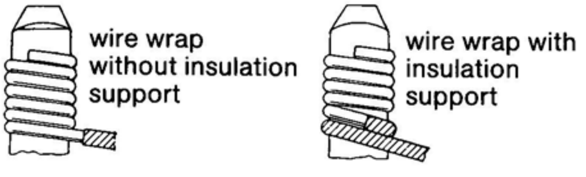


Fig. 168: Wire wrap connection

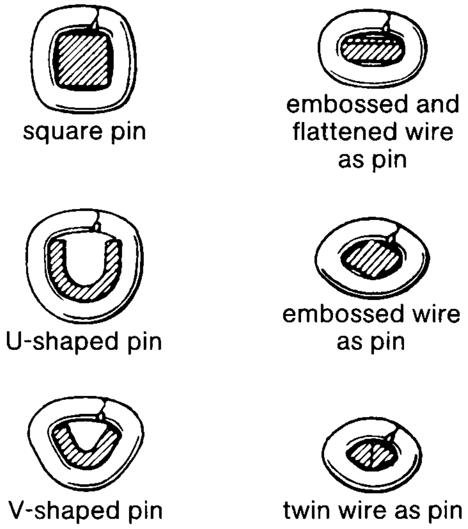


Fig. 169: Wire wrap pin shapes

Wiring diagram (of a Relay): An illustration which shows how the terminals are to be wired. Distinction is made between the view of the wiring side (bottom view) and the view of the relay in the installed position (top view).

Work Gradient: A straight line passing through the origin in the B.H diagram (→ Hysteresis), the gradient of which depends on the geometric dimensions of the magnetic circuit; (but not on the material characteristics of the magnet). Its point of intersection with the demagnetization curve is the working point of the magnetic circuit (fig. 170).

Working Point, Magnetic: Point of intersection of the *work gradient* with the demagnetization curve (→ Hysteresis), which represents the values of the induction B, and the field strength H, in the operating condition of a magnet (magnetic circuit, fig. 170). With permanent magnets, the optimum position is usually that where the *energy density* (magnetic) B.H has a maximum.

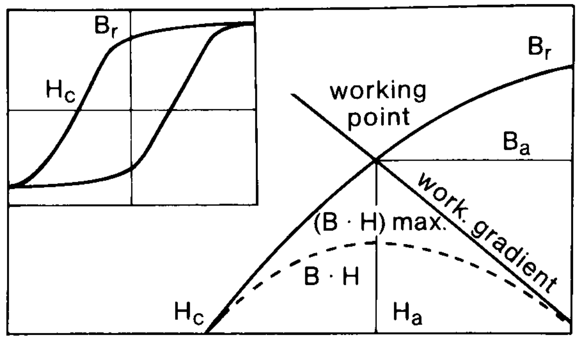


Fig. 170: Demagnetization curve of a permanent magnet showing the working point and gradient

Yoke: Flux guide plate which represents the magnetic bridge between the core and the armature. In conventional relays, it is often used to attach the contact sets and to receive or support the armature.

2.2 Units of Measurement

In general the international system of SI-Units (SI = Système International d'Unités) is used. The SI-Units are based on seven basic units: length, mass, time, electric current, temperature, light intensity and quantity of matter.
As conversion factors only integral powers of 10 appear; decimal parts and multiples of units are described by aid of certain prefix values. → Decimal Powers.
The following table shows generally used quantities, units and symbols.

Quantity	Unit	Symbol	Abbre-viation	Relationship to the basic unit	Comments
Length	Metre	l	m	Basic unit	$1\,Å = 10^{-10}\,m$
Mass	Kilogram	m	kg	Basic unit	
Time	Second	t	s	Basic unit	
Angle	Radian	α, β, γ, ...	rad	$1\,rad = 1\,m \cdot 1\,m^{-1}$	
Solid angle	Steradian	Ω, ω	sr	$1\,sr = 1\,m^2 \cdot 1\,m^{-2}$	
Frequency	Hertz	f	Hz	$1\,Hz = 1\,s^{-1}$	
Force	Newton	F	N	$1\,N = 1\,m \cdot kg \cdot s^{-2}$	$1\,dyne = 10^{-5}\,N$ $1\,Kp = 9{,}807\,N$
Pressure, mechanical tension	Pascal	P	Pa	$1\,Pa = 1\,N \cdot m^{-2}$	$1\,bar = 10^5\,Pa$ $1\,atm = 1{,}01325 \cdot 10^5\,Pa$ $= 10\,mH_2O$ $1\,at = 9{,}8067 \cdot 10^4\,Pa$ $1\,Torr = 133{,}322\,Pa$
Work, Energy, Heat energy	Joule	W, E, Q	J	$1\,J = 1\,m^2 \cdot kg \cdot s^{-2}$	$1\,J = 1\,Ws = 1\,Nm$ $1\,erg = 10^{-7}\,J$ $1\,cal = 4{,}19\,J$
Power	Watt	P	W	$1\,W = 1\,m^2 \cdot kg \cdot s^{-3}$	$1\,W = 1\,J \cdot s^{-1} = 1\,VA$ $1\,W = 1\,Nm \cdot s^{-1}$ VA for apparent power VAR for reactive power 1 PS = 0,735 kW (metric) 1 HP = 0,746 kW (imperial)
Electric current	Ampere	I	A	Basic unit	
Quantity of electricity	Coulomb	Q	C	$1\,C = 1\,A \cdot s$	
Voltage	Volt	U	V	$1\,V = 1\,m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$	$1\,V = 1\,WA^{-1}$
Electric field strength	Volt per metre	E	Vm^{-1}	$1\,Vm^{-1} = 1\,m \cdot kg \cdot s^{-3} \cdot A^{-1}$	$1\,Vm^{-1} = 1\,WA^{-1}$
Capacitance	Farad	C	F	$1\,F = 1\,m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$	$1\,F = 1\,CV^{-1}$
Electric polarization	Coulomb per square metre	D	Cm^{-2}	$1\,Cm^{-2} = 1\,m^{-2} \cdot sA$	
Electric resistance	Ohm	R	Ω	$1\,\Omega = 1\,m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$	$1\,\Omega = 1\,VA^{-1}$
Resistivity	Ohm meter	ϱ	Ωm	$1\,\Omega m = 1\,m^3 \cdot kg \cdot s^{-3} \cdot A^{-2}$	

Quantity	Unit	Symbol	Abbre-viation	Relationship to the basic unit	Comments
Conductance	Siemens	G	S	$1\,S = 1\,m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$	$1\,S = 1\,\Omega^{-1}$
Conductivity	Siemens per metre	σ	Sm^{-1}	$1\,Sm^{-1} = 1\,m^{-3} \cdot kg^{-1} \cdot s^3 \cdot A^2$	
Magnetic flux	Weber	Φ	Wb	$1\,Wb = 1\,m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$	$1\,Wb = 1\,Vs$
Magnetic flux density (magnetic induction)	Tesla	B	T	$1\,T = 1\,kg \cdot s^{-2} \cdot A^{-1}$	$1\,T = 1\,Wb \cdot m^{-2}$ G = Gauss $1\,G = 10^{-4}\,T$
Magnetic field strength	Ampere per metre	H	Am^{-1}		Oe = Oersted $1\,Oe = \frac{10^3}{4\pi}\,Am^{-1}$
Inductance, permeance	Henry	L	H	$1\,H = 1\,m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$	$1\,H = 1\,Wb \cdot A^{-1}$
Temperature (thermo dynamic)	Kelvin	T, ϑ	K	Basic unit	
Temperature difference	Degree Kelvin Degree Celsius Degree Centi-grade	Δϑ	K, °C	1 Degree Celsius = 1 Kelvin	°C (Celsius), °F (Fahrenheit) $t_C = \frac{5}{9}(t_F - 32)$
Light intensity	Candela	I	cd	Basic unit	
Luminance	Candela per square metre	L	$cd \cdot m^{-2}$		
Light current	Lumen	Φ	lm	$1\,lm = 1\,cd \cdot sr$	$1\,lm = 1\,cd \cdot m^2 \cdot m^{-2}$
Illuminance	Lux	E	lx	$1\,lx = 1\,m^{-2} \cdot cd \cdot sr$	$1\,lx = 1\,lm \cdot m^{-2}$
Quantity of light	Lumen second	Q	$lm \cdot s$	$1\,lm \cdot s = 1\,s \cdot cd \cdot sr$	
Quantity of matter	Mol	n	mol	Basic unit	

2.3 Formulae of Electro Technology
Formulae frequently used in relay technology

2.3.1 Direct Current

Quantity Equation	Explanation	Unit	Comments	Relationship with other quantities
Conductor resistance $R = \frac{\varrho l}{A}$	R = conductor resistance ϱ = specific resistivity A = conductor cross section l = length of conductor	Ω $\frac{\Omega mm^2}{m}$ mm^2 m	Specific conductivity $\sigma = \frac{1}{\varrho}$	$R = \frac{U}{I} \cdot P = I^2,\ R = \frac{U^2}{R}$ $U = \frac{Il}{\sigma A}$ U = voltage I = current P = power
Conductance $G = \frac{1}{R}$	G is conductance R is resistance	S Ω		

Quantity Equation	Explanation	Unit	Comments	Relationship with other quantities
Ohm's law $I = \frac{U}{R}$	I is electrical current U is voltage R is resistance	A V Ω		$I = UG = \frac{P}{U} = \sqrt{\frac{P}{R}} = \frac{W}{Ut}$ $U = IR = \frac{I}{G} = \frac{P}{I} = \sqrt{PR} = \frac{Q}{C} = \frac{W}{Q} = \frac{W}{It}$ G is conductance P is power W is electrical work (energy) Q is charge C is the capacitance of a capcitor t is time
Resistance and temperature $R_2 = R_1(1 + \alpha\Delta\vartheta)$ $\Delta\vartheta = \vartheta_2 - \vartheta_1$	R_1 is the resistance when cold R_2 is the resistance when warm ϑ_1 is the initial temperature ϑ_2 is the final temperature $\Delta\vartheta$ is the temperature difference α is the temperature co-efficient	Ω Ω °C °C K $\frac{1}{K}$	On low temperature conductors α is positive. On high temperature conductors α is negative $\alpha_{Cu} = \frac{1}{235 + \vartheta}$ ϑ in °C $\alpha_{Cu}(20°C) = \frac{0{,}0039}{K}$	Temperature increase of a relay coil $\Delta\vartheta = \frac{\Delta R}{R_0}(235 + \vartheta)$ ϑ is ambient temperature $\Delta\vartheta$ is temperature increase of coil due to energisation R_0 is resistance of de-energised coil ΔR is increase in resistance due to energisation
Kirchhoff's law No. 1 $\sum_{\gamma=1}^{n} I_\gamma = 0$	I_γ are the algebraic currents flowing into the point γ is the index of 1 to $n \geq 2$	A	The sum of currents at a point is zero. Currents flowing into the point are positive. Those flowing out are negative.	
Kirchhoff's law No. 2 $\sum_{\gamma=1}^{n} U_\gamma = 0$	U_γ are the voltages inside a network γ is the index of 1 to $n \geq 2$	V	The sum of the voltages in each mesh of a circuit is zero.	
Electrical work Energy $W = UIt$	W is electrical work (energy) U is voltage I is current t is time	Ws V A s		$W = \frac{1}{2}CU^2 = \frac{1}{2}LI^2$ C is capacitance of capacitor L is inductance of a coil
Electrical load $P = UI$	P is electrical load U is voltage I is current R is resistance	W V A Ω		$P = \frac{U^2}{R} = I^2R = U^2G = \frac{W}{t}$ G is conductance W is electrical work (energy) t is time

Quantity Equation	Explanation	Unit	Comments	Relationship with other quantities
Electric heat $P = \frac{m c \Delta\vartheta}{\eta t}$	P is electrical load m is the mass to be heated $\Delta\vartheta$ is the temperature increase t is duration of heating η is the efficiency c is the specific heat capacity	W kg K s $\frac{J}{kg \cdot K}$		

2.3.2 Electric Fields

Quantity Equation	Explanation	Unit	Comments	Relationship with other quantities
Charge on a capacitor $Q = CU$	Q is the electrical charge C is the capacitance of the capacitor U is voltage	As F V		
Capacitance of a plate capacitor $C = \varepsilon_0 \varepsilon_r \frac{A}{d}$	C is the capacitance A is electrode surface area d is separation between plates ε_0 is the electrical field constant ε_r is dielectric co-efficient	F m^2 m $\frac{As}{Vm}$	$\varepsilon_0 = 8{,}854 \cdot 10^{-12}\,Fm^{-1}$	$C = \frac{Q}{U} = \frac{2W}{U^2} = \frac{Q^2}{2W}$ I is current U is voltage Q is charge W is electrical work (energy)
Multiplate capacitor $C = (n-1)\varepsilon_0 \varepsilon_r \frac{A}{d}$	n is the number of plates			
Energy stored in a charged capacitor $W_c = \frac{1}{2} C U^2$	W is the electrical energy C is capacitance U is voltage	Ws F V		
Time constant of an RC network $\tau = RC$	τ is the time constant R is electrical resistance C is capacitance	s Ω F		

2.3.3 Magnetic Fields

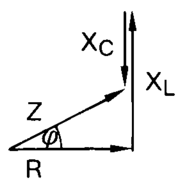
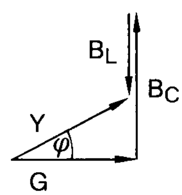
Quantity Equation	Explanation	Unit	Comments	Relationship with other quantities
Ampere turns (magneto motive force) $\Theta = IN$	Θ is the magneto motive force I is current N is No. of windings	A A		$\Theta = HI = \Phi R_m = \frac{BI}{\mu_0 \mu_r} = \frac{\Phi I}{\mu_0 \mu_r A}$ Φ is magnetic flux R_m is magnetic resistance B is magnetic flux density A is magnetic cross section μ_0 is magnetic field constant μ_r is relative permeability
Magnetic tension $V = HI$	V is magnetic tension H is magnetic field strength I is effective length of lines of flux	A Am^{-1} m		
Magnetic field strength $H = \frac{IN}{I}$	H is magnetic field strength I is current N is number of windings I is effective length of lines of flux	Am^{-1} A m		$H = \frac{\Theta}{I} = \frac{B}{\mu_0 \mu_r} = \frac{\Phi}{\mu_0 \mu_r A}$ Θ is ampere turns B is magnetic flux density Φ is magnetic flux A is magnetic cross section μ_0 magnetic field constant μ_r is relative permeability
Magnetic flux rule $H_1 I_1 + H_2 I_2 + \ldots + H_n I_n = IN$	$H_1 \ldots H_n$ are the magnetic field strengths I is current N is number of windings	Am^{-1} A	The sum of magnetic tensions is equal to the magneto motive force.	
Magnetic flux density (magnetic induction) $B = \mu_0 \mu_r H$	B is magnetic flux density (magnetic induction) H is magnetic field strength μ_0 is magnetic field constant μ_r is relative permeability	$Vs \cdot m^{-2}$ Am^{-1} $\frac{Vs}{Am}$	Absolute permeability $\mu = \mu_0 \mu_r$ $\mu_0 = 4\pi \cdot 10^{-7} Vs \cdot A^{-1} \cdot m^{-1}$	$B = \frac{\Phi}{A} = \frac{\mu_0 \mu_r \Theta}{I}$ Φ is magnetic flux Θ is magneto motive force A is magnetic cross section I is effective length of lines of flux

Quantity Equation	Explanation	Unit	Comments	Relationship with other quantities
Magnetic flux $\Phi = BA$ $\Phi = \frac{\Theta}{R_m}$	Φ is magnetic flux B is magnetic flux density A is magnetic cross section Θ is magneto motive force R_m is magnetic resistance	Vs $Vs \cdot m^{-2}$ m^2 A H^{-1}	Equation is valid only when B is perpendicular to A "Ohms Law of magnetic circuits"	$\Phi = \mu_0 \mu_r H A = \frac{\mu_0 \mu_r \Theta A}{l}$ μ_0 is magnetic field constant μ_r is relative permeability H is magnetic field strength l is effective length of lines of flux
Magnetic resistance $R_m = \frac{l}{\mu_0 \mu_r A}$	R_m is magnetic resistance l is length of lines of flux A is magnetic cross section μ_0 is magnetic field constant μ_r is relative permeability	H^{-1} m m^2 $\frac{Vs}{Am}$	$1\,H\,(\text{Henry}) = 1\,Vs \cdot A^{-1}$ $\mu_0 = 4\pi \cdot 10^{-7} Vs \cdot A^{-1} \cdot m^{-1}$	$R_m = R_{mL} + R_{mE}$ $= \frac{l_L}{\mu_0 A_L} + \frac{l_E}{\mu_0 \mu_E A_E}$ L is air gap value E is the iron value of the magnetic circuit
Magnetic conductance $\Lambda = \frac{1}{R_m}$	Λ is magnetic conductance R_m is magnetic resistance	H H^{-1}		
Maxwells pulling force formula $F = \frac{\Phi^2}{2\mu_0 A}$	F is pulling force Φ is magnetic flux A is cross sectional area of a magnetic pole μ_0 is the magnetic field constant	N Vs m^2 $\frac{Vs}{Am}$		$F = \frac{B^2 A}{2\mu_0}$ B is the magnetic flux density
Induction rule $U_L = -N \frac{d\Phi}{dt}$ $U_L = B l v$	U_L is the induced voltage N is the No. of windings $\frac{d\Phi}{dt}$ is the time dependent change of flux B is magnetic flux density l is length of conductor in the magnetic field v is the velocity with which the conductor is moved in the magnetic field	V V $Vs \cdot m^{-2}$ m $m \cdot s^{-1}$		
Inductance $L = \frac{N\Phi}{I}$	L is inductance N is No. of windings Φ is magnetic flux I is current	H Vs A		$L = N^2 \Lambda = \frac{N^2}{R_m}$ Λ is the magnetic conductance R_m is the magnetic resistance

Quantity Equation	Explanation	Unit	Comments	Relationship with other quantities
Inductance of a coil $L = N^2 \frac{\mu_0 \mu_r A}{l}$	L is inductance N is number of windings A is effective cross section l is coil length μ_0 is magnetic field constant μ_r is relative permeability	H m^2 m $\frac{Vs}{Am}$		
Energy of an inductor $W = \frac{1}{2} L I^2$	W is energy L is inductance I is current	Ws H A		$W = \frac{1}{2} B H = \frac{1}{2} \mu_0 \mu_r H^2$ B is magnetic flux density H is magnetic field strength μ_0 is magnetic field constant μ_r is relative permeability
Time constant of RL network $\tau = \frac{L}{R}$	τ is time constant L is inductance R is electrical resistance	s H Ω		

2.3.4 Alternating Currents

Quantity Equation	Explanation	Unit	Comments	Relationship with other quantities
Frequency Angular frequency $f = \frac{1}{T} \quad \omega = 2\pi f$	f is frequency T is period ω is angular frequency	Hz s s^{-1}		
RMS (root mean square) values $U = \frac{\hat{U}}{\sqrt{2}}, \quad I = \frac{\hat{I}}{\sqrt{2}}$ Rectified value $\lvert\bar{U}\rvert = 0{,}637\,\hat{U}$ $\lvert\bar{I}\rvert = 0{,}637\,\hat{I}$	U, $\hat{U}$ is the effective, crest value of the voltage I, $\hat{I}$ is the effective, crest value of the current	V A	Valid only for sinusoidal current and voltage	$U = Z I = \frac{R}{\cos\varphi} I = \frac{X_L - X_C}{\sin\varphi} I$ Z is the apparent resistance R is the effective resistance X_L is the inductive and X_C the capacitive reactance φ is the phase angle
Momentary values of current and voltage $i = \hat{I} \sin \omega t$ $u = \hat{U} \sin \omega t$	i, $\hat{I}$ is the momentary, crest value of the current u, $\hat{U}$ is the momentary, crest value of the voltage ω is the angular frequency t is the time	A V s^{-1} s	Sinusoidal waveform of current and voltage	

Quantity Equation	Explanation	Unit	Comments	Relationship with other quantities
Inductive reactance $X_L = \omega L$	X_L is inductive reactance L is inductance ω is angular frequency	Ω H s^{-1}	Susceptance $B_L = \frac{1}{\omega L}$	
Capacitive reactance $X_C = \frac{1}{\omega C}$	X_C is capacitive reactance C is capacitance ω is angular frequency	Ω F s^{-1}	Susceptance $B_C = \omega C$	
Impedance $Z = \sqrt{R^2 + X_L^2} = \frac{U}{I}$ $Z = \sqrt{R^2 + X_C^2}$	Z is impedance U is voltage I is current R is resistance X_L is inductive and X_C is capacitive reactance	Ω V A Ω Ω Ω	Series connection	$Z = R\cos\varphi = \frac{U^2}{S} = \frac{S}{I^2}$ cos φ is the power factor S is apparent power
Impedance of series connected oscillatory circuit $Z = \sqrt{R^2 + (X_L - X_C)^2}$	Z is impedance R is resistance X_L is inductive reactance X_C is capacitive reactance	Ω Ω Ω Ω		$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$ $= \frac{1}{Y} = R\cos\varphi$ L is inductance C is capacitance Y is admittance ω is angular frequency cos φ is power factor
Admittance of a parallel oscillatory circuit $Y = \sqrt{G^2 + (B_C - B_L)^2}$	Y is admittance G is conductance B_C is capacitive susceptance B_L is inductive susceptance	S S S S		$Y = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\omega C - \frac{1}{\omega L}\right)^2}$ $= \frac{1}{Z}$ C is capacitance L is inductance ω is angular frequency
Resonant frequency $f_0 = \frac{1}{2\pi\sqrt{LC}}$	f_0 is resonant frequency L is inductance C is capacitance	Hz H F	Resonant condition is achieved by $\omega_0 L = \frac{1}{\omega_0 C}$ with $\omega_0 = 2\pi f_0$	
Active power $P = UI\cos\varphi$	P is active power U is voltage I is current cos φ is the power factor φ is the phase angle	W V A		$P = S\cos\varphi = \sqrt{S^2 - Q^2}$ $= Q\cot\varphi$ S is apparent power Q is reactive power
Reactive power $Q = UI\sin\varphi$	Q is the inductive (or capacitive) reactive power U is the voltage I is the current	var V A	Volt-ampere reactive	$Q = S\sin\varphi = \sqrt{S^2 - P^2}$ $= P\tan\varphi$ S is apparent power Q is active power

Quantity Equation	Explanation	Unit	Comments	Relationship with other quantities
Apparent power $S = UI$	S is apparent power U is voltage I is current	VA V A	Volt-ampere	$S = \frac{U^2}{Z} = I^2Z$ $= \sqrt{P^2 + Q^2}$ Z is impedance P is active power Q is reactive power
Power factor $\cos\varphi = \frac{P}{S} = \frac{R}{Z}$	$\cos\varphi$ is power factor P is active power S is apparent power R is resistance Z is impedance	 W VA Ω Ω	For purely resistive loads $\cos\varphi = 1$	$\cos\varphi = \frac{U_w}{U} = \frac{I_w}{I}$ $\sin\varphi = \frac{U_b}{U} = \frac{I_b}{I}$ U_w, U_b is active, reactive voltage I_w, I_b is active, reactive current

2.3.5 Three Phase Currents

Quantity Equation	Explanation	Unit	Comments	Relationship with other quantities
Star-connection $I_L = I_{ph}$ $U_L = \sqrt{3}\,U_{ph}$ Delta-connection $U_L = U_{ph}$ $I_L = \sqrt{3}\,I_{ph}$	I_L is the line current I_{ph} is in the phase current U_L is the line voltage U_{ph} is the phase voltage	A A V V	$\sqrt{3}$ is interlinking factor	
Active power $P = \sqrt{3}\,UI\cos\varphi$	P is active power U is voltage I is current $\cos\varphi$ is power factor	W V A		$P = S\cos\varphi = \sqrt{S^2 - Q^2} = Q\cot\varphi$ S is apparent power Q is reactive power
Reactive power $Q = \sqrt{3}\,UI\sin\varphi$	Q is the inductive (or capacitive) reactive power U is voltage I is current	var V A	Volt-ampere reactive	$Q = S\sin\varphi = \sqrt{S^2 - P^2} = P\tan\varphi$ S is apparent power P is active power
Apparent power $S = \sqrt{3}\,UI$	S is apparent power U is voltage I is current	VA V A		$S = \sqrt{P^2 + Q^2}$ P is active power Q is reactive power

3 Application Examples

The successful operation of a given piece of equipment or installation depends essentially on the correct specification of the components used within it and on their correct application. This selection demands a depth of experience, which is not easily passed on, especially since every application has its own peculiarities. In particular, where relays are involved, a multitude of special characteristics need to be taken into account.

Even just setting the guidelines (P 233) from which the relay tables in section 4 were made up is difficult enough. Nevertheless, the reason for undertaking the task of preparing a check list for the selection of relays is to simplify selection and to make use of experience gained over many years in the application of relays generally so that their special features may be recognized and used to their best advantage.

The search for a suitable relay always revolves around technical and economic aspects. Relay design, in particular the design of second generation relays, has proved that higher quality often offers price advantages, even during manufacture. This means that the costs of individual relay characteristics can, and should, now be assessed differently from what would have appertained only a few years previously. This is justified in the relay tables at the end of this book.

3.1 Check List for the Selection of Relays

The following criteria concerning individual characteristics listed in the Relay Tables (section 4), are intended to provide a few pointers and offer help so as to achieve the best possible application of relays. The positions listed refer to the appropriate line in the Relay Tables (section 4).

Pos. 1: For a considerable period of time the dimensions of relays have been considered as unimportant. The view had been expressed by some [3] that miniaturization of relays would of necessity lessen their efficiency as well as their reliability, and would increase manufacturing costs. These opinions have since been proved to be wrong.

Although it had been proved many times that sensibly designed miniature relays are much more efficient than conventional relays, it has taken about 12 years for those original opponents of modern relay technology to now become its imitators.

Relay dimensions themselves are a factor of economic importance. For an average packing density, the present day cost of space amounts to approx. DM 0.5/cm^3 [21]. For the K2-relay (fig. 305), having a volume of 15.7 cm^3, this implies DM 7.85. By contrast, the modern DS2E (fig. 292), has comparable ratings but has a space cost of only DM 0.97. Thus, the space cost for the K2-relay (fig. 305) is higher than the combined purchase cost and space costs of the DS2E-relay (fig. 292).

The reliability of the K2-relay as illustrated in fig. 127, with its quality features, is unsurpassed by any other relay of this type. However, the very much smaller second generation DS2E-F-relay (fig. 294) has substantially improved ratings which result in even higher reliability. The constancy of its low contact resistance, fig. 61, substantiates this point. The author

[59] points out that of the 21 different relay types from different manufacturers, only one type (DS2E-F) has been able to satisfy reliabilty requirements. He has given convincing reasons which substantiate this fact, but what was not mentioned by him was that the efficiency (7400) of the DS2E-FL-relay has proved to be 10 to 20 times higher than that of the relays with which it was compared. This too is an important factor to consider when discussing the size of relays.

Pos. 2: The part number of relays is either self-descriptive (e.g. S2-12 V) or is designated in accorcance with administrative considerations, (e.g. R47-375-801). A self-descriptive, self-evident part number can minimize errors in both ordering and delivery. In addition to the part number, the supplier must also be known.

Pos. 3: *Approvals* (e.g. UL, VDE, SEV etc.) are demanded for many applications.
The date when production of a relay commenced, gives a clue as to its modernity, and also of its production stage. (Avoiding manufacturing faults which have not previously been encountered is almost impossible.) Just how much quality can depend on the period of time a relay has been in production, is illustrated in fig. 19.

Pos. 4: The comments made on every individual relay highlight its peculiarities, in particular its relevance for specific applications.

Pos. 5: The *contact type* is circuit dependent. If a contact is not required, a parallel or series connection should be considered in order to increase the contact reliability, the load capacity, the dielectric strength or the life.
However, it should be mentioned that a parallel connection of contacts generally serves only to increase the continuous current carrying capacity but not the break current, since parallel contacts virtually never switch precisely simultaneously. Thus, ON/OFF switching is always effected by just one contact.
Similarly, series connection of contacts does not, in general, permit an increase in switching voltage, but serves instead to increase the dielectric strength. With inductive loads, series connection, by virtue of the resultant increase in gap width opening speed, can beneficially reduce arc duration.

Pos. 6: *Contact pressure* and *contact resistance* — in addition to contact shape, contact material (figs. 3 and 4), and the degree of protection (Pos. 26) — predetermine the switching ranges of current, voltage and load. In measuring technology in particular, low stable contact resistance is required, to safely permit the switching of contact voltages in the mV range and contact currents in the μA range. Such low contact loads can be switched safely only with very low (<20 mΩ) constant contact resistances (contact forces >6 cN). Recommendations which suggest switching contact voltages of <80 mV with contact resistances of 100 mΩ, must be viewed critically. → Fritting Voltage, → Getter [13].

Pos. 7: The *bounce time* has a significant influence on the life and reliability of a relay. Special attention should be given to the number of contact bounces during the bounce time, if this is more than a few milliseconds duration. If the contacts open repeatedly during high inrush peak current switching (e.g. with capacitive loads or lamp loads), an arc will strike on every contact opening. Due to the intense heating at the arcing points, the contacts may weld.
A simple, yet extremely effective method of making bounce times significantly shorter than those illustrated in fig. 89, is described in part 2.1 (→ Bounce suppression circuit).

Pos. 8, 9, 10: Care should be taken when switching very low loads, especially since

certain publications state that, for such loads, the permitted number of switching cycles can be based on the mechanical life. Such advice can prove costly. Experience has shown that even Au bifurcated contacts in protective gas, with contact force (<12 cN), can become unstable after 25×10^6 operations at 1 mV, 1 µA, whereas a load one thousand million times higher (10 V, 0.1 A), can be safely switched 200×10^6 times. Bifurcated contacts lead to a considerable improvement of reliability. Fig. 167 shows the life expectancy of the S-relay in the switching load range of 1 nW to 1 kW.
When switching higher loads, it must be remembered that:
- an *arc extinction* circuit for the contacts can considerably increase the *life;*
- long connection lines represent additional capacitive loads, which can cause increased inrush currents, if no limiting resistors are incorporated;
- with high frequency alternating currents, the voltage can return after the zero-axis crossing, before de-ionization of the air path, so that the arc remains active;
- bifurcated contacts can be of advantage, since one contact half usually takes over the load switching, leaving the other half at low resistance.

Pos. 11: If the inrush current is very much higher than the continuous current (capacitive or lamp load), particular care should be taken with contact bounce. Contact bounce with high contact currents will quickly result in contact welding. Additionally the rated contact current gives rise to contact heating and possibly arcing, when the contact opens.

Pos. 12, 13: Short pull-in and drop-out times can significantly extend the life of a relay, especially since arc duration depends on the contact opening speed. If switching times faster than those specified in the data sheet are required, an over-excitation of the relay coil (e.g. the use of a 16 V relay with 24 V energizing voltage, or switching via a *C-switching circuit*), can be considered. The latter reduces the pick-up time by approx. 50%. The power consumption will be reduced to only 0.1%.
It should, of course, be recognized that many protection circuits result in an increase in relay switching times.

Pos. 14: The maximum switching frequency is determined by the pull-in and drop-out times, any resulting arc and contact bounce. Under the influence of arcing, the life of a relay depends very much on the switching frequency.

Pos. 15: The mechanical life is of relatively minor importance, since load-free operation of a relay seldom takes place. The life at minimum load, however, reveals a good deal about the cleanliness and reliability of the relay.

Pos. 16: Although knowledge of the maximum permissible switching loads within the range of 10^4 to 10^8 switching cycles makes the selection of relays easier, it is not advisable to ignore the need for a check of the particular operating conditions, if, for example, excessive ambient temperatures or other stresses are encountered. The *life* of a relay frequently depends on more factors than just those shown in a data sheet. Of course, reliability data, as detailed in fig. 167, provide valuable information on the life expectancy at given switching loads, but they cannot substitute for tests performed under the operating conditions of a particular application.
An example showed that a relay encapsulated in a metal can functioned very reliably under normal conditions, but failed, due to contact interruptions, under the influence of "white noise" (many vibrations of differing wave length and amplitude). Such failures have not been reported with plastic-encapsulated relays, since plastics obviously dampen the vibrations

that could adversely affect the contacts. Excessive temperatures and the contaminating layers due to organic polymers which form on the contacts are particularly detrimental to the life. However, these are now largely neutralized by the modern methods of gettering (→ Getters). The progress made in this field in recent years has been remarkable (see fig. 19).

Pos. 17, 18: The pull-in and operating power consumption can, of course, be ignored if the relay is required to be energized only rarely and only over short periods of time, but otherwise it must be kept as low as possible, for many reasons. The energy consumed in a relay has a detrimental effect on the reliability of equipment and installations, due to the effects of additional heating.
As a matter of principle, therefore, the use of bistable relays or the *C-switching circuit* with monostable operation, (neither of which consume power to remain operated), should be considered.

Pos. 19: Coil voltages are usually between 1.5 VDC (single cell operation), and 250 VAC (mains operation). DC voltages of 5, 9, 12, 15, and 24 V are most frequently used.

Pos. 20: The permissible limit temperature range must be determined by the user from ambient temperature, coil heating and contact heating during operation. Contact heating results from power loss due to contact resistance ($I^2 \times R_C$) and any arcing which may occur. The more the user makes use of the upper limit temperature range quoted in the data sheets, the less the likelihood of the relay achieving the quoted life. As a rule, operational life data is tested in an ambient temperature range of 20 to 25°C. Relays for a limit temperature range of −65 to +250°C are illustrated in fig. 323.

Pos. 21: Thermal resistance is dependent on design, the materials used and the radiating surface area. Thermal resistance should be kept as low as possible so that the self-heating of the relay is also held low.

Pos. 22: The *thermo-electromotive force* is a critical factor, chiefly where relays are used in measuring technology. Here too, the use of bistable relays or C-switching circuits will bring about substantial improvements.
Contact capacitance is of influence when switching higher frequencies (e.g. with antenna change-over switching). → HF Relays.

Pos. 23: Dielectric strength indirectly provides information on the condition of *creepage distances and clearances* in a relay.

Pos. 24: The insulation resistance between the open contacts, or between the contact and the energizing circuit (coil) is many times greater in relays than in solid state switches and is a contributory factor towards the increasing use of relays.

Pos. 25: Shock and vibration resistance are important features in mobile applications or in plant which is exposed to vibrations, such as occurs in machine shops.
Where higher requirements are demanded, the manufacturer should be consulted as to the most suitable orientation relative to the shock direction for any particular given application.

Pos. 26: Sealed relays are available in metal or plastic housings. Metal housings are applied to advantage in very damp conditions, whilst plastic housings are suited to very noisy environments, (see also position 16). Sealed relays should always be used when dirty, salty or sulphurous atmospheres are present.
Since the mechanical and chemical properties of plastics used for housings are continuously being improved, and their

Analogue + digital **Measurement Control Regulation** **Of** **In**	Temperature			Humidity			Gases			Light			Pressure			Weight			Time			Speed			Acceleration			Dimensions			Power			Loudness			Impulse		
Relay Generation	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Communication																					●											●		●	●			●	●
Supervision systems		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●
Signaling systems										●	●								●	●	●													●	●			●	●
Remote control systems		●			●			●			●			●			●			●			●			●						●			●			●	
Lighting		●	●							●	●								●		●																		
Medical technology		●	●		●	●		●	●					●			●			●	●																	●	
Analysing equipment		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●					●	●		●	●		●	●
Test equipment		●	●								●			●			●		●	●	●										●	●							
Optical equipment		●	●								●	●								●	●		●	●					●	●		●						●	●
Office machines		●									●									●	●																		
Computers																																						●	
Domestic equipment	●	●								●	●									●	●																		
Toys										●	●	●							●	●		●															●		
Entertainment electronics	●									●									●															●	●		●	●	
Switchboards	●									●			●						●		●										●	●						●	●
Automation	●	●								●			●	●		●	●		●	●	●	●	●					●			●	●						●	●
General installation systems	●	●		●	●		●	●		●	●		●	●		●	●		●	●	●	●	●		●	●		●	●		●	●		●	●		●	●	
Machinery	●	●											●	●	●	●		●	●	●	●		●								●	●							
Aerospace		●	●		●	●		●	●		●	●		●	●					●	●		●	●		●	●					●	●					●	
Military engineering		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●			●	
Power stations		●									●			●						●	●		●									●						●	
Water supply	●	●		●	●		●	●					●	●						●	●		●									●							
Mining/tunneling		●		●	●			●			●			●			●			●	●		●															●	
Traffic systems	●	●			●			●			●			●						●	●		●			●						●			●				
Transportation equipment													●	●		●	●		●	●	●	●	●					●	●			●							

Table 45: Range of application of 1st, 2nd and 3rd generation relays

Current			Voltage			Resistance			Frequency			Field strength			Rays			Level			Program flow		
1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	●			●			●			●	●								●	●		●	●
	●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●
																					●	●	●
	●			●			●			●			●			●			●			●	
																						●	●
	●	●		●	●		●	●		●	●					●			●			●	●
	●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●
●	●	●	●	●	●	●	●	●										●	●		●	●	●
																●	●						
●	●		●	●			●															●	●
	●			●																		●	●
●	●		●	●																		●	●
●			●																		●	●	
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●	●		●	●		●	●														●	●	●
●	●		●	●		●	●		●	●						●	●		●		●	●	●
	●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●
	●			●			●			●	●		●	●		●	●		●	●		●	●
●	●		●	●		●	●		●	●					●	●	●		●	●	●	●	●
	●			●			●												●	●	●	●	●
	●			●			●																
●	●		●	●		●	●			●									●			●	
●	●		●	●		●	●														●	●	●

disadvantages with respect to metal housings rapidly disappear, metal housings are now mostly used only where electrical and magnetic shielding is required.

Pos. 27: *Efficiency* can be described as a quality feature of foremost importance. It is related to the life obtained for a given contact load, and thus indirectly takes into account other quality features not stated in the formula (→ Efficiency), such as contact resistance, contact bounce, self-heating and switching speeds.

Pos. 28: The relay tables contain relays of the first generation (e. g. type K or NF), which are widely employed in areas of application for which the more technically and economically advantageous second generation relays are also now available. Such "alternatives" are referred to on line 28.

Pos. 29: Prices depend on quantities. Thus, bulk orders usually provide the benefit of cost saving. Furthermore, it is expedient to also consider the cost of transportation, since otherwise additional costs and administrative expenditure may be incurred. It is worth noting that original purchase costs are usually lower than operating costs (see table 3).

3.2 Range of Application for Relays of the 1st, 2nd, and 3rd Generations

Relays of the first generation are conventional relays, such as relay types: A, DA, HA, HB, HC, HP, JB, JC, K, NB, NF, NT. These are nonpolarized (neutral), reed or clapper-type relays, with a state of development having 130 years of relay history behind them.
Relays of the second generation are modern relays of the types: DR, DS, DX, MB, MC, R, S, SP, ST. These polarized, monostable or bistable (latching) relays are 10

to 300 times more efficient than conventional first generation relays.
Relays of the third generation, (also known as IC-relays) are of the types: DRC, RHC, TR, TS, TS-b, TS-w, IC, VS, S-NS. These relays represent a symbiosis of modern relays and electronics, and are about 500 times more efficient than modern relays of the second generation.
Although it is impossible to tabulate all ranges of relay application, the tabulation set out on pages 176/177 provides typical cases of application. This table was compiled from the results of enquiries made of customers.

3.3 Advantages of Modern Electromechanical Relays over Solid State Relays

Characteristics concerning modern relay and semiconductor technologies have been compared and explained in table 46. If, as so often has been done, a simple "Black-and-White" argument were presented then the result would favour modern relays over solid state switching by a factor of 15:4. Closer examination of individual characteristics however, shows that such evaluations should not be made, especially since some characteristics can vary by several orders of magnitude. For semiconductors, only some of the types could be specified for certain operating conditions. For some applications no alternative form of switching is possible.
Such tabular information cannot alone replace the specific component data sheets. For the designer of electronic equipment or switchgear this new data may point to more elegant possibilities of solving switching applications.
Since the invention of solid-state switches, there has been continuous dialogue regarding "relays or semiconductors" Even in the seventies, many authors agreed that a symbiosis of the two types of device in the form of a hybrid relay would point the way to the future. However, in combining conventional relays with conventional electronic modules, the resulting relays did not prove to be the "partners of electronics" which it was intended they should be. Operating costs were too high, space requirements too great and *efficiency* too low.
A totally different picture is presented when integrated circuits (CMOS, ROM etc.) are connected with much more efficient polarized relays, the permanent magnet of which simultaneously makes possible the following:
- monostable or bistable (latching) switching behaviour, with short pull-in times;
- a considerable increase of contact reliability, when the magnet has been activated as a getter [13, 43, 44];
- high contact force with low power consumption;
- compensation of ambient temperature influences on the pull-in voltage, [12];
- storage of significant portions of the pull-in force in the contact springs, so that — without loss of contact travel — no power consumption is required for the contact force and forced contact operation is ensured (figs. 13, 14; table 1) [11].

The construction of a relay which takes into account the first four of the above listed measures is shown in figure 171.
In contrast to conventional reed changeover relays whose contact reeds are fused into a glass tube, the measures taken in accordance with Fig. 171, show the following:
- contact force of 10 cN, approximately 6 times higher;
- contact resistance approximately 70 mΩ lower, and more stable;
- contact reliability, and consequently relay reliability, more than 100 times higher;

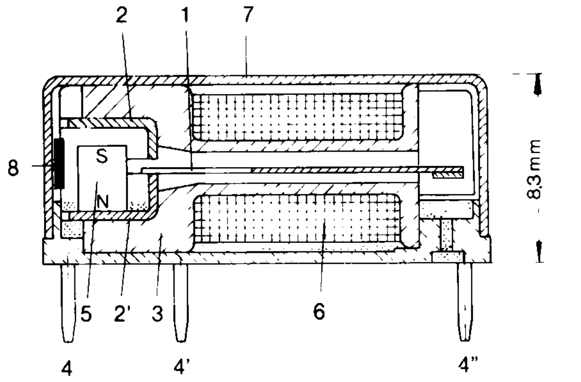


Fig. 171: Modern reed changeover relay type DR (table 2, 46). The split reed contact 1 bestows bifurcated contact operation along with the fixed contacts 2,2′ (which also act as the pole shoes). These, along with the connections 4,4′ and 4″ are embedded in the coil body. If the magnet 5 lies symmetrically between the pole shoes 2,2′ thus bistable (latching) operation is achieved, whilst when mounted asymetrically, monostable operation results. The coil 6 is either totally or partially embedded in resin and the ferromagnetic cover 7 is used for both flux conduction as well as magnetic shielding. In addition to the getter activated permanent magnet 5 there is a new type of additional getter 8 resulting in negligible build up of foreign body layer resistance [60].
In contrast to conventional reed relays the adjustment takes place in the relays own magnetic field resulting in more accurate pick up and drop out values. → magnet systems, fig. 100.

- switching load range approximately 5000 times greater;
- *efficiency* approximately 600 times better;
- purchase price lower.

Improvements of such magnitudes can be described as evolutionary leaps from the first to the second generation of relays.

3.3.1 Advances in Semiconductor Technology

The advances in semiconductor technology are in no way inferior to the development success in relay technology as previously described. As with relays, solid-state switching technology can already boast components of the third generation (VMOS, CMOS, bipolar transistors).
As early as 1968, an almost ideal switch was developed in the MOS highpower transistor. Its principal characteristics are:

- minimal power consumption;
- no secondary breakdown — insensitive to overload;
- thermal stability;
- low volume resistance (approx. 20 to 300 mΩ for 100 V types);
- switching times in the ns-range.

3.3.2 Comparison: Relays — Solid State Switches

From the characteristics, which differ for both relays and solid state switches (table 46), it is clear why the two are generally employed for different switching functions and are seldom used to replace each other.
The term **contact arrangement** would apply mainly to relays. Semiconductors have, as a rule, only a single switching function which may be either a closing or an opening function, depending on the application. An exception being the CMOS switch (table 46).
With bipolar transistors, thyristors and triacs, values for saturation voltage or the voltage drop in the ON-state are given instead of the **contact or volume resistance.** With a known carry current, the volume resistance can be calculated. The volume resistance R_v, of a transistor depends, initially, on the relation between base and collector current I_B:I_C) and on the absolute value of the collector current (fig. 172).
The **insulation resistance** of relays is a measure of the electrical isolation of input and output circuits, and also of the isolation of open contacts. The latter corresponds to the blocking resistance of semiconductors but is higher by several orders of magnitude. Electrical isolation between input and output does not exist with most semiconductors, except for semiconductor relays and optocouplers.

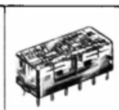
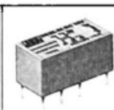
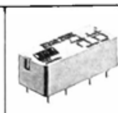
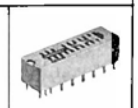
Modern relays											
Construction											
Type (m monostable, b bistable (latching), st stepper)		DR m	DRL b	DRC m	S m	SL b	DS2 m	DS2L b	ST m	STL b	S-C3 m/b/st
1 Contact arrangement (NO normally open, NC normally closed, CO changeover)		1CO		1CO	2NO 2NC 4NO 3NO-1NC		2CO		1NO 1NC 2NC		2NO 2NC 4NO 3NO 1NC
2 Volume resistance/contact resistance	mΩ	30/10		30/10	30/10		35/10		10/6		30/10
3 Blocking or insulation resistance contact/contact 7)	Ω	10^{10}		10^{10}	10^{10}		10^{10}		10^{9}		10^{10}
4 Contact capacitance coil (or screen) earthed	pF	0,3		0,3	0,5		3		1,5		0,5
5 Space required	cm^3/contact	0,84		0,84	0,84		0,46		2,39		1,2
6 Current switching range	A	10^{-6} ... 3		10^{-6} . 3	10^{-7} ... 5		10^{-5} ... 3		10^{-3} ... 8		10^{-7} ... 5
7 Voltage switching range	V	10^{-5} .. 250		10^{-5} ... 250	10^{-5} .. 250		10^{-4} ... 250		0,1 ... 380		10^{-5} ... 250
8 Load switching range 8)	W/VA	10^{-9} ... 30/60		10^{-9} ... 30/60	10^{-10} ... 100/1000		10^{-7} ... 60/125		10^{-4} ... 150/2000		10^{-10} .. 100/1000
9 Max. continuous current 8)	A	3		3	5		3		8		5
10 Max. bounce time	ms	0,4		0,4	1		2		–		0,5
11 Pick-up time	ms	1		0,5	8		3		10		8
12 Pick-up power consumption at 20°C and max. continuous current	mW	60	40	336 3)	97	48	200	88	150	70	225
13 Power consumption at max. continuous current	mW	100	0 2)	0,04	200	0 2)	420	0 2)	240	0 2)	10
14 Permissible deviation from nominal voltage	%	+150 −20		+100 −20	+100 −30		+100 −25		+150 −20		−5 ... 200
15 Electrical life 6)	No. of ops.	10^{8}		10^{8}	2 x 10^{8}		10^{8}		5 x 10^{7}		2 x 10^{8}
16 Permissible ambient temperature at 100% duty cycle 9)	°C	−55 +85		−55 +75	−55 +65		−55 +70		−40 +65		−25 +65
17 Shock/vibration resistance	g-g/Hz	100-20/2k		100-20/2k	50-20/1k		50-20/1k		20-12/55		50-18/55
18 Standard voltage (current) 10)	V/mA	1,5 – 24		5, 12	1,5 – 48		1,5 – 48		3 – 48		4,75 – 15
19 Price per contact (for 1000 pcs) 1) 20)	£	0.70	0.80	1.30	0.55	0.90	0.30	0.32	0.75	0.85	0.98

Table 46: Comparison of significant data of modern relays and solid state switches

1) As Sept. 1984.
2) When controlled by impulses.
3) Limited to approx. 0.5 ms.
4) Typical value.
5) By calculation with typical value.
6) Referred to the most favourable switched load. For solid state devices the life is mainly influenced by variations in ambient temperature.
7) For solid state devices the min. value given is for max. switched voltage and housing temperature of +100°C (MC 14066/14853 +85°C).
8) For solid state devices the value with heatsink is given. Values for ambient temperature of 40°C are given in brackets.
9) For solid state devices the max. system temperature (T_j) is given. Depending on the power consumption and the heatsink the max. ambient temperature can be established. However

Contact capacitance is a measure of the high frequency suitability of a component. Differentiation is made in the capacitance between open contacts, between contact sets one to another, and between contacts and ground. The values listed in table 46 apply to open contacts (coil or housing grounded). With transistors, this definition corresponds to the no-load depletion layer capacitance which is voltage dependent. The capacitance of small power transistors is between 5 and 10 pF, whereas it is approx. 100 pF with high voltage switching transistors. As shown in table 46, these values are seldom stated.

The **switching current range** of relay contacts is determined by the contact force, the contact materials used, their cleanliness, and also the cross sections of the contact springs, connections etc. For semiconductors, it is mainly determined by the chip size and its thermal resistance, since power loss of up to 1 watt per ampere of contact current may occur.

Whilst the **switching voltage range** of relays depends on contact resistance (minimum voltage) and on contact opening (maximum voltage), it is limited in solid-state switching devices by the saturation voltage and/or by the largest collec-

Modern solid state switches									
									Alter-native
TIL 126 Opto coupler[11] m [115]	BD 241 C Transistor m [113]	TIPL 760 A	TIC 106 M Thyristor m/b [113]	TIC 206 M Triac b/m [113]	IRF 522 MOSFET m [116]	IR 6001 Darlington m [116]	AQ1 Solid state relay m	MC14066/MC14053 Analog switch CMOS m [114]	
1NO	1NO	1NO	1NO	1NO	1NO	1NO	1NO	4NO (3CO)	
10[5]	400(100)[12]	1250(175)[12]	340(240)	(520)	400(300)	150[16]	500	$2{,}8 \times 10^5$ ($8{,}0 \times 10^4$)[19]	
2×10^6	5×10^5	4×10^6	$1{,}5 \times 10^6$	5×10^5	10^5	4×10^5	10^5 [17]	$1{,}5 \times 10^7$	
		–			200		160		
0,25	0,8	0,8	0,8	0,8	1	5	8,25	0,2	
10^{-5} ... 0,04	10^{-2} ... 5	10^{-3} ... 8	0,008 ... 5(30[13])	0,03 ... 4 (30[13])	0,01 ... 15	0,01 .. 20	0,05 ... 2	10^{-5} ... 0,025	
1 ... 30 DC	1 ... 100 DC	1 ... 420 DC	1 . 600	1 ... 220 AC	0 .. 100 DC	1 ..450 DC	100 ... 350 AC	0 ... 18 DC	
	10^{-2} .. 500 (200)	10^{-3} 1680 (840)	0,008 1100 (250)[14]	0,03 .. 880 (180)[14]	0 ... 1500 (200)	0,01 .. 4000 (1000)	3,5 ... 500	0 .. 0,4	
0,01	3 (2)[12]	4 (2)[12]	5 (1)	4 (0,8)	4 (2)	15 (4)[16]	2	0,025	
						–			
0,002	0,0003	0,00055	0,004		0,0001	0,0005	phase sensitive [18]	0,0001	
12	300	900	1[2]	11	–[15]	2000 (300)	60	–[15]	
60	2000 (1600)[12]	6000 (1600)[12]	3000 (1000)	4500 (1000)	4000 (1400)	18000 (3000)[15]	60	150	
							–		
∞	∞	∞	∞	∞	∞	∞	∞	∞	
0 + 100	-65 +150	-65 +150	-40 +110	-40 +110	-55 +150	-65 +150	-30 +80	-40 +85	
–								–	
1,4 (40)	1,0[12]	1,1[12]	0,7 (10)	1,2 (10)	5 ... 10 (→0[15])	2 (1000)[16]	10 ... 30	15 (→0[15])	
0.65	0.28	0.69	0.32	0.37	2.08	5.95	5.65	0.09	

in normal cases depending on the power consumption and the max. ambient temperature the required heat dissipation can be calculated.

10) The values given for solid state devices are required for the max. switched load. They partly reduce considerably for low loads (fig. 173).
11) Solid state components with a defined galvanic separation of control power circuits.
12) For $I_E/I_B = 5$ and max. continuous current.
13) Only ½ wave 50 Hz - sine.
14) For 220 V/50 Hz supply.
15) Frequency dependent (capacitive input impedance).
16) For $I_C/I_B = 15$.
17) With RC switching circuit $R = 33\ \Omega$, $C = 33$ nF. Max. rest current 7 mA in total.
18) Zero voltage turn-on and zero current turn-off.
19) Operating voltage $V_{CC} = +15$ V.
20) 1 Changeover = 2 contacts.

tor emitter blocking voltage U_{CES}. In practice, the smallest voltage to be switched should be a multiple of the saturation voltage. The upper limit is normally around U_{CEO}. By appropriate measures, it can be increased to U_{CBO}.

When compared to that of relays, the **switching load range** of semiconductors has narrow limits. The upper limit is given by the appropriate diagram of the safe operating area (SOA). This may under no circumstances be exceeded, as damage to the transistor will result within only 10^{-6} sec. If a load is to be switched over longer periods of time, the continuous current is calculated in accordance with U_{CEO}. Thyristors and triacs are, in most cases, operated by rectified, nonsmoothed DC or directly by AC voltage. For this reason, a supply of 220 V has been taken as the basis in table 46, for the calculation of the maximum switching capacity. It is of course possible to switch higher voltages, up to the maximum withstand voltage.

In a transistor the **pick-up power** is the product of input voltage (U_{BE}) and that input current (I_B) which will just effect a saturation. I_B greatly depends on the switching current I_s.

The **nominal power consumption** of relays is higher than the pick-up power by a safety factor which takes into account environmental influences, wear phenomenon and tolerances. For solid-state switching devices the nominal power consumption results from pick-up power consumption plus a margin of safety and the collector power loss ($I_C \cdot U_{CE\ sat}$). In the case of DRC and S-C3 relays, nominal power consumption is the power required to hold the switched condition.

The upper **limit temperature** for the relay is dependent on the plastic materials used. The permissible ambient temperature is the difference between the temperature which results from coil and contact heating and the upper limit temperature. With semiconductors, this corresponds to the permissible junction temperature T_j of, for example, 150°C, which as fig. 173 shows, is mainly influenced by the volumetric loss, P_{CE}. This is one reason why semiconductors should be provided with heat sinks when used in the upper range of the quoted nominal power.

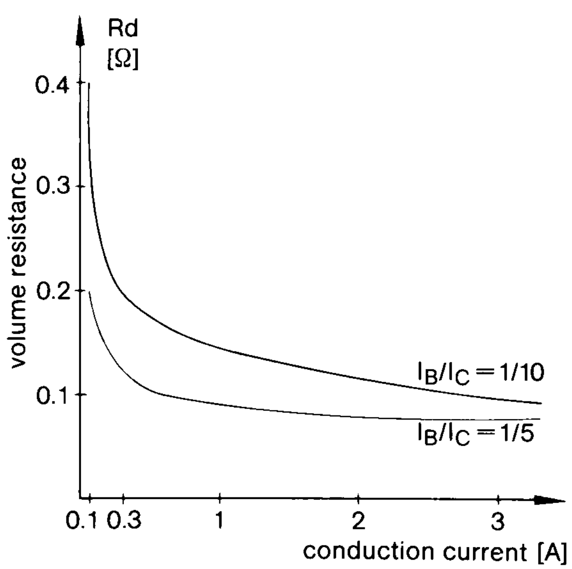


Fig. 172: Typical resistance curves of a silicon transistor shown in relationship to conduction current

For bistable relays with pulse operation, or relays using a C-switching circuit but having monostable switching characteristics, the power loss in the coil is negligible.
It should be noted that the power loss in the coil $P_{R\,coil}$ of the S-relay is sufficient to operate 4 contacts, (i.e. carry out 4 switching functions) whereas only one switching function is possible with a transistor.

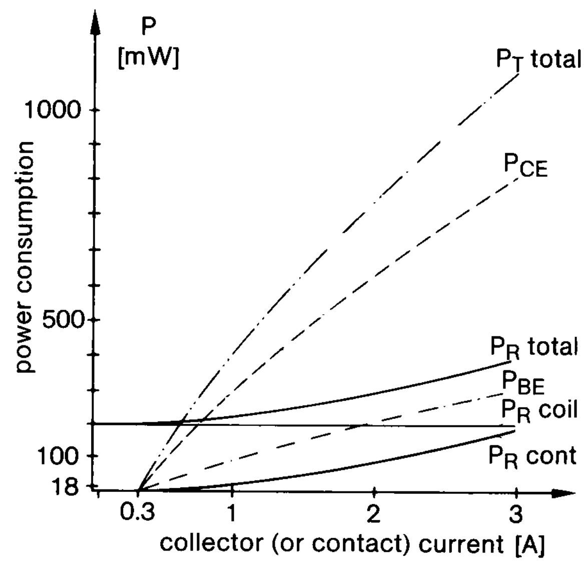


Fig. 173: Power loss comparison between transistor type BD 241C and the S-relay (table 46)

P_{BE} = control power loss of transistor
P_{CE} = volumetric loss of transistor
$P_{T\,total}$ = $P_{BE} + P_{CE}$
$P_{R\,coil}$ = power loss in coil of relay
$P_{R\,cont}$ = contact power loss of relay
$P_{R\,total}$ = $P_{R\,coil} + P_{R\,cont}$

Dependent on the properties required, experienced engineers decide in favour of:

Solid-state Relays where,
- switching times <0.2 ms;
- contacts must be free from bounce;
- life is not dependent on the number of switching cycles;
- load-free switching during zero crossover is required;
- resistance to shock and vibration is required.

Relays where,
- overload withstand is required, without costly protective measures;
- high withstand of electrical interference is required;
- linear contact switching behaviour is required;
- switching must be independent of current direction (DC, and AC up to the GHz range);
- low switching losses are required;
- electrical separation of all contacts from each other, and from the coil, is required.

In order to obtain significant advantages from both technologies, the *C-switching circuit,* the *VS-module* and *IC-relays* have been developed.

3.4 Electromechanical and Electronic Time-Delay Relays

Time delay relays have an intended time function behaviour in accordance with DIN IEC 255/VDE 0435. The time delay can be achieved in several ways (e.g. by mechanical, pneumatic, electromechanical or electronic means). The observations here, however, have been confined to the technologies which have won most widespread acceptance — electromechanical and electronic relays.

Distinction is made between pull-in-delay and drop-out-delay operations. Additionally, with drop-out-delay relays distinction is made between versions which require an auxiliary power supply voltage and those which do not.

How is the time delay achieved? In the case of the single delay relay, this is achieved by using a motor drive and gear elements. With multi-range time relays, several transmission ratios can be selected within the gearbox. This has been the case for many years, the only change being that metal has often been replaced by high-quality plastics.

Only a few years ago, more than 260 individual elements had to be mounted in a circuit board construction, using screws, rivets and splitpins. Now only approx. 80 precision components are needed. Their simple push-in assembly, from the adjusting knob to the transparent cap, is effected in logical sequence, self-locking and self-supporting.

For electronic relays, there are two possibilities of achieving the elapse time. Distinction is made between a time delay through an RC network with a comparator and a time delay based on an oscillating circuit with pulse counting circuitry.

The best known, and for many years the most commonly used process, must be the charge (or discharge) of a capacitor. The capacitor is charged or discharged, and the voltage changes, which occur as time elapses, are measured against a predetermined reference voltage by means of a comparator circuit. When the reference voltage is reached, the output is activated. Where RC networks are used for the time function, it is possible to set the time delay by a variable resistance or a special potentiometer circuit. It must be recognized, however, that using this technology there are limits to the setting of long delays and to achieving short restoring times. Repeatability is not always sufficiently accurate. RC networks used to be very sensitive to temperature changes.

Nowadays, their tolerances are small. Temperature behaviour and long-term stability are very good. If high demands are made of accuracy and reset times, these can be fulfilled only by use of an oscillating circuit with pulse counting stages. There are two possible arrangements for such a system.

The first possibility is the application of an RC oscillator. The interval of the output pulses of the oscillator circuit can be set via a potentiometer. The pulses are "added" in the counting unit. Relatively small physical size, achievement of long time delays and time setting by means of a potentiometer, as well as relatively low cost, are characteristics of this system. The outputs can be directly connected in series with the load or used as a relay output.

In the second possibility, a crystal oscillator generates a fixed, highly accurate pulse sequence. These pulses are counted in the counting unit and compared with the preselected number of pulses. When the pulse count reaches the preset number, the output is activated. Long time delays of very high accuracy and very good repeatability can be met by this system. It is further possible to achieve an exact representation of the time elapsed. As with the use of an RC oscillator, it is possible to choose between a relay output and direct switching in series with the load.

Both technologies — electromechanical and electronic, time-delay relays — are offered in housings of 45 mm or 22.5 mm widths, with terminals mounted on top. These housings are equipped for mounting either by screw attachment or by snap-clamp mounting to a top-hat rail.

Which system should be used will depend on several criteria (e.g. system operating conditions, available space, power supply available at the operating site, whether a visible display of elapsed time is required, remote control, etc).

The following comparison lists some crucial factors to aid in the decision making process:

Mechanics

- Drive with synchronous motor. The time regulating element is only as precise as the mains frequency;
- constant and linear mechanical linkage ensures accurate time scale;
- display of elapsed time;
- times can be programmed in the range of hours or days;
- long times and multi-range versions at economic prices;
- times are unaffected by mains voltage fluctuations;
- times are unaffected by temperature variations;
- time summation and voltage loss protected versions can be provided at low cost;
- tolerance data is related to the scale end values.

Electronics

- Shorter resetting time of timing element;
- time spread is same over the entire setting range;
- delays in millisecond range are possible;
- remote setting of times possible;
- versions for DC operation are possible at low cost;
- timing accuracy is not affected by mains frequency, thus enabling operation over a large frequency range;
- crystal accuracy repeatability (e.g. $\pm 10^{-2}\%$);
- tolerance data relates to the set scale end value.

In addition to single function relays, manufacturers also offer multi-function relays which can operate as pull-in-delay or drop-out-delay time-delay relays or as pulsing or wiping relays. This can reduce the costs associated with storage. However, if one considers that the required single functions can be divided into approximately:

65% pull-in-delay time relays,
15% drop-out-delay time relays,
15% pulsing relays,
5% wiping relays,

the question arises whether the relatively small requirement for additional individual functions — with the exception of pull-in-delay timing — justify higher purchasing costs? For the large volume buyer (e.g. automobile and machinery manufacturers), the functions required are, in any case, clearly specified, so that

Fig. 174: Schleicher D-series; used in all sectors of automation

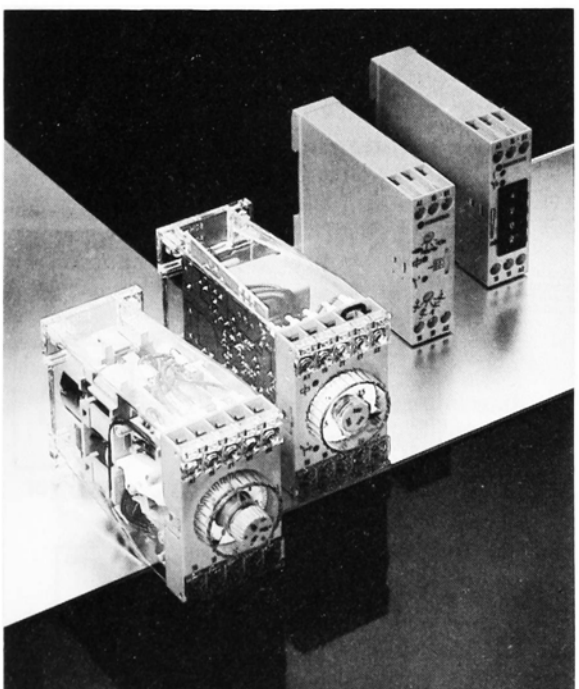


Fig. 175: Schleicher system-series and compact series; the extensive range for demanding industrial applications or for double density mounting due to half width units

the much more economically priced single function relay will be used. For laboratory use, or in direct service application where functions have not yet been clearly defined, or the replacement need can be established only at the operating site, multi-function relays will surely make life easier.

3.5 Modern Relays for Use in Measuring Applications

Every type of control system, measuring system or automation requires easily processable input signals (i. e. electrical measured values), to ascertain the actual condition of the controlled variable. All physical variables can now be converted into electrical variables with the aid of appropriate converters. They can then be compared with reference variables and after processing can initiate control functions. The demands made of measuring technology are now very high, taking into account the multitude of physical variables which need to be measured and the required accuracy now demanded.

Electrical separation of the sensors from the measuring devices or of the measuring devices from the processing of the measured data, is often both necessary and advantageous. As a rule, this separation is still achieved by using relays. The same high demands are made on these relays as are made on the measuring equipment itself.

In particular, these demands are:

- electrical separation of control and contact circuits,
- no distortion of the measured results. This implies low contact resistance, with stability of contact resistance over a long operational life,
- suitability for switching very low level currents,
- suitability for high frequency,
- high reliability,

- wide ambient temperature range,
- high shock and vibration resistance,
- sealed against harmful environmental influences,
- minimal self-heating. This implies low thermo-electromotive force,
- low power consumption (important with battery operated devices),
- small dimensions,
- suitability for installation in printed circuit boards,
- directly controllable from ICs,
- reasonable cost.

By use of modern relay technology it has been possible to achieve all the stated demands. Magnet systems of optimum design in conjunction with energy storage in the contact springs, ensure a low pull-in power requirement while still providing high contact force, the latter being a prerequisite for low contact resistance of typically a few milliohms.
Gold plated, bifurcated welded contacts are the best available in terms of offering minimal contact resistance, high reliability and long life. This contact form permits safe switching of the smallest loads (10^{-10} W), as well as high loads of up 1000 VA. Integrated getters bind any gaseous pollutant that may exist and thus ensure that the excellent characteristics of the relay are maintained over a long life.
There is normally a choice of three relay versions available each offering different methods of operation: Relays with monostable switching behaviour; relays with bistable (latching) switching behaviour (these have a single coil and polarity must be reversed to achieve change-over); relays with bistable (latching) switching behaviour having two coils.
Bistable (latching) relays have the great advantage of requiring operating power only during the instant of change-over switching. They therefore have virtually no self-heating and thus generate virtually no unnecessary thermo-electromotive force at the contacts. That is particularly important when switching low DC voltages, (i.e. with wire strain gauges). If monostable switching behaviour is required for such applications, it is possible to use single-coil bistable relays with an IC-module. The IC-module bestows monostable switching behaviour on the relay and contains electronic circuitry which limits the energizing current to the period of pick-up (approx. 1 ms), after which

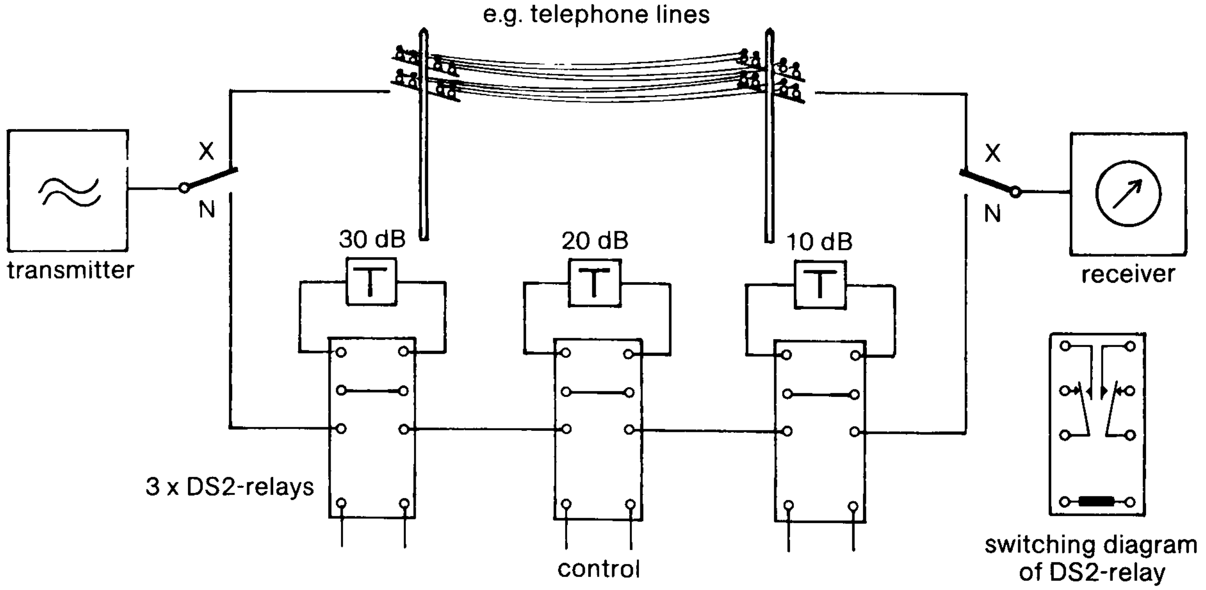


Fig. 176: Relay switching circuit for a X/N comparator measurement

only a leakage current of approximately 50 µA flows. In some relay types, this IC-module has already been built into the relay enclosure. → C-switching circuit, fig. 216.
An entirely new development in the relay sector are LSI compatible relays with built-in control electronics which can be driven directly from LSI, PLA, ROM, CMOS or TTL. These relays can operate in four different drive modes: set, reset, monostable and stepper. They operate on pulsed negative logic signals (advantageous for noise protection).
By illustration with a few application examples, the use of modern relays in the field of measuring technology will be discussed. First, an example from communications and measurement technology: The X/N comparator measurement with the aid of an automatically controlled reference circuit (fig. 176).
Using a relay with two change-over contacts effects an extremely simple switching arrangement.

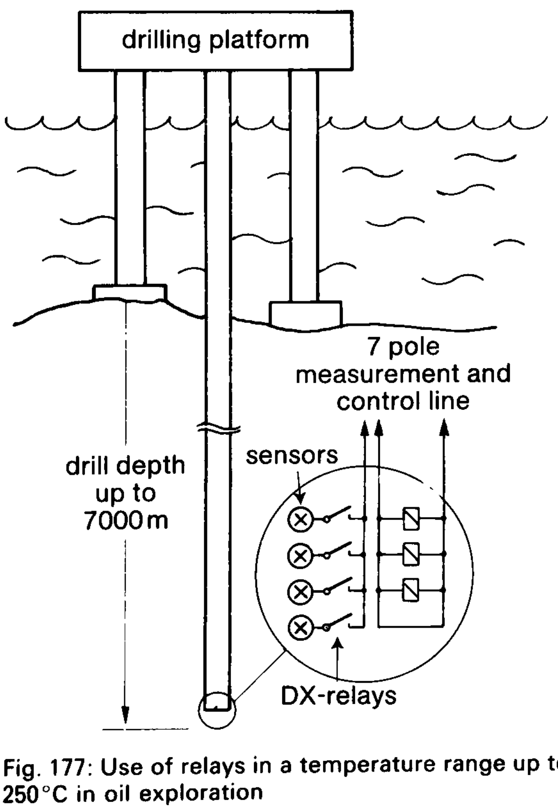


Fig. 177: Use of relays in a temperature range up to 250°C in oil exploration

The second example is from the field of geophysics (fig. 177). During test drilling in the search for oil or natural gas it is necessary to measure several parameters, such as temperature, pressure, density, sound/echo waves from different directions, radiations etc. The "geo-probe" inserted into the drill hole contains the measuring sensors and must carry out various control functions. Since only a 7 core cable is available, the leads have to serve a variety of functions. The relays carry out the switching functions. A problem is that at a depth of 7,000 m in the drill hole, temperatures of +250°C can occur.

The third example is the crosspoint matrix of an automatic component test equipment set (fig. 178). Here the problem to be solved was the coupling of several test objects, to several measuring devices such that, in place of a measuring device it is also possible to use a power supply unit. The relays must, therefore, be able to reliably switch the smallest test voltages as well as the power supply (220 VAC/up to 4 A), at any rate of change. A further factor to be taken into consideration was that the test voltages were not only DC, but also low and high frequencies, up to several MHz.

The relay selected was a two-coil, bistable relay with four normally open contacts (5 layer bifurcated contacts). Four normally open contacts because for every coupling point, two contacts can be connected in parallel (highest reliability with minimum coupling resistance and the best HF behaviour), and two-coil/bistable because of the ease of driving and the low self-heating of the relay.

The prerequisite for introducing this relay into the "crosspoint matrix" example was the behaviour of its contact resistance throughout its life (fig. 179). With a contact load of 4 A/250 V, the volume resistance at 18,000 switching cycles is approx.

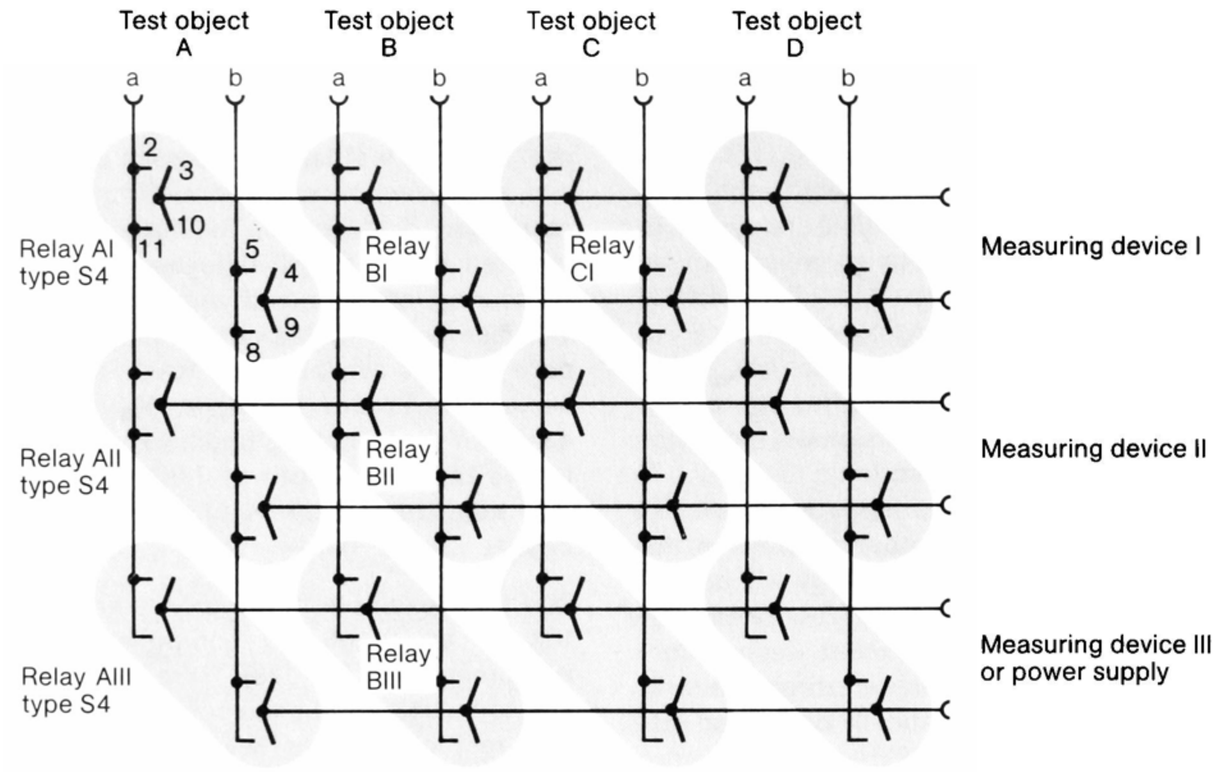


Fig. 178: Crosspoint matrix of an automatic component test equipment

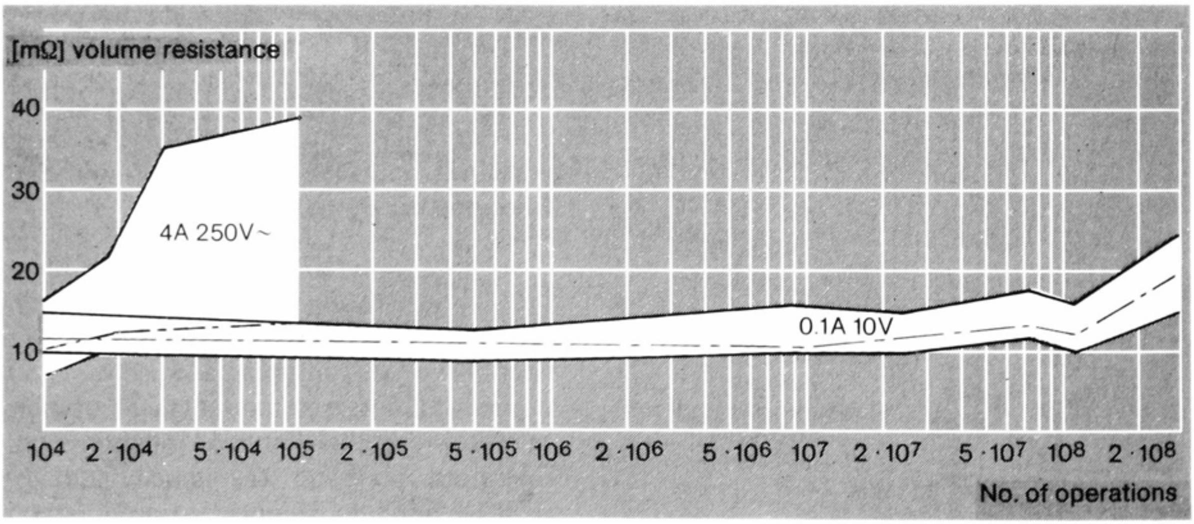


Fig. 179: Change of contact resistance of bifurcated linear contacts as shown in figs. 3 and 4 for contact loads of 1 and 1000 W

20 mΩ. After 100,000 switching cycles it is still below 40 mΩ. The values for a load of 0.1 A/10 V remain virtually constant to beyond 100 million switching cycles.

Although the electromechanical relay has often been pronounced dead, experience in the field has shown that not all switching applications can be solved by "electronics". The growing sales figures for modern relays support this assertion.

3.6 Automatic Test Systems Favour the Application of Modern Relays

The developers of automatic test systems (ATE Automatic Test Equipment), one of the fastest growing markets, decided in favour of electromagnetic relays for the switching matrix of these test systems.
The very stringent requirements for these relays, namely the switching of undistorted signals, down to the micro-signal level, for several 100 million switching operations and at high switching speeds, lead, depending on the application, to the use of reed relays with dry or wetted contacts. However, not only technical, but also economic considerations were decisive in this development.
The ATE market does not simply request electromagnetic relays. It lays down demands of high quality and reliability which have hitherto been regarded as unattainable. By returning to the old virtues of relays, a new life was given which secured a firm place for these relays against other switching technologies.
One of the most remarkable evolutions of recent years — miniaturization — led to the development of SIL relays (e. g. Clare DSS4). These relays require a base area of $2M \times 8M$ ($M = 2.54$ mm) and provide the designer of measuring equipment with a considerable saving in printed circuit boards, which in turn leads to a reduction in the physical size of the entire system. The pin arrangement of 2M-2M-2M was chosen, with the required dielectric strength in mind (up to 1000 V_{RMS}).

Fig. 181: SIL relay from Clare

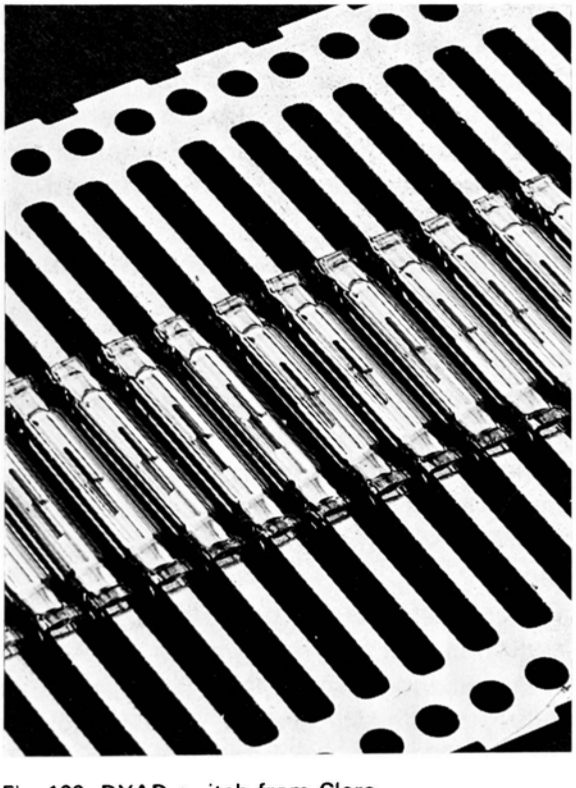


Fig. 180: DYAD switch from Clare

Very special demands are made on the "heart of the relay" — the reed switch. These demands have led to considerable quality improvements by several manufacturers. The new DYAD switch, developed by Clare, deserves particular mention. This is a reed switch with twin contacts. The contact material (ruthenium) is vapour-deposited in a vacuum, and the glass-to-metal sealing is effected by laser technique. 250 million switching cycles, outstanding constancy of the transition resistance (important in the area of micro-signals), and high switching speeds (250 μs, including bounce), are some of the characteristics which meet the demands of ATE designers.
A second remarkable development — influenced by the demands of the ATE market — is a new switch with wetted contacts.
This MYAD switch from Clare, combines the advantages of a reed relay with those of a mercury wetted contact switch. This

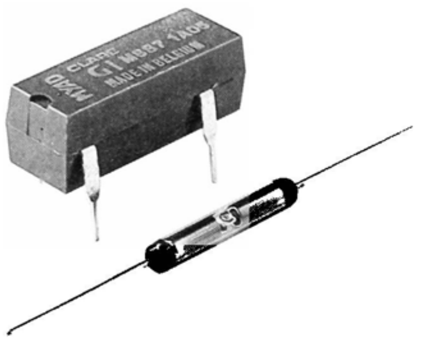


Fig. 182: MSS7 and MM3 from Clare

switch is unaffected by installation attitude, is of miniature construction, with a switching capacity of 30 VA (development target 50 VA), and can achieve more than 100 million switching operations.

As relays, these switches are supplied in the well-known DIL construction. High contact dielectric strength (1000 V_{RMS}) is demanded mainly for circuit boards and cable testers. A special 4-pin version of the DIL design (MSS7), guarantees the required dielectric strength of 2,000 V_{RMS}.

The challenge which the ATE market has presented to relay manufacturers — and which has been met — is further proof that electromechanical relays have their chance now, and will continue to have in the future.

It can be reasoned that the development of highly specialized relays is by no means concluded and that the use of relays will continue to grow along with the electronics market.

3.7 Relays with Forced Contact Operation

Safety relays have the function to positively isolate safety circuits of presses, manufacturing and machines, furnaces, medical apparatus etc. This requires at least two contacts, independent of each other and series connected. These are almost exclusively the normally open contacts of monostable relays. Independence is achieved as follows: If one contact welds, the series connected second contact (of the second relay) must carry out the switch-off (safe isolation).

In fault analysis, it can be assumed that an identical fault, such as contact welding or spring fracture, will occur only at **one** contact. The possibility of a second fault occurring simultaneously on a second contact can be discounted. Every individual fault must be immediately recognizable or be actioned. The action then must prevent a subsequent contact make. With simpler controls, the action may be a capacitor which requires charging. With more complex controls, the action takes place via a microprocessor (a growing tendency).

This fault recognition of the disturbed normally open contact is undertaken by a forced operation, normally closed contact. The forced operation relates only to a synchronous switching behaviour of these two contacts, which means that if, for example, the normally open contact is closed, then the normally closed contact which serves for monitoring, must be open and vice versa. In the event of a fault (contact welding), synchronous switching behaviour must be ensured.

3.7.1 Application of "Conventional" Safety Relays

In this context, conventional means that **all contacts are forced operated in relation to all others.**

Function: In the de-energized state (schematic as drawn) the two capacitors are charged via the closed monitoring contacts.

On simultaneous operation of both switches, the two drive relays will switch first and then, with a time delay, the two safety relays will switch. The capacitors are discharged, the relay goes into self-holding, and the safety cicuit is closed.

Should a safety circuit contact weld, the second contact in the safety circuit, on opening of the switches (the relay drops out), will undertake safe isolation. Due to the "forced operation" of the contacts, the welded safety contact prevents the closing action of the monitoring contact of the same relay, and the capacitor in this circuit cannot be charged for a subsequent switching action.

The two principal demands made of a safety circuit have been fulfilled thus:

a) In the event of a fault (contact welding), safe isolation of the safety circuit is carried out by the second contact.
b) Fault recognition and evaluation is achieved via the monitoring contact, which prevents the next switch-on action.

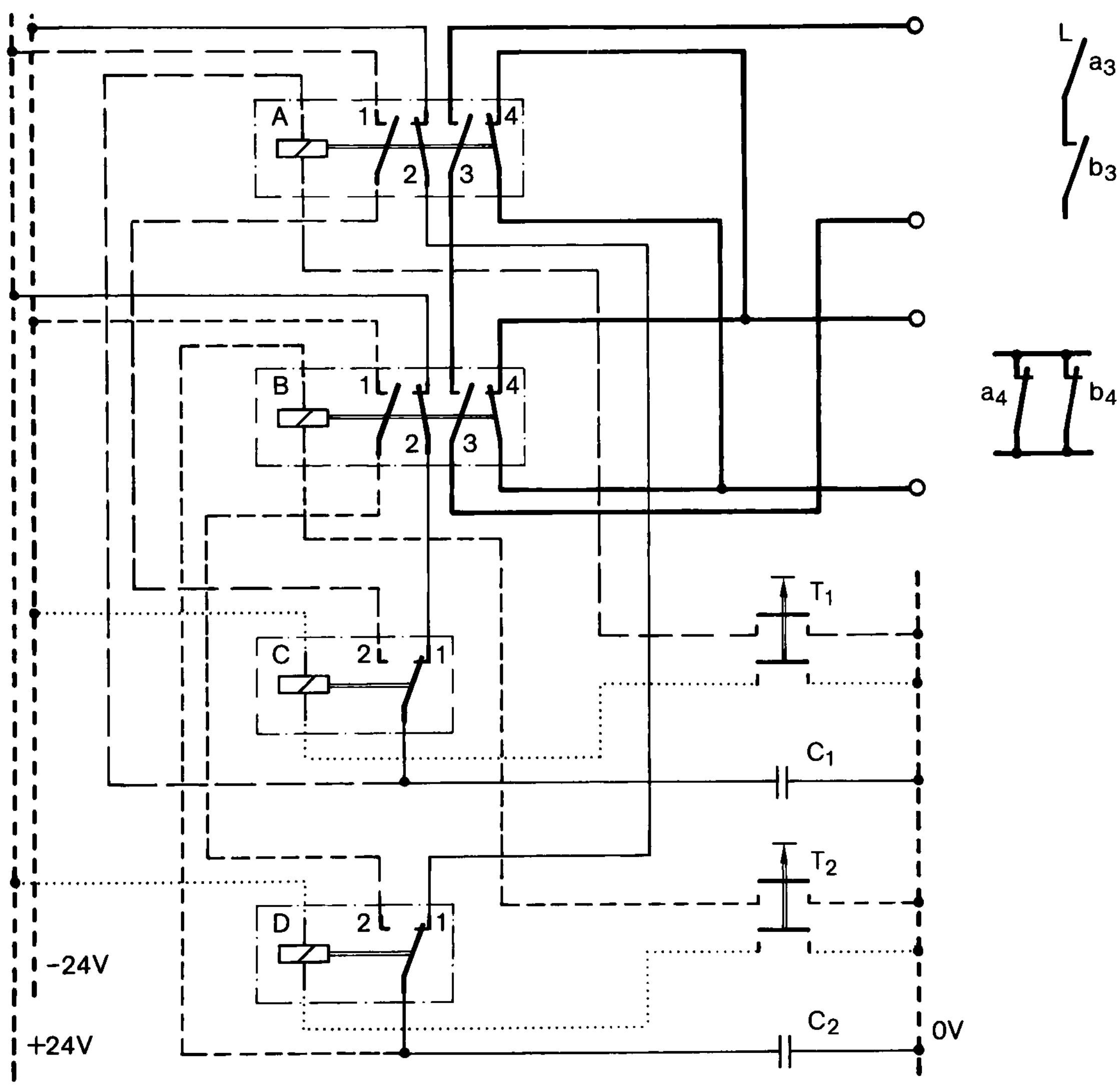


Fig. 183: Principle of a two-hand circuit of a press machine control equipment [117]

A/B safety relay
C/D drive relay
C_1/C_2 capacitor
T_1/T_2 push button

safety circuit (1) with main contacts a_3/b_3
closed circuit (2) with main contacts a_4/b_4
charging circuit (1) with control contacts b_2/c_1 for C_1
charging circuit (2) with control contacts a_2/d_1 for C_2
- - - - - holding circuit (1) with control contacts a_1/c_2 for A
-------- holding circuit (2) with control contacts b_1/d_2 for B

The disadvantage however is, that due to the forced contact operation of all contacts, one to another, a "spring fracture" fault of parallel connected contacts (fig. 183), will not be recognized and that in the case of all contacts within a safety circuit welding, relay drop-out into the safe condition (closed circuit) is not possible.

3.7.2 Safety Relays with Twin Forced Contact Operation

In contrast to conventional safety relay technology, with this new version **each main contact is allocated an auxiliary** (or control) contact.
The new safety relay illustrated in fig. 184, can also be used for two-handed operation of press controls. Outwardly it appears to operate in the same manner as the conventional safety relay, but it has the following special features:

- With suitable selection of the NO contacts, it is ensured that, in the event of a fault whereby all contacts of the safety circuit are welded, the relay will drop-out into the safe condition. This is possible only by using twin, forced contact operation.
- Improved space saving (approximately 40% less volume required).

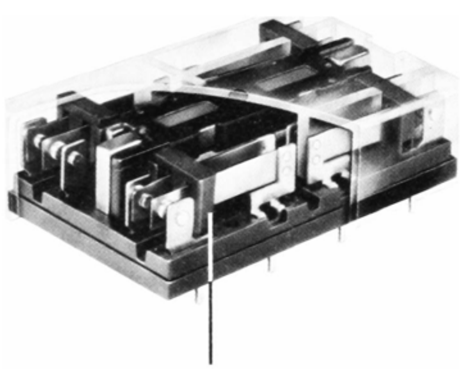


Fig. 184: Safety relay with pair forced operation contacts (4NO/4NC)

- Improved power saving (approximately 65% less energy; i.e., conventional relays consume 3 times the energy), which could mean that the user could manage with a much smaller power supply or is even spared the need of a transformer.
  The new safety relay with this contact arrangement (fig. 309) has been designed not only for two-handed operation of presses. The example of the switching circuit was used only to compare the fault analyses of both possibilities, and to prove that the new safety relay complies with the regulations and offers in addition a number of advantages, which can be used to increase reliabilty and safety.

3.8 The Significance of Load Limit Curves for the Assessment of Relay Load Switching Capacity

During the switching of DC loads an *arc* will occur from the outset of a given load (switching voltage × switching current). This damages the contacts and, in certain circumstances, can lead to faulty switching (see explanation to fig. 185).
In order to achieve the required operational life (number of switching cycles), and to avoid faulty switching, it is necessary to know and observe these load limits, (which depend largely on the relay design, the contact material and environmental conditions).
There is one load limit curve for change-over contacts (fig. 185) and another for normally open (or normally closed) contacts (fig. 186). The load limit curves of the DR-relay are used as an example.
In the case of change-over operation the arc must extinguish during the short transit time (time between opening of the NC contact and closing of the NO contact), so that no faulty switching can occur through bridging of the NC/NO contacts.

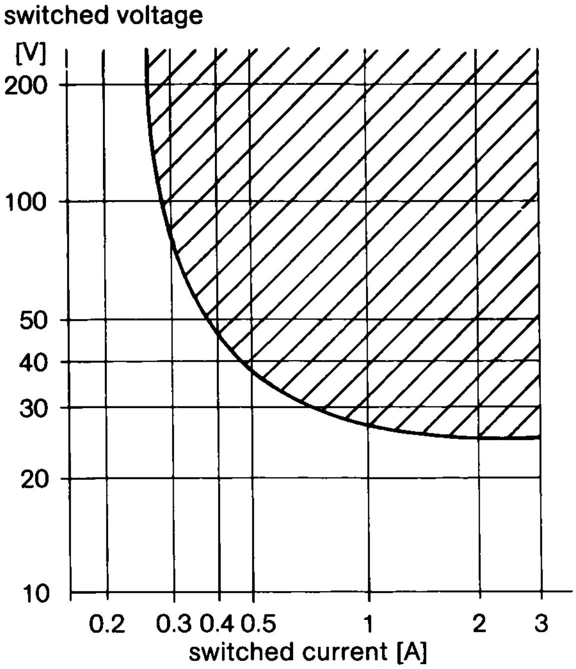


Fig. 185: Load limit curve for changeover contacts of DR relay (fig. 283)

This condition is fulfilled below the load limit curve, in the non-hatched area of the graph, e.g. at 30 V/0.5 A (fig. 185).

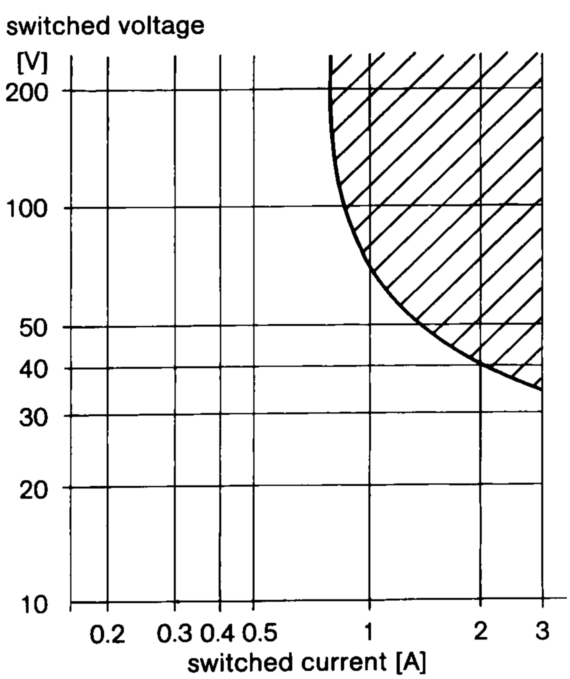


Fig. 186: Load limit curve of DR relay (fig. 283) using only one normally open (or normally closed) contact

With NO or NC contacts, the arc has a longer time in which to extinguish. As a consequence, higher switching capacities (e.g. 70 V/1 A or 40 V/2 A) are permissible. This implies arc loads below the load limit curve in the non-hatched area of the graph of fig. 186.
In practice, both load limit curves are drawn on a common graph and the hatching is dispensed with.

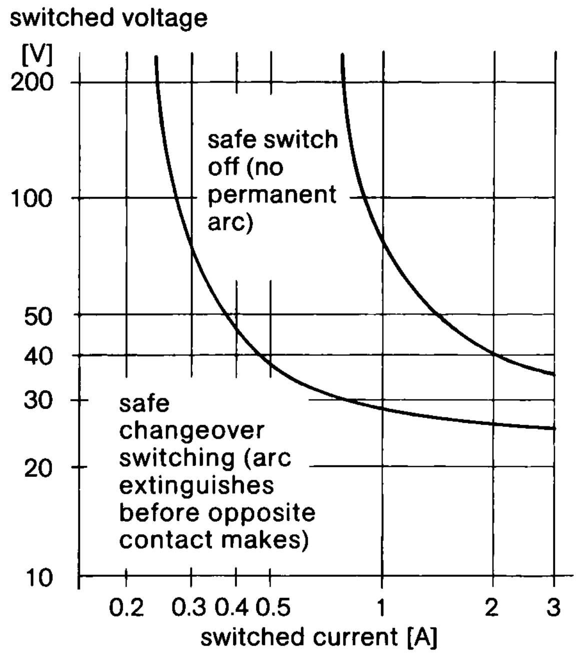


Fig. 187: Usual representation of the load limit curves (e.g. for DR-relay, fig. 283)

3.9 Advice on the Use of Relays

Current practice is to mount modern electromechanical miniature relays densely together with many varied semiconductor components on printed circuit boards. In order to ensure reliability of the relays, while at the same time keeping production processes as simple as possible, the use of sealed relays is recommended.

Soldering and Cleaning

Colophony (rosin) should be used as solder flux since, due to its low chemical reactivity, subsequent cleaning of circuit boards is not required or will at least be made simpler. With relays that are not sealed from the atmosphere, the ingress of flux or flux vapours into the relay must be avoided. The soldering process, at a temperature of 250°C, must not exceed 10 seconds, and at 350°C, it must not exceed 3 seconds. Fig. 188 illustrates a well proven dip soldering process. The heating stage serves both to effect quick drying of the flux (no further penetration of the flux into the components) and to improve solderability.

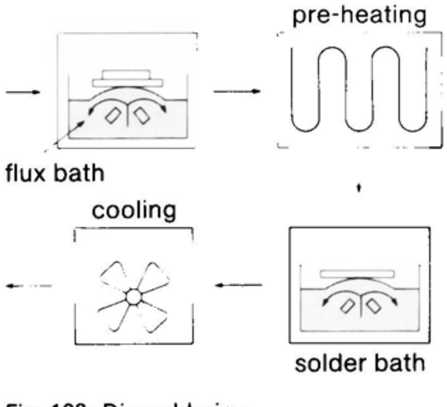


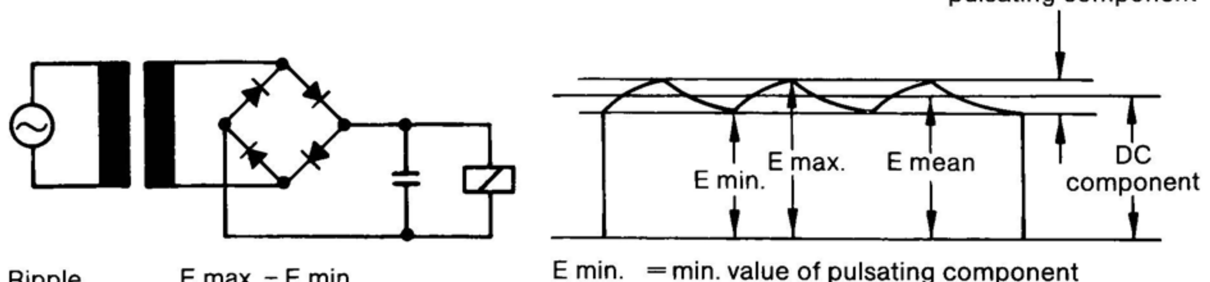
Fig. 188: Dip soldering

During subsequent cleaning of circuit boards, it must be ensured that the solvent is compatible with the material of the relay covers (table 47), otherwise tensions and fissures can occur in the cap and result in relay failure.

Solvent \ Cover material		PBT	PC
Florinated	Freon TF, Te	●	●
	Freon TMS	●	●
	Freon TMC	●	×
	Alpha 1001, 1003	●	●
Aqueous	Indusco 624, 1000	●	●
	Lonco Terg	●	×
	Hollis 310	●	●
Chlorinated	Perclean B-5, D	●	×
	Chlorothene VG, N	●	×
	Chlorosolv	●	×
	Trichloroethane	●	×
	Alpha 564	●	×
Alcoholic	IPA	●	●
	Ethanol	●	●

● compatible
× noncompatible
PBT Polybuthylenterephthalate (Crastin)
PC Polycarbonate

Table 47: Solvent compatibility of the two most common relay cover materials



$$\text{Ripple factor } (\%) = \frac{\text{E max.} - \text{E min.}}{\text{E mean}} \times 100\%$$

E min. = min. value of pulsating component
E max. = max. value of pulsating component
E mean = average value DC component

Fig. 189: Ripple factor of rectified alternating voltage

It is advisable not to use ultrasonic cleaning for relays with closed contacts, as the contact areas will be damaged by the micro-frictional movements. This applies in particular to gold contacts (→ Contact sticking). It is advantageous to clean circuit boards in a vapour bath (e.g. Freon vapour).

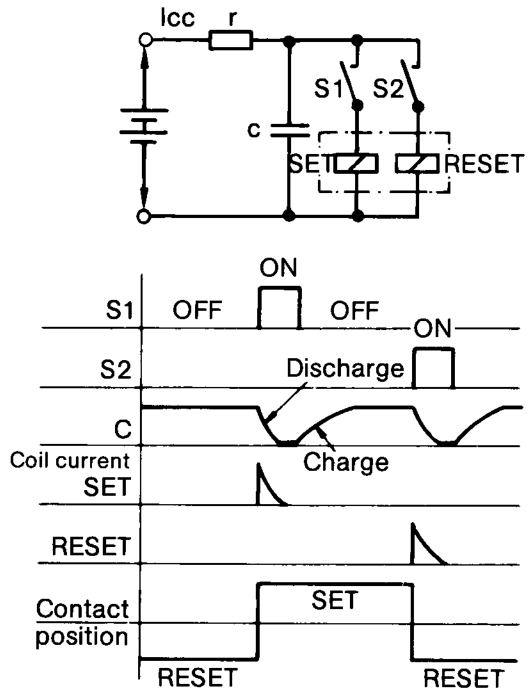
Control Circuit

Ripple Factor

Where DC relays are operated from an AC supply, via a rectifier, it must be remembered that the pull-in and drop-out values, in particular, can change. To avoid any possible damage to the contacts, the ripple factor (fig. 189), especially with reed relays (→ Contact sticking), should be reduced to below 5%.

Polarized Bistable Relays

Fig. 190 to 194 show a number of common drives of bistable (latching) relays, with their associated characteristics.



Note: The larger impedance of r becomes, the smaller the peak value of Icc becomes. Note that delayed response of the circuit may be resulted in this case.

Fig. 190: Set/Reset operation under small capacity of power supply (latching 2 coil relay)

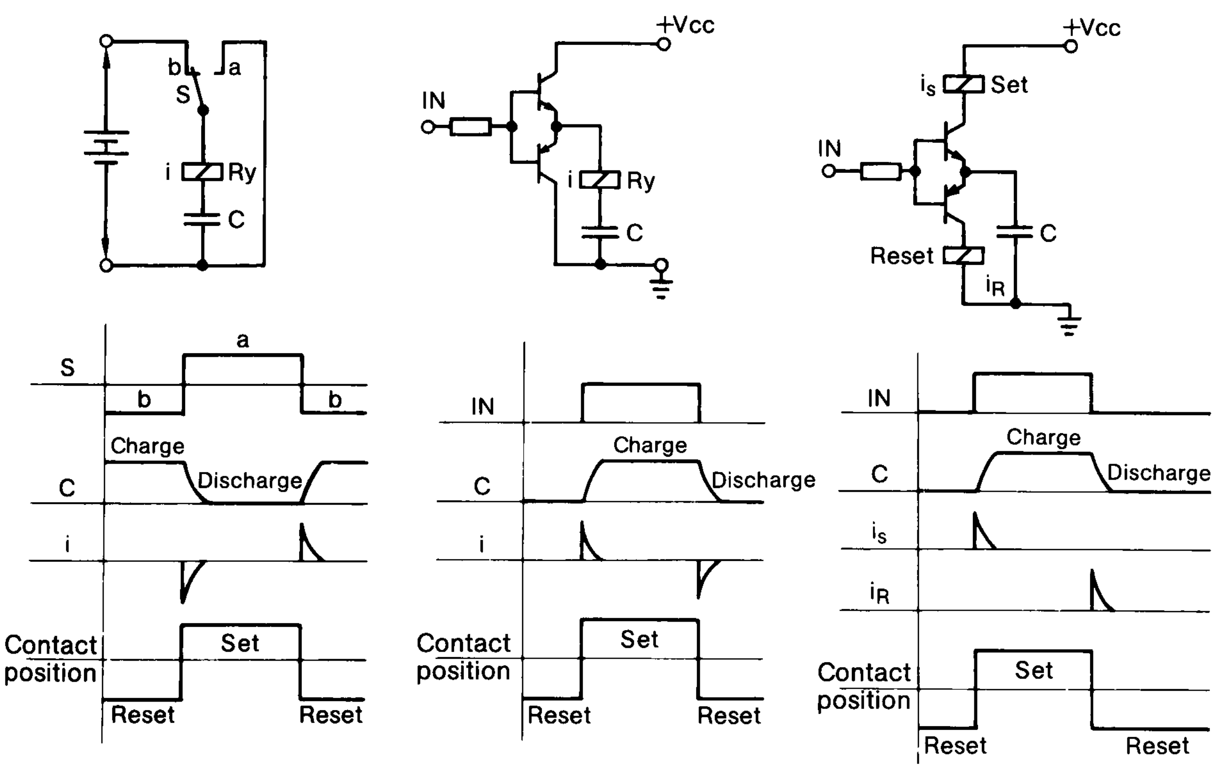


Fig. 191: Monostable relay operation with low power consumption (→ C-switching circuit)

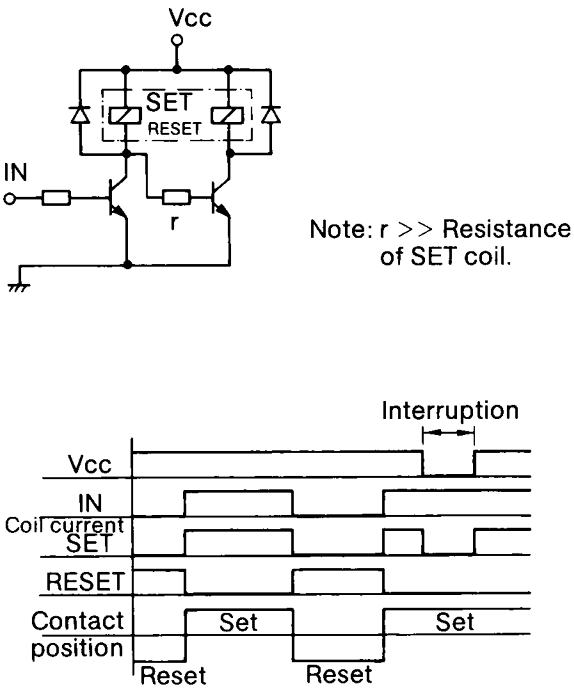


Fig. 192: Monostable relay operation with memory function for power failure back-up (→ IC-relay)

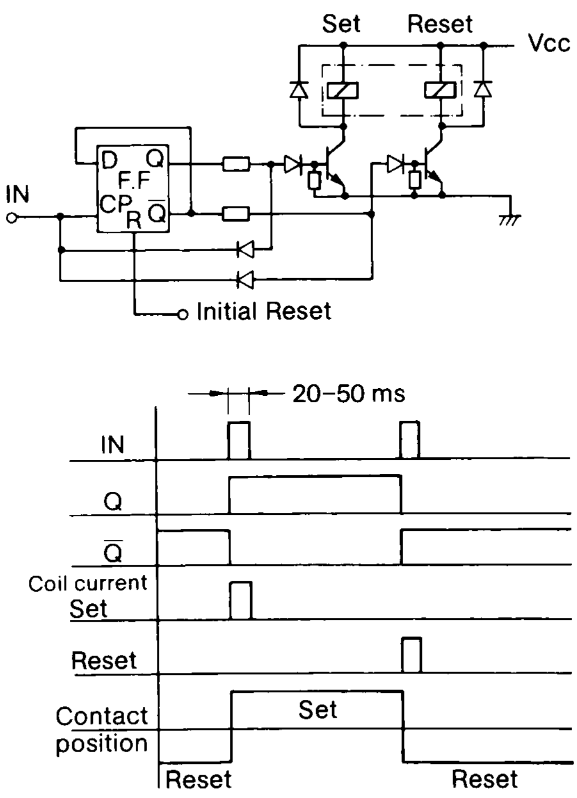
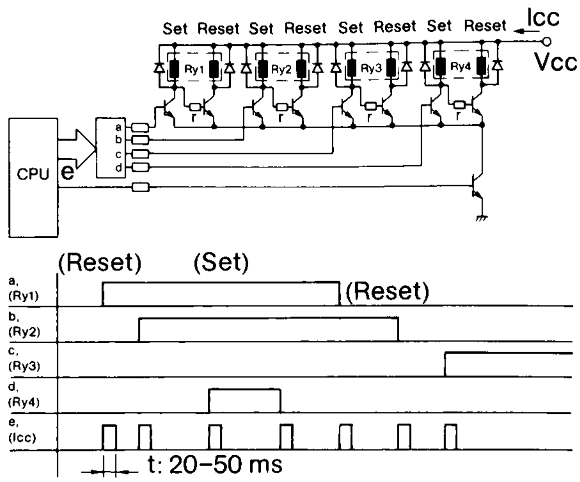


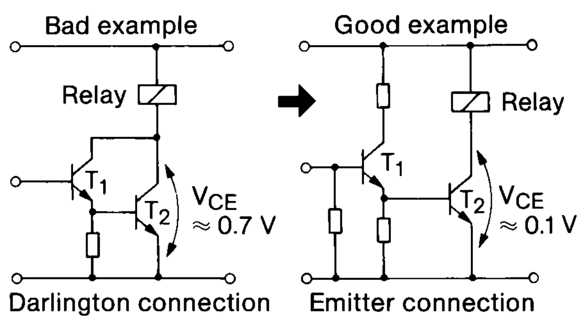
Fig. 193: Toggle operation with low power consumption (→ VS module)



1. Each relay keeps the previous contact position after power supply is interrupted.
2. The pulse "e" for operating relays shall be generated in synchronization with variations of the relay control output "a" through "d"

Fig. 194: Multiple relays controlled by CPU

When relays are driven via transistors, a Darlington circuit is unfavourable, as explained in fig. 195.



- Because of wasted power consumption, heat develops.
- A strong transistor for T_1 is required.

- T_2 conducts completely.
- T_1 is sufficient for signal use.

Fig. 195: Transistor control of relays

Furthermore, due to the high sensitivity of modern relays, the dark current in the circuit, see fig. 196, should be kept fairly low in order that it should not cause any partial response of the relay, which in turn could reduce contact force and vibration resistance.

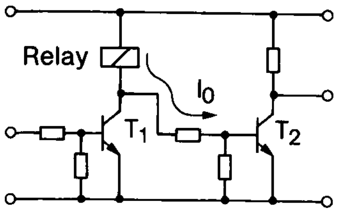


Fig. 196: Example of a circuit with nominal dark current I_0

Load Circuit

The type of load with its specific current characteristic, has such a significant influence on contact life that it is absolutely necessary that its nature is known precisely. The most common load types are listed below:

a) Resistive load: Inrush current i is equal to the rated current i_0;

b) Lamp load: In circuits w with discharge lamps having a large power factor and where the source impedance is small, the inrush current may even be 20 to 40 times that of the rated current (fig. 197);

c) Motor load (→ Utilization Categories): In this case the inrush current can rise to a value 50 times that of the rated current (fig. 198);

d) Solenoid load: See fig. 199;

e) Contactor load: See fig. 200;

f) Capacitive load: With a capacitive load, a multiple of 20 to 40 times that of the rated current (dependent on the ohmic resistances of the load circuit), must be anticipated at switch-on (fig. 201);

g) Inductive and capacitive DC loads: If a circuit which has inductive elements is opened, the energy stored in the inductance will dissipate via the contact (due to arcing). This can lead to such intense heating of the contact points that the contact material evaporates and precipitates on the opposite contact (fig. 202);

The direction of the material migration depends on the direction of the current (→ Arc, → Fine migration). Excessive migration will eventually lead to contact sticking or contact welding.

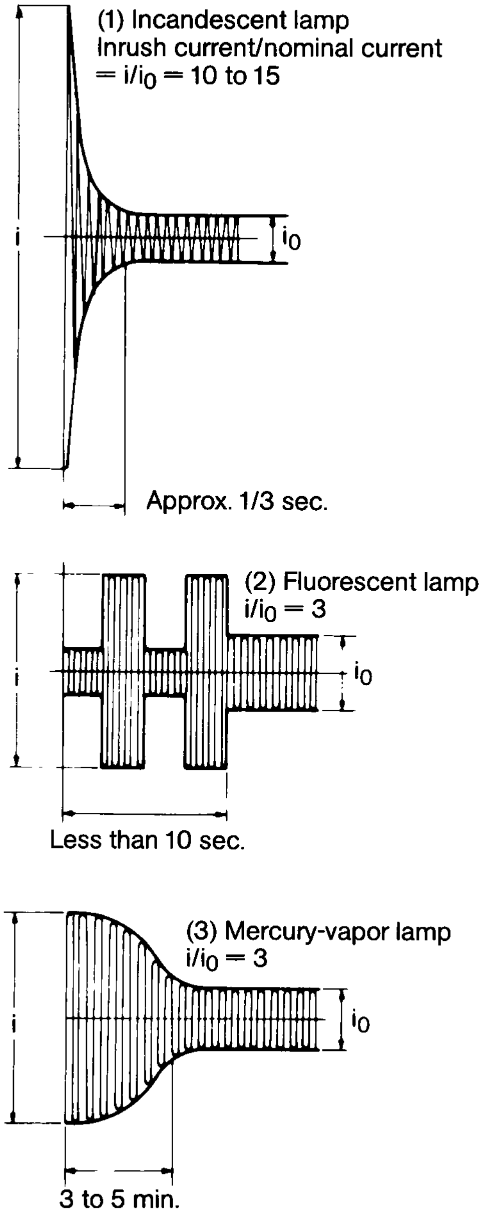


Fig. 197: Inrush current flow for lamp load

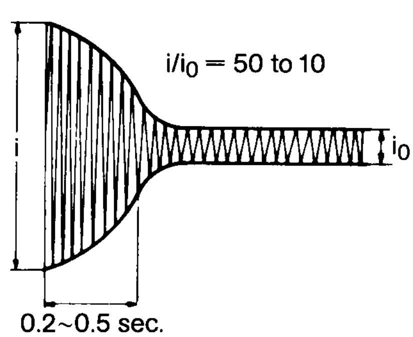


Fig. 198: Current flow for motor load

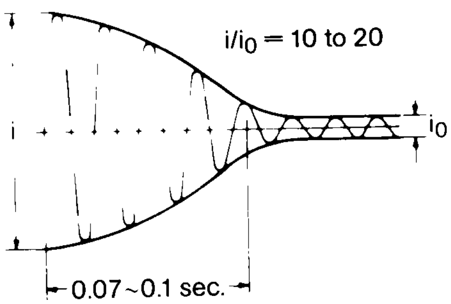


Fig. 199: Current flow for solenoid load

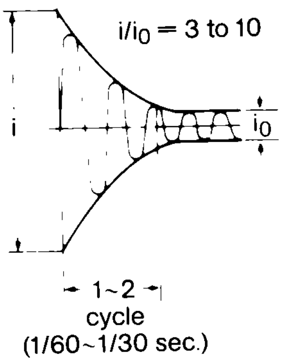


Fig. 200: Current flow for electromagnetic contactor load

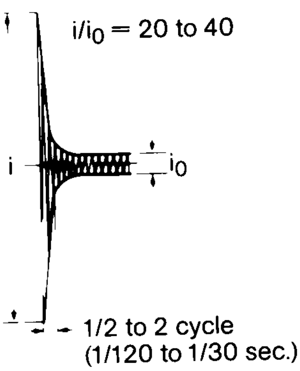


Fig. 201: Current flow for capcitor load

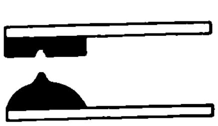


Fig. 202: Material migration at a contact (schematic)

If a capacitive load, (existing due to long conductors) is switched on (see f), switching arcs can occur which will lead to contact welding. In both cases, therefore, it is necessary to carry out *arc extinction.*

Circuit Diagram Design

Finally, two annotations of a general nature may be made on the use of relay contacts.

a) Thyristor Control of Relays:
Since thyristors switch off on zero axis crossing of an AC voltage, a relay contact is always opened or closed at the same phase position of the current. Dependent on the pull-in and drop-out times of a thyristor controlled relay, contact opening or closing can occur at any point of the phase (i. e. even with maximum current). This means that the actual load conditions must be accurately established with every relay application.

b) Short-Circuit Currents:
The arrangement of change-over contacts shown in fig. 203, can lead to short circuits as shown, should an arc develop. For this reason, circuit arrangements of this type should definitely be avoided.

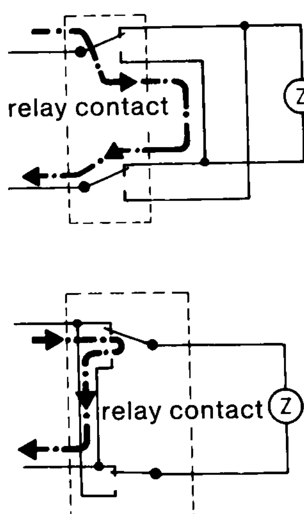


Fig. 203: Circuit which could lead to conduction c short circuit currents (thick arrows)

In the use of relays, the observance of basic principles such as are outlined here, will result in a significant increase in the reliability of the circuit. However, considering that specific design-related characteristics of the relays may frequently play an important role in optimum circuit design, it is advisable to discuss any critical application with the relay manufacturer before final specification.

3.10 Relay Operation Using Long Conductors

With a fixed operating voltage, the power available at the end of a long supply line is often not sufficient to effect a positive pull-in of the relay although it may be sufficient to hold the relay. An example of such an application is with emergency call equipment where the use of auxiliary power supplies is not possible.

By using the auxiliary pull-in circuits illustrated in figs. 204, 205 and 206, safe pull-in of the relay is ensured by reversal of the polarity of the DC voltage on both supply lines. In this way the voltage available to operate the relay, at the end of the line, is doubled [110].

The supply lines L1, L2 are symbolically represented as resistors, the auxiliary pull-in circuit for the relay R is comprised of three diodes D1, D2, D3, and a capacitor C. Fig. 204 shows the circuit in a state of rest, with the operating voltage U being applied so that L1 is positive and line L2 is negative. In this condition the capacitor C is charged via diode D1, up to the operating voltage U. Pick-up of the relay R will thus be prevented by the diode D3.

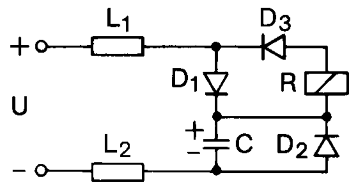


Fig. 204: De-energized condition of the auxiliary control circuit

When the relay is to be operated the polarity of the operating voltage U is reversed, and the circuit is then operated. Fig. 205 represents the first part of this operation (the pull-in phase of the relay). In this condition, the voltage U of the charged capacitor C is added to the operating voltage U to attain the value 2U. The consequence of this is that a current flows through the relay coil. This current is now sufficient to ensure pull-in of the relay.

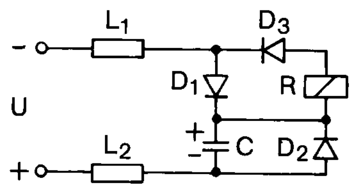


Fig. 205: Relay pick-up phase

After pull-in of the relay and discharge of the capacitor C, the diode D2 takes over the current flow passing through the relay coil. The normal operating voltage U is now sufficient for holding the relay in the operated state. This condition is illustrated in fig. 206. The capacitor C thus acts like a battery (with the terminal voltage U) which is briefly connected in series with the operating voltage during the relay pull-in phase.

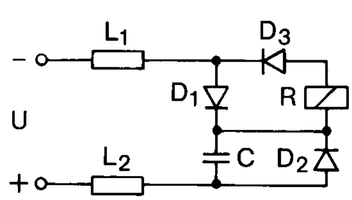


Fig. 206: Holding phase of the relay

3.11 Elimination of Relay Contact Bounce

In relay technology, the search for bounce-free contacts is almost as old as the relay itself, not only because a prolonged bounce time reduces the life of the contact, but also because it adversely affects contact reliability.
The "bounces" are particularly disturbing where relays are used as pulse generators for input counting, as they can quite easily lead to uncontrolled counting errors.
With the mercury wetted reed, a bounce-free contact has been developed. However, this relay type is usually position dependent and is relatively expensive. Thus, it is rarely used in practice.
Bounce tendency has been significantly reduced by use of bifurcated linear contacts (see fig. 3 and fig. 89).
Considerable success in reducing contact bounce has been achieved with the development of the FLOC contact (Flexure Lift-Off Contact). Fig. 13 illustrates the operation of this contact. Use of this contact also leads to an increase in reliability due to forced contact operation during contact opening.
A further effective method for bounce suppression of relay contacts is the use of electronic semiconductors, as illustrated in the circuit shown in fig. 207. The following semiconductors can be recommended:

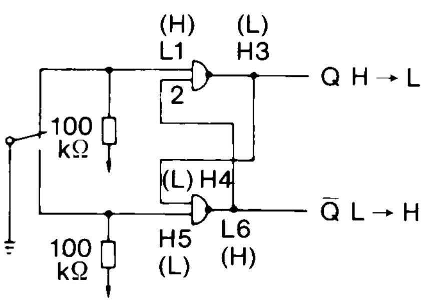


Fig. 207: Contact bounce elimination circuit

- National MM 74 C00 (MC 4012) 4 gates
- Motorola MC 14490 (MCMOSLS) 6 gates

(Supply voltage range 3 to 18 V).

3.12 Simple Timing Circuits

With the exception of time-delay relays, the pull-in and drop-out times of electromagnetic relays generally lie in the millisecond range. These times can be varied by use of external control of the relays.
However, relatively wide tolerances in the time lag must be anticipated with all timing circuits, since many factors are involved in constituting the timing function. Accurate calculation in advance is therefore very difficult.
Accurately timed switching in conjunction with relays is therefore mainly achieved by using electronic components. Relays with time delay function with one or more contacts for pull-in delay or drop-out delay operation of up to 800 secs. or with wiping contact operation are now available. (→ Relay Table, Time-Delay Relays TR/TS; → C-switching circuit, → IC-Module).
A few examples of simple timing circuits are given in the next few paragraphs.

3.12.1 Methods of Acceleration

Relay pull-in and drop-out times are mainly determined by the time taken for the build-up, or the decay, of the magnetic field, which in turn is primarily dependent on the inductance of the coil. Comparable relays, therefore, switch faster, the lower their coil inductance.

Pull-In Acceleration

The build-up of the field can be accelerated if a relay having a low inductance is operated with a much higher voltage than the coil nominal voltage, via a series resistor. As an example: An S4-24 V relay (fig. 298) has a pull-in time of 7.4 ms at rated voltage. If this time is to be reduced to say, 6 ms, the relay can be operated on 27 V; or, a 16 V relay with a 500 Ω series resistor, or a 12 V relay with a 900 Ω series resistor, can be used in conjunction with the 24 V supply.

For bistable (latching) relays with pulse drive, a series resistor is not required. The energizing voltage can be a multiple of the rated voltage of the coil.

3.12.2 Methods of Time-Delay

Delay is achieved by an appropriately slow build-up (pull-in delay) or slow decay (drop-out delay), of the magnetic field. Basically, longer drop-out delays are more easily achieved than longer pull-in delays. Depending on the relay design, simple pull-in delays are possible only up to approximately 100 ms, and drop-out delays up to approximately 30 seconds.

Pull-In Delay

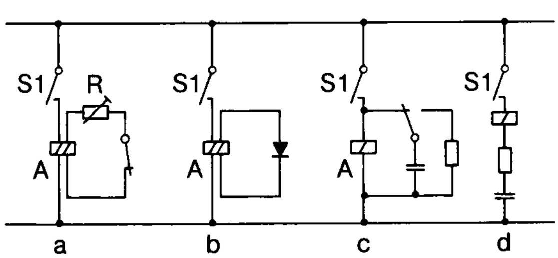


Fig. 208: Circuit to achieve pull-in delay

a) With Short-Circuit Winding:
The delay can be up to 100 ms. The lower the resistance of the short-circuit winding, the greater the delay. By using a normally closed contact in the shorted circuit, the delay is effective only on pull-in.

b) With Short-Circuit Winding and Diode:
Depending on relay design; minor delay times can be achieved.

c) With Capacitor:
The delay can be up to 100 ms. After closing contact S1, the current flows through the capacitor. With the charging of the capacitor, the current rises in the relay coil. The relay will switch when the pull-in value is reached.

d) With RC-Network:
The curves in fig. 209 provide information on the charging of a capacitor via a resistor.

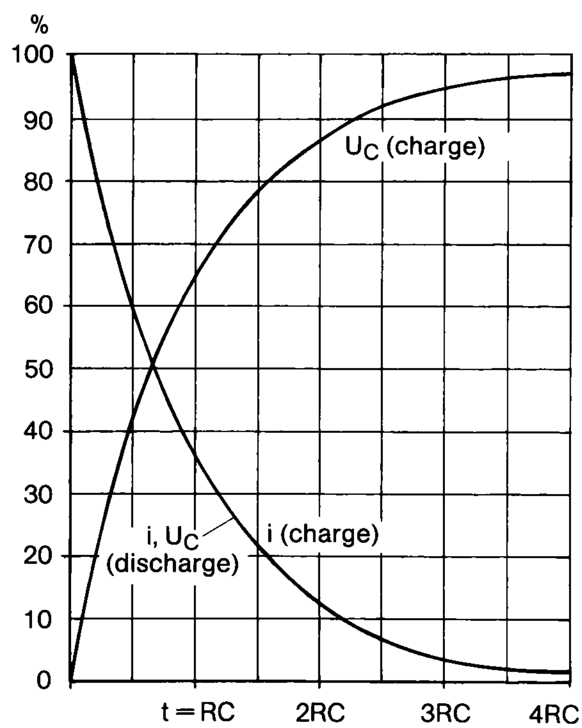


Fig. 209: Curves of current and voltage when charging/discharging a capacitor

The time constant t, is calculated from:

$t[ms] = R[k\Omega]\ C[\mu F]$

Drop-Out Delay

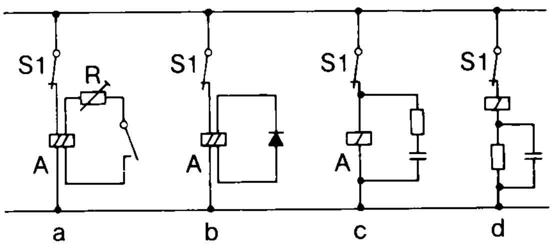


Fig. 210: Circuit to achieve drop-out time delay

a) With Short-Circuit Winding:
The time delay can be up to a few 100 ms. The short-circuit winding is closed via a normally open contact. If, for a given drop-out delay, a minor pull-in delay is acceptable, then the short-circuit winding can remain continuously shorted. If a potentiometer is connected in the shorted circuit, the time will be adjustable.

b) With Short-Circuit Winding and Diode:
Depending on relay design, delay times in the millisecond range can be achieved.

c) With Capacitor:
Delays of up to about 30 seconds are possible. When contact S1 opens, the capacitor discharges via the resistance of the coil. The relay remains pulled-in, up to the point where the current falls below the holding value.

d) With RC-Network:
It should be remembered that almost all circuits designed for arc suppression will also effect a drop-out delay. The discharge curve in fig. 209 provides information on current and voltage during the discharge of a capacitor. It shows, with increasing time t, the decreasing voltage U_c on the capacitor, and the decreasing discharge current i in conjunction with it. For the time constant t, the formula given in the pull-in delay section applies.

Other methods of delaying pull-in and drop-out times exist such as the use of temperature dependent resistors, NTC or PTC, with delay times of 10 seconds and more being obtainable. These components have the advantage of low space requirement, but disadvantages (additional heat development, energy loss, and timing faults, due to the ambient temperature) need to be accepted.

3.12.3 Impulse Operation of Relays (Wiping Relays)

With many circuits, the problem arises that for step-by-step action, despite continuous energization, only one switching pulse, a so-called "contact wiper", is required. In order to obviate the need for a special wiping relay, the following simple circuits are recommended.

Impulse Operation of Relays with a Normally Closed Contact

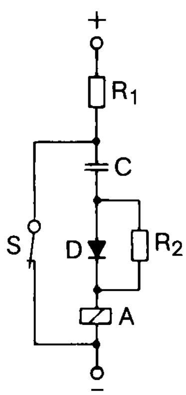


Fig. 211: Impulse operation of a relay using a normally closed switch

In the de-energized condition, switch S is closed. Current flows via the resistor R_1 and contact S.

On opening of contact S, the capacitor C is charged via resistor R_1, the diode D and the coil of relay A. The charging current is determined by R_1 and A. The relay A will initially pull-in as charging of the capacitor commences and, when the charging current decreases, it will again drop-out.

If contact S remains open, then relay A will remain dropped out, since the capacitor is charged.
If contact S is closed, the capacitor will discharge via resistor R_2 and relay A. R_2 must be of such high impedance that the pull-in of the relay is avoided. The time between the two actuations must be long enough to ensure discharge of the capacitor.

Example:	$U = 24$ VDC
	$R_1 = 1.8\ k\Omega$
	$R_2 = 6.8\ k\Omega$
	$C = 50\ \mu F$
Impulse duration:	approx. 0.2 s
Discharge time:	$\sim 3\ (R_2 + A)\ C$

Impulse Operation of Relays With a Normally Open Contact

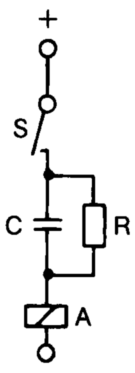


Fig. 212: Impulse operation of a relay using a normally open switch

On closure of contact S, capacitor C is charged. The charging current results in the pull-in of relay A. When the contact opens, the capacitor discharges via resistor R.
The resistor R selected must be of such a value that with a charged capacitor C, the residual current is not sufficient to hold the relay.

Example:	$U = 24$ VDC
	$R = 12\ k\Omega$
	$C = 50\ \mu F$
Impulse duration:	approx. 250 ms

Impulse Operation of Relays With a Changeover Contact

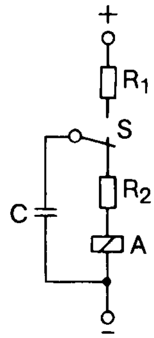


Fig. 213: Impulse operation of a relay by using a changeover contact

In the de-energized condition, the capacitor C is connected in parallel with the coil. When the contact S is actuated, the capacitor C is charged via resistor R_1. The charging time is very small (due to the low value of resistor R_1).

When S returns to the rest position, capacitor C discharges via R_2 and relay A. R_2 serves mainly to extend the time of discharging and that of the pulse.

Example:	$U = 24$ VDC
	$R_1 = 1.0\ k\Omega$
	$R_2 = 1.8\ k\Omega$
	$C = 50\ \mu F$
Impulse duration:	approx. 500 ms

Impulse Operation of Relays With a Normally Closed Contact, Impulse Emission on De-Energized Position being Achieved

In the de-energized condition, current flows via the resistor R_1 and the contact S. Due to the high voltage drop across resistor R_1, the voltage on capacitor C is too low and as a consequence the charging current is insufficient to cause relay A to pull in.

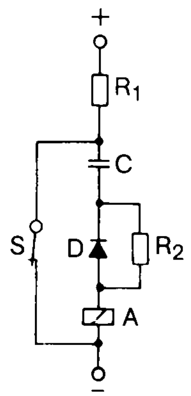


Fig. 214: Impulse operation of a relay by using a normally closed switch and impulses when the switch is in the rest position

When contact S is opened, capacitor C fully charges at full voltage.
On closing of the contact, the capacitor discharges via the relay A and the diode D down to the initial voltage which is below the holding voltage. The relay is pulled in during this discharge.

Example:	U = 24 VDC
	R_1 = 5.6 kΩ
	R_2 = 5.6 kΩ
	C = 50 μF
Impulse duration:	approx. 500 ms

3.12.4 Flip-Flop Circuit Using a Monostable Relay

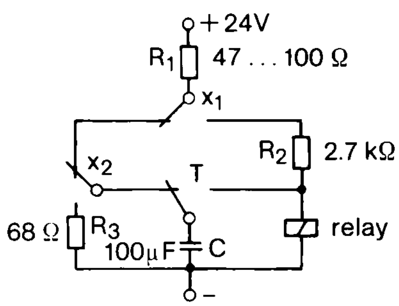


Fig. 215: Flip-flop operation of a monostable relay

It is a regular requirement of certain control systems, that a relay operated by monopolar drive pulses must alternately be switched in one direction or the other. This function is often performed by a mechanically interlocked toggle relay.
In the circuit shown in fig. 215, the required relay flip-flop function is achieved entirely by electrical means.

Relay Pull-In
Using the pulse switch T, the charged capacitor C is connected in parallel with the relay. The relay pulls in and holds, via contact X_1 and resistor R_2. On return of the pulse switch T to the rest position shown in fig. 215, the residual charge of the capacitor is dissipated via R_3 and contact X_2.

Relay Drop-Out
With the next operation of the pulse switch T, the relay coil is momentarily short-circuited through the capacitor C, this causes the relay to drop-out. With the pulse switch T in the rest position, the capacitor is again charged.

3.13 Improved Relay Characteristics by Using an Integrated C-Switching Circuit

Through the combination of polarized miniature relays with a simple semiconductor circuit, it has become possible to achieve monostable switching behaviour, but still utilize features hitherto applicable only to bistable (latching) relays, as has already been reported elsewhere [118, 119]. In the operation of relays which use the C-switching circuit, certain factors with which the circuit designer will be familiar need to be considered but which are new in electromechanical relay technology. The following is an attempt to familiarize the user with such special considerations.

3.13.1 The C-Switching Circuit, Operation and Characteristics

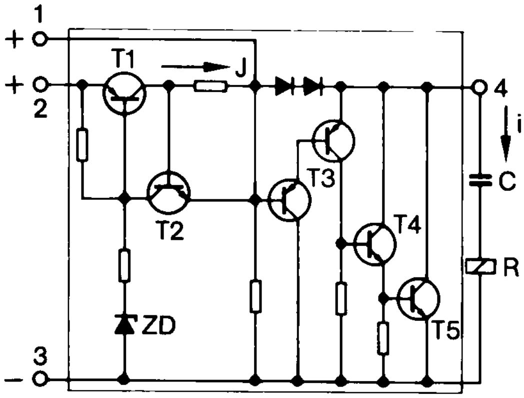


Fig. 216: Diagram of the C-switching circuit

As shown in fig. 216, the C-switching circuit consists of an inversion circuit T3, T4, T5 which is connected in parallel with the series connected bistable relay R and capacitor C, and a series connected trigger circuit T1, T2.

To drive the relay R, either input 1 or input 2 can be used. Input 1 for black-and-white operation, (sharp rise and fall of the energizing voltage operating edge). Input 2 has a pull-in voltage pre-determined by the threshold voltage of the zener diode ZD. If a voltage is applied between one of these inputs and ground (pin 3), a charging current i (fig. 217) will flow through the relay coil. The relay will pull in and the capacitor will be charged. The capacitance value of the capacitor C is chosen taking the coil resistance of the relay R into account such that the charging time constant lies within the range of the pull-in time of the relay. Thus current consumption is generally limited to the pull-in time of the relay, (a duration of milliseconds), after which there is no further current flow, except perhaps for unavoidable leakage currents of a maximum 100 µA. If the relay were monostable, it would now immediately drop out, but a polarized bistable relay remains operated until it receives a counter-pulse. This happens when the energizing voltage U is interrupted. The capacitor C then discharges via the trigger circuit T3, T4 and T5, and a current -i now flows through the relay coil (fig. 217). For the relay R, this implies a reversal in polarity of the energizing voltage. The relay then switches back to the contact rest position. Since the energy required was stored in the capacitor C, no further power is consumed from the power supply for the switch-off action. This is illustrated in fig. 217, in the comparison of the current consumption I, of the C-switching circuit, with the operating current, i.

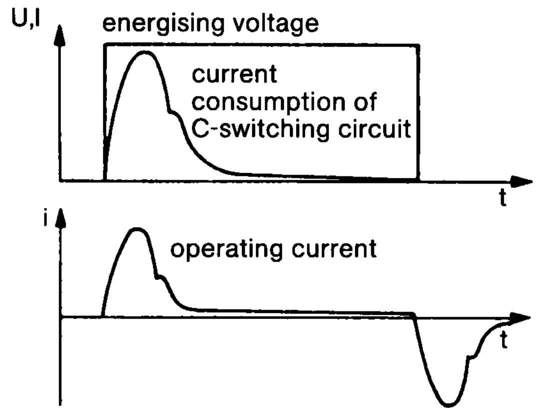


Fig. 217: Main curves for energizing voltage and current when using the C-switching circuit

By using the C-switching circuit, monostable switching behaviour is obtained at extremely low power consumption. Depending on the duty cycle or the switching frequency, a saving of up to 99.9% of the energy required for a conventional monostable relay can by achieved. This energy saving results in minimal self-heating, which reduces the heat load on the relay and also that on adjacent components, permits high packing density and gives rise to the lowest thermo-electromotive force on the contacts with a magnitude of $<1\ \mu V$.

By using a bistable magnetic system to achieve monostable switching, it is possible to have simple symmetric conditions at the change-over contact in contrast to those achieved with conventional monostable relays. The major benefit, however, is that it is possible to obtain higher contact force and thus lower contact resistance, than with conventional monostable relays. As a consequence, shorter switching times and less contact bounce are realized. This, in turn, increases the life of the relay. Up to 50% reduction of the relay pull-in time can be achieved by using a C-switching circuit.

Of special importance for the user is that the C-switching circuit does not require its own power supply, but is controlled instead by the power source which would normally be available for a conventional monostable relay. The need for a power supply specifically for the control circuit can, therefore, be dispensed with. Due to the trigger circuits T1, T2, ZD, definite pull-in and drop-out voltages for the relay are ensured. The ratio of pull-in drop-out voltage of approximately 1.1:1 is more advantageous in many cases than that of approximately 4.5:1 for conventional relays.

It should be remembered that the pull-in and drop-out values of the C-switching circuit have a negative temperature coefficient of 28 mV/°C. For example, a relay which at 75°C ambient temperature will pull-in with an energizing voltage of 7.6 volts, will require 9.8 V at −5°C. However, if definite pull-in and drop-out voltages are dispensed with, e.g. with RH-C-5 V, DR-C-5 V relays [121, 122], or, if relays are driven via input 1 of the C-switching circuit, the effect of temperature will only be −6 mV/°C.

In contrast to conventional monostable relays, the contact position of a new relay which incorporates a C-switching circuit is arbitrary. Hitherto, the user has been aware of this condition only in bistable relays. This possibility of random contact position does not present any basic difficulty because, after the first switching cycle, the switching position is defined. The same condition applies to bistable relays which incorporate C-switching circuits. As with pulse controlled bistable relays, steps must be taken when using relays which incorporate a C-switching circuit, to ensure that relay operation is not effected mechanically due to any intolerably high shocks or vibration.

In contrast to monostable relays, bistable relays are only controlled by pulses. Thus they consume much less energy. The C-switching circuit uses this advantage for a monostable operation. Power is taken from the power supply only as a short duration pulse in all cases, (apart from negligible leakage). Its magnitude is determined by the capacity of the capacitor selected.

3.13.2 C-Switching Circuit — Versions Available

The opportunity first arose to introduce the C-switching circuit in a well-proven, extremely fast, yet sensitive reed relay (the R-relay). Although this relay was designed long before the C-switching circuit, it was possible still to accommodate the C-switching circuit (in the form of a monolithic IC [122]), and the associated capacitor, within the same housing as the original relay. After the expectations placed in this RH-C-relay [120] had been completely fulfilled, the next step was soon undertaken in equipping a further miniature reed relay, (the DR-relay [121]) with a C-switching circuit. The user benefits when using both the RH-C-or the DR-C-relay, not only because there is no complex drive circuitry required, but also by virtue of the fact that these relays are the equivalent conventional monostable R- or DR-relays. In cases where hitherto monostable R- or DR-relays were used, replacement with relays of the new generation, (RH-C- or DR-C-relays), could be made without need for any circuit modification.

The C-switching circuit can also be connected externally as an addition to all

modern polarized bistable relays. For this purpose, it is offered without capacitor, in the form of an IC-module [122]. The capacitor must be selected in relation to the relay type and the operating voltage. For the application of the C-switching circuit, the bistable relays of the series R, DR, DX, DS, S, ST and SP, available from SDS, are recommended. The data sheet of the IC-module [122] will be of assistance in selection and dimensioning the associated capacitor.
For the S-relay, there is an active socket connector with built-in C-switching circuit [123]. A bistable S-relay plugged into it attains monostable switching behaviour. A monostable relay plugged into the active socket becomes a wiping relay, because the power consumption is restricted to the charging time of the capacitor, which in turn is selected to be similar to the pull-in time of the relay.

3.13.3 Methods to Control the C-Switching Circuit

If a relay with a C-switching circuit cannot be controlled directly due to the pulse-form current requirement (e.g. because the internal resistance of the control source is too high), the recharge of an auxiliary capacitor C_H, can be utilized. A drive circuit for a RH-C-12 V relay which is to be supplied from a 28 V power supply with an internal resistance of 2.2 kΩ, is shown in fig. 218.

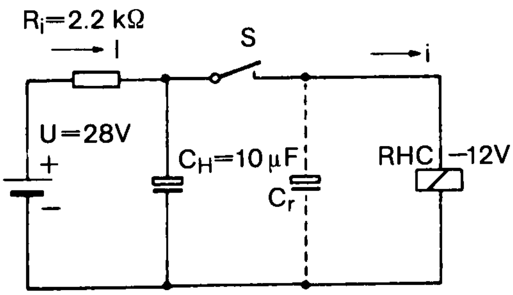


Fig. 218: Drive circuit for an RH-C-relay with a high impedance power source

In order to have an energizing voltage of sufficiently low resistance available to drive the relay, a 10 µF auxiliary capacitor C_H is connected in parallel with the voltage source. With switch S open and the RH-C-12 V relay non-energized, the capacitor C_H is charged. The maximum charge current I, is approx. 13 mA. After a few milliseconds the capacitor C_H is charged to 28 V (fig. 219). When switch S is closed, the capacitor C_H discharges. The operating current i now flowing to the relay attains a peak value, for a few milliseconds, of approximately 200 mA, and operates the relay safely into the working position. The relay retains this position for as long as the voltage U is applied. If the voltage is switched off, by opening switch S, the storage capacitor within the RH-C-relay will discharge via the C-switching circuit which is integrated within the relay, and the relay returns to its de-energized position.

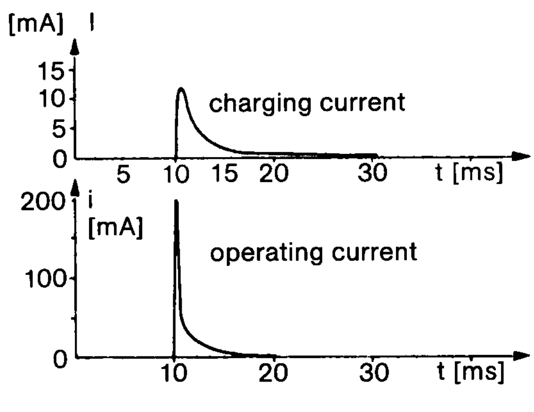


Fig. 219: Charging and operating current curves for the circuit shown in fig. 218

Independent of the described charge transfer circuit, a capacitor C_r, connected in parallel with the input terminals of the RH-C-relay (or the C-switching circuit), provides the means of operating the relay with a drop-out delay. The drop-out delays obtainable are, 0.26 s/µF for 12 V operation and 0.56 s/µF for 24 V operation.

3.13.4 Operation via Drive Circuits

If it is necessary to use drive circuits, relays with C-switching circuits can be controlled in accordance with the suggestions shown in fig. 220. The decision as to which variant should be used, will be made by the user, taking into consideration the characteristics of the control signal.

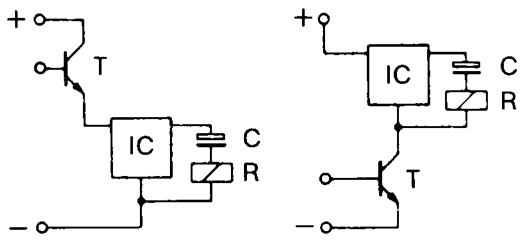


Fig. 220: Operation of relays using the C-switching circuit by using a transistor drive circuit

As indicated in fig. 221, there are no difficulties in operating several C-switching circuit relays via a single drive circuit. Since the input level is the same for all C-switching circuits, IC1, C1, R1; IC2, C2, R2 etc., there is no risk of unwanted mutual interference. It is only necessary to ensure that the driver transistor T, is capable of supplying sufficient operating current.

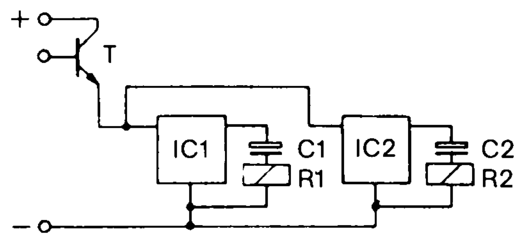


Fig. 221: Operation of several relays using the C-switching circuit having the same input drive circuit

It can happen, however, that several relays with C-switching circuits are to be controlled by a single transistor the collector of which is connected in series with the individual C-switching circuits and differing high voltage supplies (fig. 222).

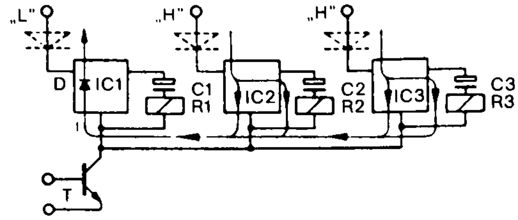


Fig. 222: Operation of several relays using the C-switching circuit but having different input drive circuits

In this case it is possible for the relay R1 to be energized by a parasitic current i, via the diode path D in IC1, even while the transistor T is still shut off. In order to prevent such unwanted operation of relay R1, it is necessary to insert decoupling diodes in the input of every C-switching circuit, IC1, IC2, IC3, (shown dotted in fig. 222).

Where a VMOS driver is used (fig. 223), the power source with voltage U, has only to supply currents of µA value to ensure reliable operation of the relay. To reduce the base current, even with ordinary drive circuits, the RC combination shown at the input of the transistor is recommended. The value of resistors R1, R2 is calculated from the base current which is required to maintain collector closed-circuit current at the level of several tens of µA. The resistor R1, and the capacitor C, are so dimensioned that the base current is adequate for the generation of the required inrush current surge on energization of the RH-C-relay.

3.13.5 Disturbances in the Control Signal

If C-switching circuit relays are controlled with faulty signals, irregularities in charging of the capacitor can cause faulty switching of the relay. An example of such a fault would be if operation took place via a heavily bouncing contact.

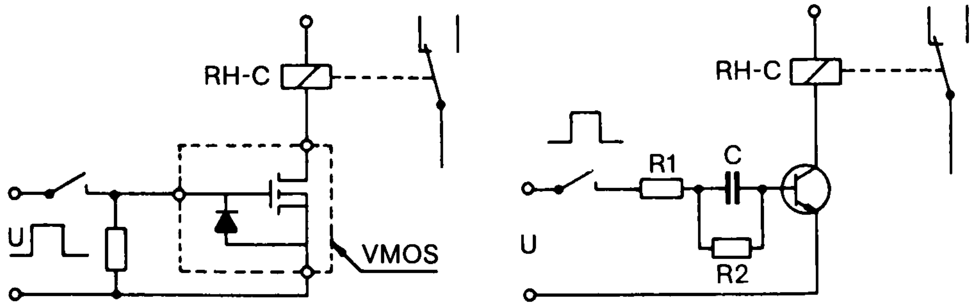


Fig. 223: Operation of an RH-C-relay using drive circuits having low base current requirements

When the RH-C-relay is used, this will occur when bouncing exceeds o.2 ms. As an example the energizing voltage U would then have a form similar to that shown in fig. 224.

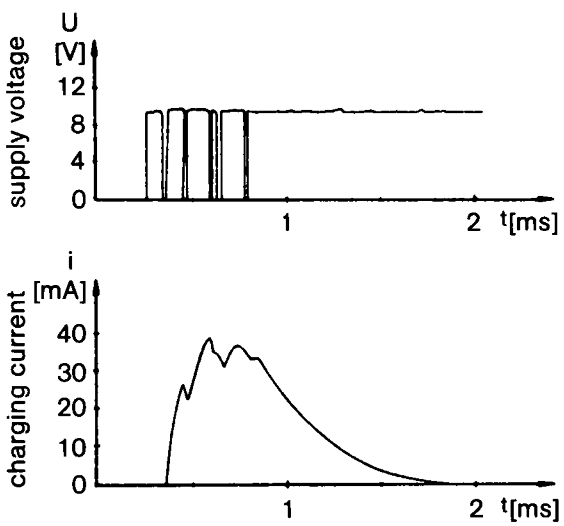


Fig. 224: Interrupted energizing voltage and consequent capacitor charging current

As a consequence of the interruptions in the voltage U, the current i, which flows is irregular. The capacitor in the C-switching circuit is then no longer charged in one burst but instead in steps. In the extreme case, this can lead to a failure in achieving the required energizing current level for relay pull-in, and the relay will not respond. If only relatively minor disturbances are to be anticipated in the control signal, a capacitor connected in parallel with the input of the C-switching circuit can provide a solution.

Use of such a capacitor means that voltage interruptions can be bridged, as shown in fig. 224, so that reliable operation of the relay is once more ensured. At the same time it must be remembered that the capacitor will result in drop-out delays. If faults occur on a larger scale, where an anti-interference capacitor alone would be insufficient, interference blocking circuits of the type shown in fig. 225 are recommended.

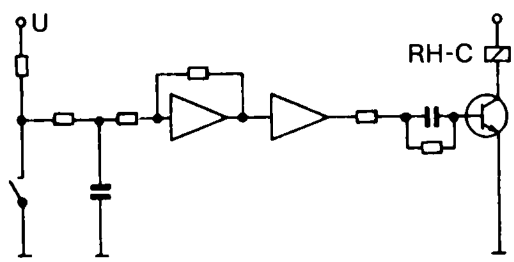


Fig. 225: Interference blocking circuit for IC-relay

3.13.6 Control of IC-Relays with Signals of Different Amplitude and Edge Steepness

When controlling the RH-C-5 V or the DR-C-5 V relay (or the C-switching circuit at input 1 (fig. 216), in conjunction with bistable relays of the types R, DR, S, DS, DX, ST, SP), there must be steep operating voltage edges (dU/dt >8 V/ms). In this case, only black-or-white operation is possible. With drive signals having an edge steepness with a lower rate of rise,

a slow charge of the storage capacitor would result, and the operating current of the relay would remain below the value required for pull-in.
If, however, the RH-C-12 V, RH-C-24 V or the DR-C-12 V relays or the C-switching circuit is operated via its input 2, (fig. 216) then, for specified pull-in and drop-out voltages, even relatively slowly rising or falling edges of the energizing voltage are permissible, as long as these have a rate of rise of dU/dt >0.1 V/s. If the rate of rise dU/dt is >8 V/ms, then the RH-C-12 V/24 V or DR-C-12 V relays can pull-in and drop-out before the threshold voltage given by the trigger circuit T1, T2, ZD (fig. 216) is reached. The switching behaviour of an RH-C-12 V relay as shown in fig. 226, with driving pulses of different amplitude, is examined below (cases A to E).

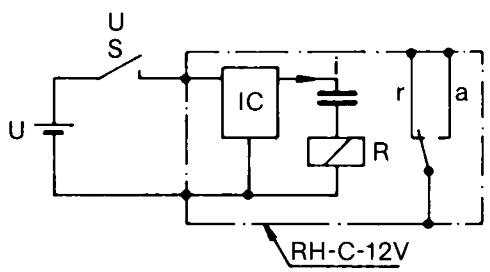


Fig. 226: Switching behaviour of an RH-C-12 V relay using drive impulses of varying magnitude

As shown in fig. 226, the RH-C-12 V changeover contact relay contains a C-switching circuit in the form of a monolithic integrated circuit and a storage capacitor C. The RH-C-12 V relay is driven with rectangular pulses obtained from the energizing voltage U via the switch S. The nominal voltage of the relay RH-C is 12 volts, although operating in a range of 10 V to 28 V is possible. The pull-in voltage provided by the internal trigger circuit (according to the RH-C-data sheet is 8–9 V) is 8.6 V for the relay used. The drop-out voltage (according to the RH-C-data sheet is >7.5 V) has a value of 8.2 V.

Case A, U ≥ 10 V
The energizing voltage U, is greater than the pull-in voltage. The relay switches without error in response to the operating voltage edges from the rest position r, to the operated position a, and back to r. Energizing current i, flows only as a pulse, as charging and discharging current of the capacitor C.

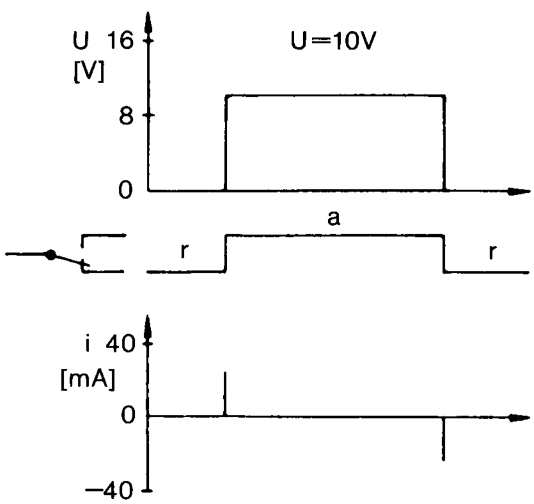


Fig. 227: Case A, U ≥ 10 V

Case B, U = 8.4 V
The energizing voltage U, is between the pull-in and drop-out voltage.
As energizing voltage U is applied, the trigger circuit T1, T2, ZD (fig. 216), becomes conductive due to the edge rise dU/dt >8 V/ms being too steep. The relay pulls in and switches from the rest position r, to the operated position a. The switched position a, will be maintained for as long as the energizing voltage U is applied, because this is greater than the drop-out voltage.

Although this switching behaviour appears normal, it is unwanted, because the relay pulls in before the specified pull-in voltage is reached.

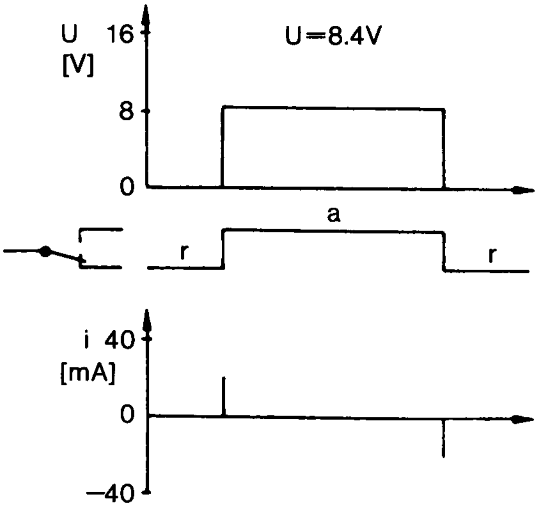


Fig. 228: Case B, U = 8.4 V

Case C, U = 8 V

The energizing voltage U, is slightly lower than the drop-out voltage.

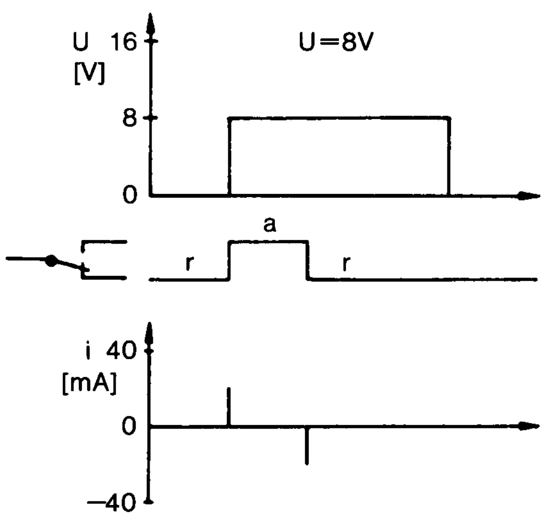


Fig. 229: Case C, U = 8 V

Here, too, the trigger circuit of the C-switching circuit becomes conductive due to the over-steep rise of the energizing voltage, the relay pulls in, and switches from the rest position r to the operated position a. However, since the energizing voltage U is below the specified dropout voltage for the relay, and since at the same time, the energy stored in the capacitor C will adequately provide the current i, required for switching the relay back, the relay does not remain in the operated position a, but returns immediately to the rest position r.

This switching behaviour is also unwanted. It can, for example, be compared with that of a wiping relay.

Case D, U = 5.5 V

The energizing voltage U is considerably lower than the drop-out voltage.

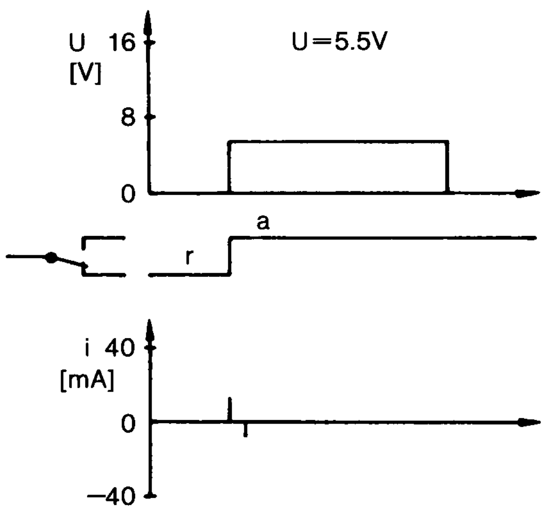


Fig. 230: Case D, U = 5.5 V

Here again, due to the steep rise of the energizing voltage, dU/dt > 8 V/ms, the trigger circuit of the C-switching circuit becomes conductive, the relay just manages to pull in with this low energizing voltage and switches from the rest position r, to the operated position a. The energizing voltage U is below the set drop-out voltage for the relay, but the energy stored in capacitor C is not sufficient to provide the current i, required for switching back, so that the relay remains in the operated position a. There is merely a low discharge of current i, from capacitor C, flowing via the trigger circuit T3, T4, T5, which has no effect on the switched condition of the RH-C-relay (fig. 216).

Case E, U = 5 V

The energizing voltage U, is so low that, although the trigger circuit T1, T2, ZD still becomes conductive due to the high dU/dt, the resulting low energizing current i, no longer energizes the RH-C-12 V relay. The capacitor C, having been charged, is immediately discharged, because the energizing voltage U is so far below the set drop-out voltage for the relay. However, the discharge takes place without the relay changing over.

As can be seen from the cases described, the RH-C-12 V relay may be operated only with rectangular pulses in the operating range from 10 V to 28 V (Case A), but in order to ensure safe switching behaviour in all cases (A–E), it is necessary for the edge steepness of the energizing voltage to apply as: 10^{-4} V/ms < dU/dt < 8 V/ms.

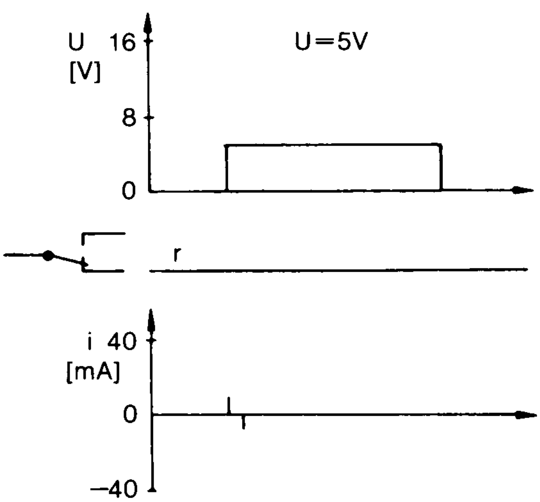


Fig. 231: Case E, U = 5 V

3.13.7 Consideration of the Switch-Off Voltage Edge on the Operation of IC-Relays

Since IC-relays contain bistable magnet systems, the same conditions apply, in principle, for ON and OFF voltage switching edges. To cover all variants, the above observations which start from the switch-ON edge, can be made analogously. In principle, a relay remains in the operated position until the energizing voltage U, with ultimate edge steepness, has dropped to the value of the drop-out voltage U_{ab} (fig. 232). The contacts will then switch from the operated position a, to the original rest position r.

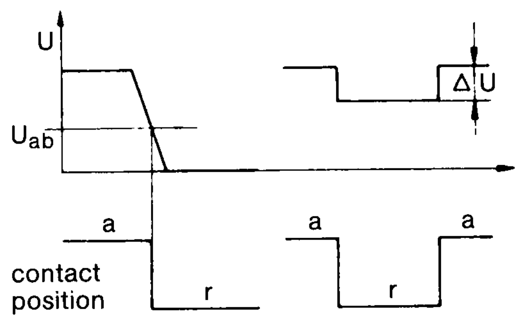


Fig. 232: Contact position of IC-relays dependent on the switch-off edge of the energizing voltage

In the event of a major voltage interruption ΔU, there is the possibility that the relay will switch back into the rest position r, even when the energizing voltage U remains above the value of the drop-out voltage. Namely, when the trigger circuit T3, T4, T5 (fig. 216), is controlled conductively by the discharge current of capacitor C.

If the drop-out voltage U_{ab} is not reached, then the permissible voltage interruptions, which will not cause switching back, will be:

RH-C- 5 V relay: 1.0 V
RH-C-12 V relay: 2.0 V
DR-C- 5 V relay: 1.2 V
DR-C-12 V relay: 3.1 V

For extreme applications of the relay, which have not been dealt with here, it is recommended that appropriate tests are made.

3.13.8 Future Prospect

With the application of the C-switching circuit, a new, third relay generation was established. Relays of the RH-C- and DR-C-types were the first to open the perspective of a new relay technology for the relay user. The IC-module has also made the advantages described accessible to the user of all modern bistable relays of types R, DR, S, DS, DX, SP and ST. In the meantime, development has progressed even further. The demand for freedom from noise interference, the need to effect control using all common logic systems, and the wish for still higher "intelligence" for programmable controlled-operation, led to the S-C3, DS-C3 and the SP-C3 relays [124] which offer monostable, bistable (latching) operation, but at the same time are operated like toggle relays using unidirectional impulses. → Section 3.15.

3.14 Modern Stepper Relays By Use of the VS-Module

If the question for many users is still, "Relay or Semiconductor", then the *C-switching circuit, IC-Relay* and *VS-Module* show that the relay's range of application can be greatly extended through integration with semiconductor control.
With the aid of the VS-module, it is possible to convert nearly all bistable two-coil relays (fig. 233) into toggle two-state *stepper relays.* The system, formed of relay and VS-module, can then be controlled via two conductors just as with conventional stepper relays but with no supply voltage being required for the VS-module.
The shape of the driving signal has no influence on the functional reliability.

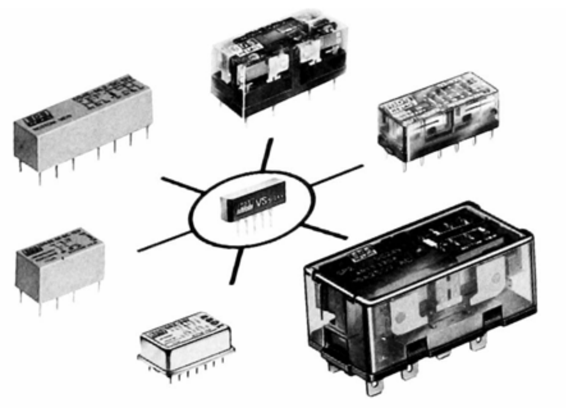


Fig. 233: Latching (bistable) relays which act as a toggle relay when controlled by a VS-module (picture courtesy of SDS-Relais AG)

Neither rectangular signals nor slowly rising voltage edges cause faulty switching.
In this respect, VS-modules and relays behave like conventional stepper relays. In addition, considerable advantages result from the use of modern, polarized miniature relays:

- smaller size;
- lower power consumption;
- greater resistance to shock;
- longer mechanical life;
- higher reliability;
- shorter switching times;
- resistance to fluid ingress during cleaning, since many miniature relays are sealed as standard.

Since the VS-module is also able to drive several relays simultaneously, the number of available switching contacts can be greatly increased.
The principle of operation of the VS-module (fig. 234) is, with the occurrence of a pulse voltage, to drive one coil (or the other), depending on the relay contact position. After the switching pulse, the contact is in the opposite switching position. This has no effect on the VS-module, due to the built-in F/F, it remains in the new adopted state until the applied voltage drops to below approximately 2 volts.

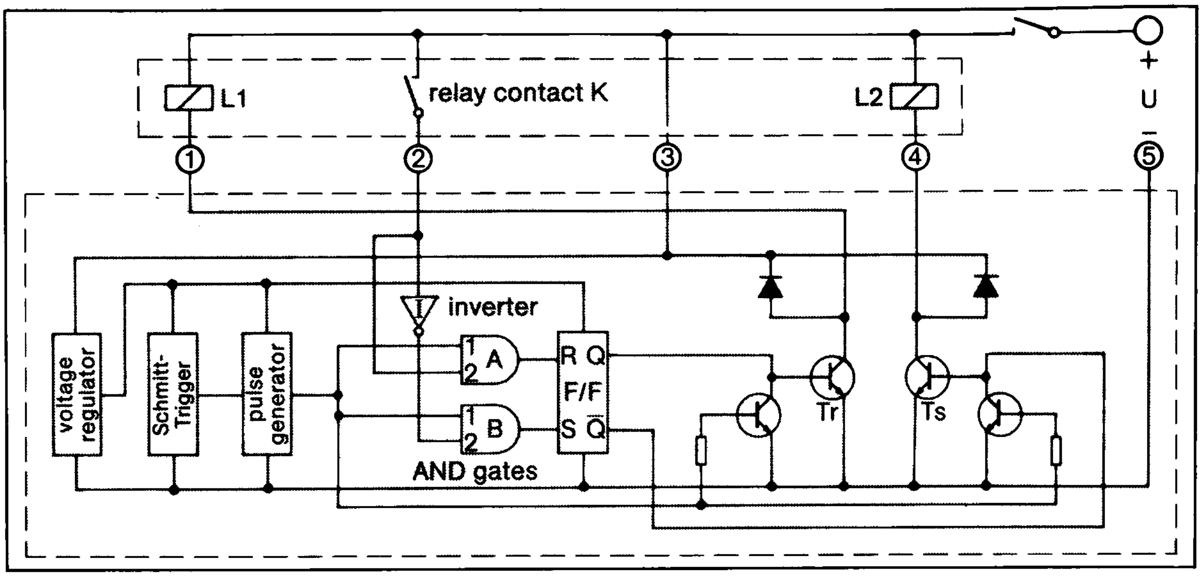


Fig. 234: Block diagram of the VS-module

As shown in the block diagram, the following functions are integrated within the VS-module:

- a voltage regulator which permits universal application, from 3.5 to 28 volts;
- a threshold switch, due to which the module will always be in a predetermined state;
- a pulse generator which ensures reliable function of the VS-module, even with severely bouncing signals.

These properties indicate that the VS-module is suitable for all applications concerned with surge behaviour and for almost all bistable two-coil relays. Most users for whom conventional stepper relays are too big, too slow or too insensitive, build their own special stepper circuit for use with a bistable relay. One disadvantage frequently occurring with this kind of circuit is that the relay is switched via one of its own contacts. With bistable relays it is, in theory, always possible that with signals that are too short, or because of vibrations, the relay will be caused to go into a center position. This can lead to failure of such stepper relay circuits. With the VS-module, this is impossible, since it utilizes only one contact during switching, and this contact will be either open or closed, even if the relay armature should go into a center position. Thus, with the arrival of a new signal pulse, the relay will switch and overcome its center position "problem".
It is a disadvantage of the VS-module that one of the relay contacts is required for the internal circuitry. This can usually be overcome by the use of a transistor. If electrical isolation between input and output is not absolutely necessary, this driving contact, in appropriate circumstances, may also be used for switching purposes.

3.15 The Use of IC-C3-Relays in Automatic Control Systems

The IC-C3-relay series was specially designed for application in electronic control systems for all types of modern equipment, machinery and plant. This section covers the technologically most advanced representatives of the third generation of relays (see 1.1 and 1.2), in which highly efficient polarized relays are combined with an IC-module integrated within the relay housing, having been specifically designed for this application.

3.15.1 Adaptation of the IC-Relay to the Requirements of Electronic Controls

Logic Compatibility
An input interface and a driver stage make the relay LSI compatible. It can be readily combined with TTL or CMOS gates, PLAs, PROMs or microprocessors, or connected with the bus line of electronic control systems. The following properties characterize the logic compatibility:

- negative logic, (i.e. IC-relays operate with negative input pulses);
- pulse operation, (i.e. drivable with pulses $\geq 100\ \mu s$);
- input level: H level ≥ 2 V, L level ≤ 0.4 V.

Multi-Function Inputs
Using a special built-in control circuit, each IC-relay can optionally be driven as a monostable, bistable (latching) or toggle relay, by virtue of the fact that the various inputs of the relay can be driven in parallel. The set and toggle inputs, for example, can be operated by the normal control programme and the reset input can be used for interlocking purposes. Thus complex control circuits can be developed in an elegant, simple manner using only a few IC-relays.

Holding Circuit in the Event of Power Failure
Following a power failure, when the operating voltage again reaches the normal value, there are three selectable options:

- automatic set,
- automatic reset,
- maintenance of the previous switched condition.

Connection for a Return Signal
IC-relays have connections for an operated state return signal. A voltage appears across these points when the relay coil receives a control signal.

Interference Pulse Suppression
IC-relays contain a filter which suppresses noise spikes of up to approximately 60 μs, in both positive or negative directions, and thus prevent faulty switching.

Chatter or Bounce Suppression
Once the IC-relay has been actuated by a control pulse, it will remain in the operated position even when several more pulses follow. The bounce suppression time — depending on the relay — is between 8 and 47 ms.

No Counter-EMF
IC-relays contain a Zener diode for suppression of the counter-e.m.f. It is therefore not necessary to protect the driving electronic circuitry.

Low Power Consumption
By using highly sensitive, polarized relays and pulse operation which limits the coil current to the pull-in time, the power consumption is reduced to a minimum (for 1 sec. energizing duration, approx. 12.5 mWs), and thus is clearly well below that of comparable *SSR*.

Low Thermo-electromotive Force
Since IC-relays operate with pulse control, very little heat develops in the coil, which means that the thermo-electromotive force at the contacts remains very low.

Relays Used
Highly efficient polarized relays are used.

The IC-relay series currently consists of 4 power-range types having rated currents of: 2, 5, 8, 16 A (for detailed comparison, → Relay Table, Page 233).
For use in automatic control systems, the following characteristics are of major importance:

- multiple contact types: 2 A/2 C/2 A 2 B
- contact/volume resistance: < 10/30 mΩ
- switching load range: e.g. 10^{-10} to 10^3 VA
- dielectric strength (contact/coil): 1500 V_{RMS} to 3750 V_{RMS}
- shock resistance: 20 to 50 g
- life: low loads: > 10^8 switching cycles; heavy loads (up to 16 A, 4000 VA): > 10^5 switching cycles
- dimensions: e.g. version for switching 8 A nominal current 6 cm^3 volume.

Circuit Simplification
The circuits normally required for direct connection of the various electronic systems — interface, holding circuit, interference pulse suppression — are already built into the relay and, therefore, need not be provided by the user. This makes control circuits relatively simple to develop, and the result is a considerable reduction in the number of components (typically 60 to 80% reduction), in wiring and circuit complexity.

Space Saving
There is a considerable reduction in the printed circuit area, (typically 50 to 70% reduction) with unchanged height requirement in comparison to that needed for the original base relay.
Universal adaption to electronic control circuitry means that IC-relays are ideal for use as miniature interfaces between automatic control systems and many different types of peripheral devices. The user benefits by having a solid state circuit at the input combined with the advantages of a modern relay at the output (very low contact resistance, high insulation resistance, high dielectric strength, high switching capacity and short-term overload capacity).

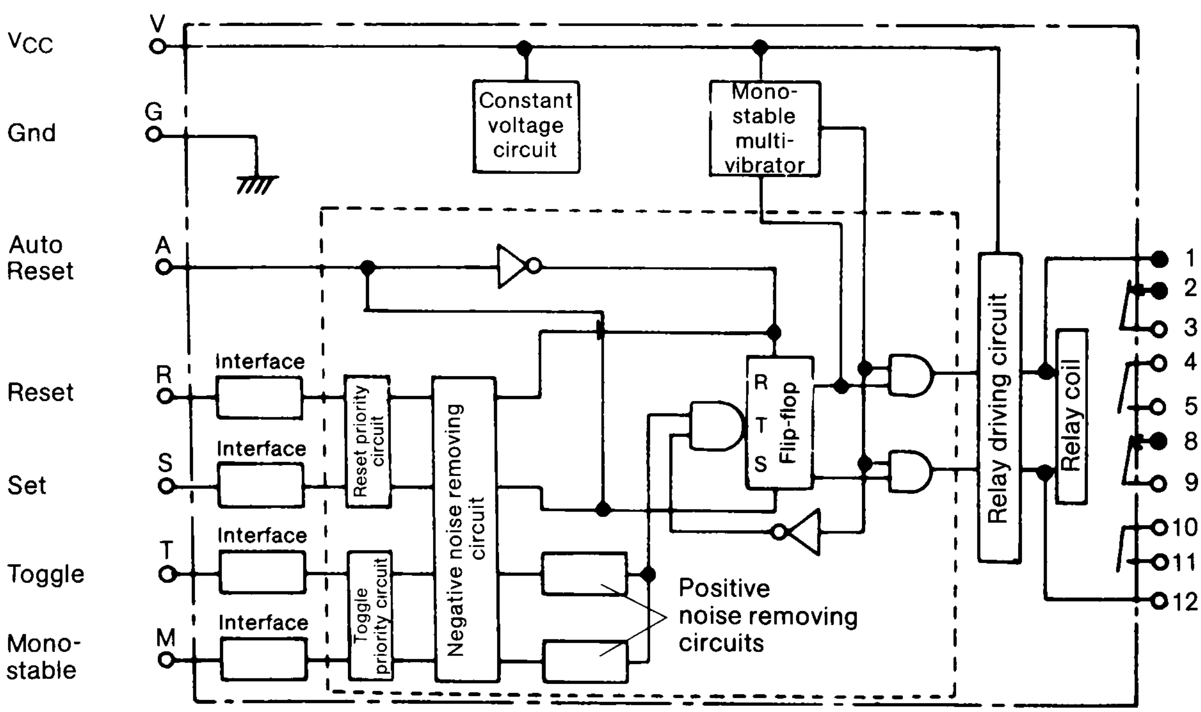


Fig. 235: Block diagram (example shown is the S-C3-relay)

3.15.2 Construction Details and Application Examples

Construction

The input interface processes the incoming signals (from TTL, CMOS) and matches them to the negative logic.
The voltage stabilizer reduces the applied operating voltage (5 to 15 V) to the required internal working voltage and holds it constant.
The interference pulse suppression and bounce suppression circuits remove interference pulses of up to 50 µs and input bounce — depending on the relay type — between 8 and 47 ms.
The single-coil bistable relay is energized during the change-over phase by the driver circuit. Induction peaks generated by the relay coil are neutralized by Zener diodes.

Function Diagram

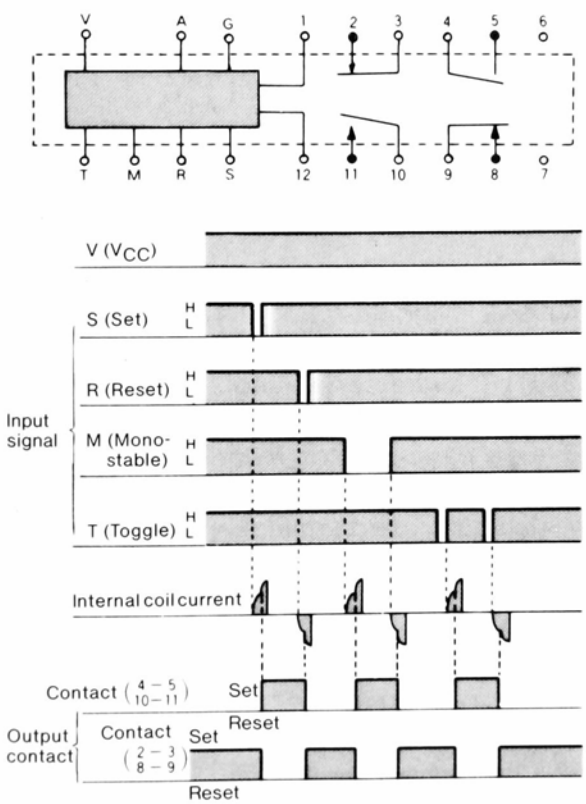


Fig. 236: Function diagram (the example shows the S-C3-relay)

V: Power source input terminal
It can be in the range of Vcc = 5 to 15 V.

G: Ground terminal
Grounding

S: Set operation terminal
Input signal terminal for setting operation of the relay. When it changes from H level to L level, the relay will go to the set condition. When the input returns to H level, the contacts remain in the set position.

R: Reset operation terminal
Input signal for resetting the relay. When it changes from H level to L level, the relay will go to the reset condition. When the input changes back to H level, it remains in the reset position.

M: Mono-stable operation terminal
Input signal terminal for non-latching operation (single side stable operation) of the relay. When it changes from H level to L level and from L level to H level, the relay operates to alternate positions.

T: Toggle operation terminal
Input signal terminal for making the relay perform toggle operation (binary stepping operation). When it changes from L level to H level, the relay operates, but when it changes from H level to L level, it does not operate.

A: Auto set and reset terminal
Terminal for setting or resetting the relay for memory function automatically when power source Vcc returns to normal after a power failure.

- Selection of Operating Condition when power source is restored.

Connections of terminal A	Position of relay contacts when power source is restored
Terminal A is open	Relay is in reset condition
Terminal A is connected to ground	Relay is in set condition
Its own N.O. contact is connected between terminal A and ground	Relay remains in the same position as it was before power source was interrupted
Its own N.C. contact is connected between terminal A and ground	Relay is in reverse position to that before the power source interruption

1-12: Terminals for return signal
Terminals for confirming that the relay has received a signal surely. (Max. current 1 mA)

Common Characteristics and Application Guidelines

Input Pulses

The pulse length must be ≥100 μs. Operation is possible with rectangular, trapezoidal and triangular pulses, if rising and falling edges of the voltage are ≥100 V/s.

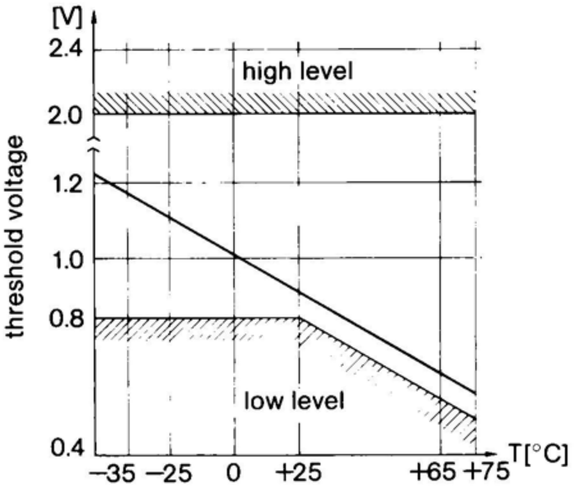


Fig. 237: Pick-up levels and temperature dependance of threshold voltage

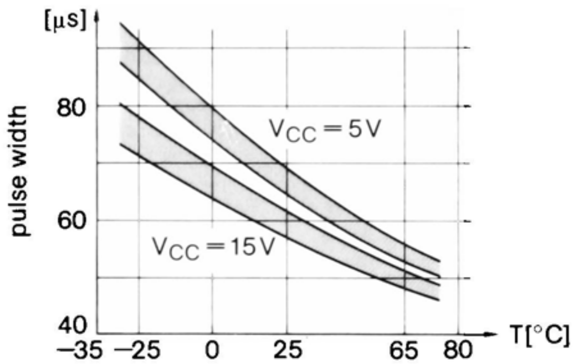


Fig. 238: Temperature and voltage dependance on pulse width for noise suppression

The high level must, therefore, be ≥2 V over the entire temperature range, the low level up to +25°C ≤0.8 V and beyond must drop to ≤0.5 V at +75°C. The area between the hatched lines must not be used for driving the relay.

Bounce Elimination Times

IC-relays respond to a subsequent control pulse only after the elapsed times set out below:

with DS-C3-relays, approximately 8 ms
S-C3-relays, approximately 10 ms
ST-C3-relays, approximately 22 ms
SP-C3-relays, approximately 47 ms.

Short Duration Failure of Operating Voltage

If the built-in functions for the switching condition after power failure, (Auto Set, Auto Reset, Memory) are intended to become operative only after a certain period following power failure, this can be achieved by connecting a capacitor in parallel with the input V/G.

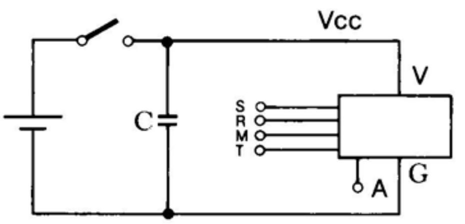


Fig. 239: Circuit to overcome short interruption in operating voltage

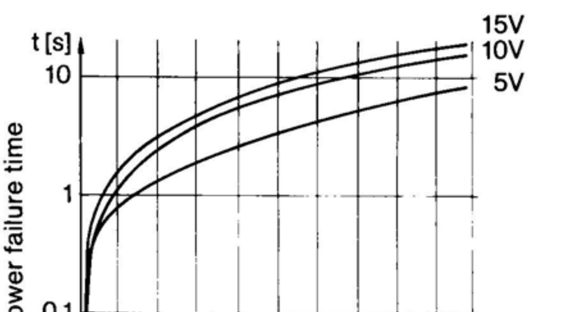


Fig. 240: Determination of the C-value for a given power failure time

Limiting the Operating Voltage
The operating voltage may vary within wide limits, (5 V to 15 V; depending on the type of relay and the ambient temperature), but it must not exceed the stated values. If appropriate, the voltage may have to be limited by a Zener diode.

Input Voltage Limitation
Where the output signal level given by TTL or CMOS circuits is greater than the maximum permissible input level of the IC-relay (5 V), it must be reduced accordingly.

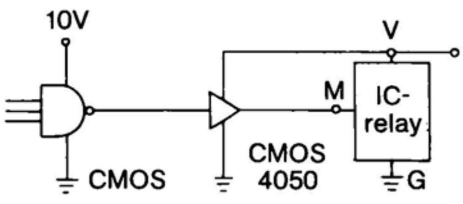


Fig. 241: Circuit for limitation to the permissible input level

Order of Precedence of Input Signals
Where two or more signals are applied simultaneously (H→ L), the priority applicable is, R<S<T<M.
If the input signal at terminal R, goes from H→ L, the relay switches to "Reset", and remains in this position even when S, T or M pulses are applied. This also happens when switching the R signal back from L→ H.
If the input signal at S, goes from H→ L, the relay switches to "Set", and remains in this position. It also remains set when the signal goes from L→ H. For as long as S is at L level, T and M pulses are suppressed, but when R switches over from H→ L, the relay switches back to the "Reset" position.

At input T, transitions from L→ H only, will lead to switchover of the relay, first into "Set" then to "Reset", and then back again to "Set", and so on. M signals are ignored. Only when signals are applied to the higher ranking inputs R and S, will the appropriate switching functions be triggered by such signals.
A signal applied to M, will, on transition from H→ L, effect a switching of the relay to the "Set" position. On transition from L→ H, the relay switches back to the "Reset" position. Pulses at the higher ranking inputs R, S and T cancel this monostable switching behaviour accordingly, or they effect a reversible switching behaviour at M.

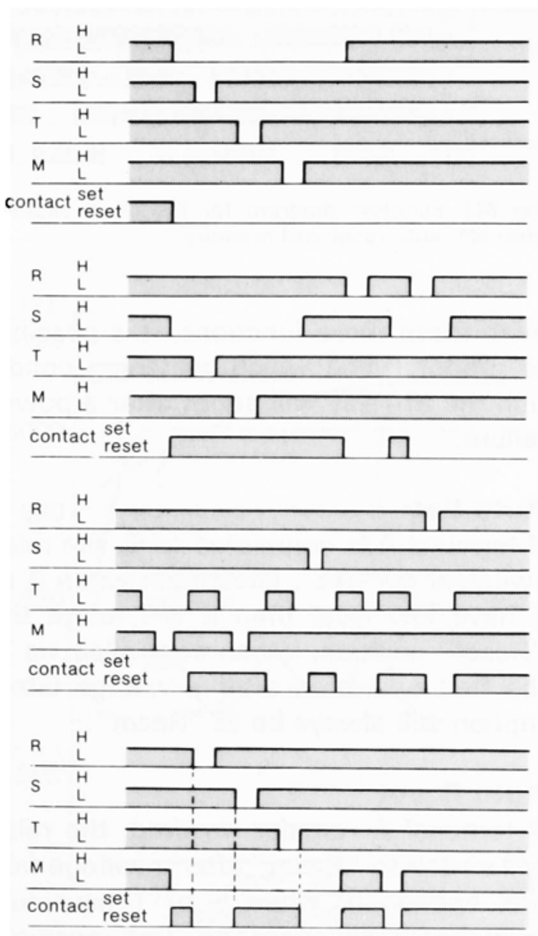


Fig. 242: Order of precedence of input signals

Input "Auto Set — Auto Reset — Memory"

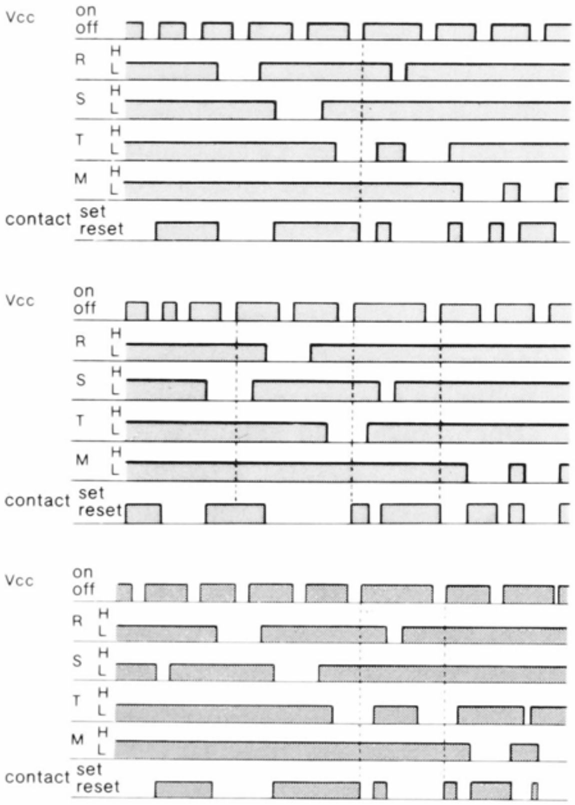


Fig. 243: Function diagram for the input circuits, auto set, auto reset and memory

With these three functions, it is possible to predetermine which switching condition the IC-relay will adopt after a power failure.

Auto Set:
If terminal A is connected to G, the relay switches to "Set" Exception: when R or T have low level then it will adopt the "Reset" position. When controlled via T, the first operation after a voltage interruption will always be to "Reset".

Auto Reset:
If terminal A remains unwired, the relay will switch to "Reset" after a voltage failure. Exception: when S or T have low level then it will adopt the "Set" position. When controlled via T, the first switching after a voltage interruption will always be to "Set"

Memory:
If terminal A is connected to G via a normally open contact of the relay, the previously existing switched condition will be reinstated after a voltage interruption. Exception: If the voltage interruption takes place while T is at low level, the opposite switching condition will occur.

Important Hints for the User

- The following listed terminals must not be connected to a voltage supply:

Relay	Terminal
DS-C3	1 and 16
S-C3	1 and 12
ST-C3	9 and 10
SP-C3	1 and 2

- Terminals A and V must not be connected together.
- The monostable operation of the IC-relays differs from the normal case in that the initial starting position is selectable.
- Where the toggle circuit (terminal T) is used, the initial position can be different, depending on the conditions at R, S or V (see 3.15.2, Order of Precedence of Input Signals).
- If IC-relays are driven with severely bouncing contacts, it must be remembered that with SET and RESET drive, the bounce time must be shorter than the pull-in or drop-out time appropriate to the relay. With monostable or toggle operation, it must be no longer than the built-in interference-voltage suppression (see 3.15.2 Bounce Elimination Times).

Terminals	A	S	R	M	T
V	47	47	47	47	47
G	11,8	14,7	14,7	14,7	14,7
A		4,7	14,7	47	14,7
S			4,3	4,3	4,3
R				4,3	4,3
M					4,3

Table 48: Permissible capacitance in nF between the terminals of IC-relays

- Faulty switching due to voltage spikes. Remedy: Inputs not required (R, S, M, T) should be connected to V. If driving is via relays, avoid voltage spikes by incorporating a quenching diode and capacitor (fig. 244), or eliminate the interference by means of an RC network, in accordance with fig. 245.

Faulty switching may occur if voltage peaks are superimposed on the operating voltage when M or T are at low level and other inputs are open (high impedance).

If there is low level at inputs S and R, and high level at the other inputs, faulty switching will hardly ever occur. Where M and T are used, the susceptibility of the circuit should be checked by means of a system simulation.

- Interference spikes in the power supply lines can also lead to faulty switching. The graph below shows the limit value of the combined voltage/pulse-lengths beyond which faulty switching could possibly occur, if M or T are at low level and the other inputs are open.

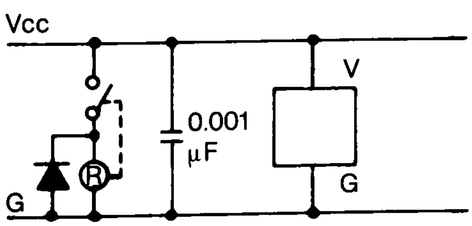


Fig. 244: Circuit to reduce voltage spikes

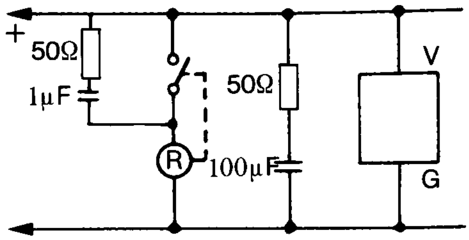


Fig. 245: Suppression using an RC-network

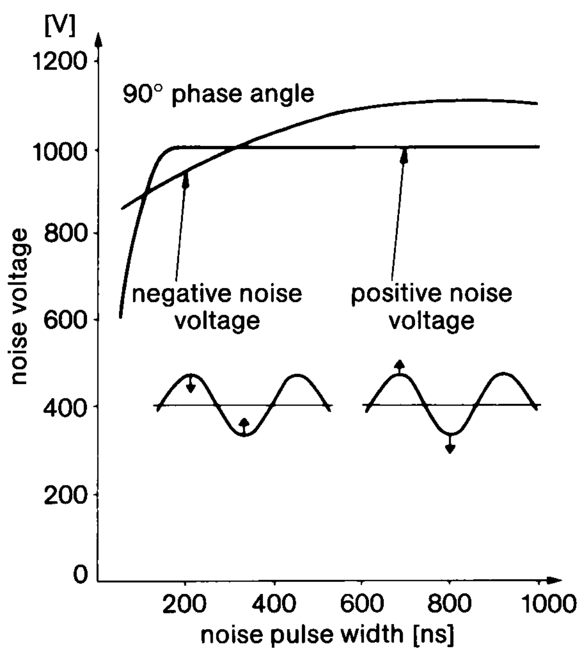


Fig. 246: Limit values for misoperations

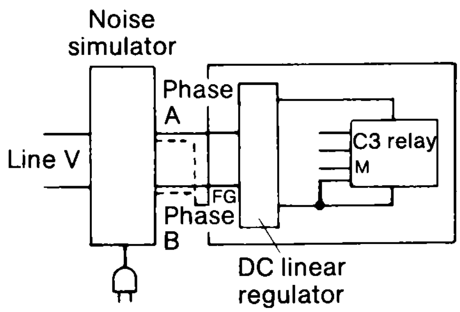


Fig. 247: Measuring circuit for the limit values given in fig. 246

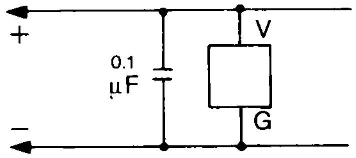


Fig. 248: Remedy against coupled noise impulses: A ceramic capacitor of 0.1 µF

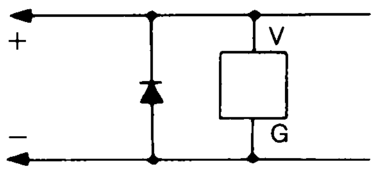


Fig. 249: Remedy against coupled noise impulses: A diode

If R and S are on low and the other inputs are on high, faulty switching due to such interference pulses will not occur. If M or T input is used, an appropriate check is recommended.

- IC-relays can also be subjected to interference from magnetic fields (of relays, motors, magnets, etc.), if the M or T input is on low.

Remedy: Connect inputs which are not required, to V. Arrange the inputs as far away from the interference source as possible. Use screened cables for the lines to M and T. If used on printed circuit boards, provide wide earth strips, and run the supply lines for M and T parallel with these, keeping them as short as possible. Couple a capacitor between M, T and earth.

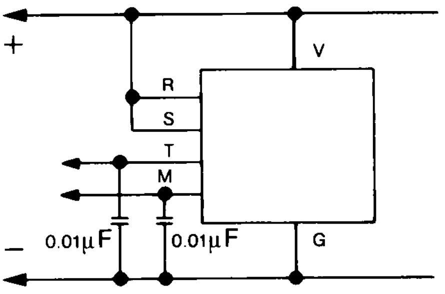


Fig. 250: Remedy against disturbance from magnetic fields

Arrange the relays so that the "load" lines on the circuit board are not parallel with the input lines on the board.

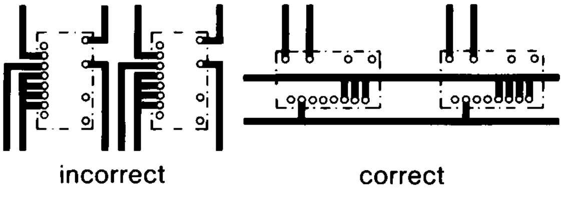


Fig. 251: Recommendation for correct pcb layout

- Faulty switching is also possible when there is an influence from an AC load line on the DC supply line to an IC-relay. This can be remedied by an interference filter.
- If the power source is the same for the DC load and for the operation of the IC-relay, it must be grounded.
- Electrostatic charges can also cause interference. Caution is advised.

3.15.3 Applications of the IC-Relay

Application	Example	Advantages
IC-relays as a component	Measuring equipment (low thermo voltage, small size) Remote control (step operation), output device of control systems	Low power consumption Low heat generation Small thermo voltage 4 types of control possibility Noise suppression Storage of the switched state during power failure
Logic circuits	Transportation systems Remote control systems Time measuring systems	Simple construction of logic circuits with simultaneous utilisation of relay features
Direct connection to PLA or PROM	Mass produced compact devices Temperature controllers Power supplies Measurement devices Communication systems EDP	Circuit simplification Reduction in number of components required Lower power consumption Low heat generation Safe against noise voltage
Direct connection to the control system bus line	Centralised manufacturing processes controls Process control Domestic control systems Telephone systems	Circuit simplification Less wiring Lower power consumption Safe against noise voltage

Table 49: Application examples of the IC-relay

Non-Programmable Relay Circuits
The principal applications of IC-relays in the field of non-programmable controls are such circuits in which the characteristics of a highly sensitive, polarized relay are used in conjunction with one or more functions of the built-in IC, such as:

- the four types of signal processing;
- interference pulse suppression;
- bounce elimination circuit;
- selection of operating position after reinstatement of failed power supply;
- driver circuit;
- low power consumption due to limitation of the coil current to the pick-up time (approx. 40 mA at 8 ms, for the SC-3 relay). By using an external capacitor, the current consumption during a switching action can be even further reduced.

For such applications, the IC-relay offers a simple development tool and a space saving circuit arrangement.

Examples of Individual IC-Relay Circuits

a) Operation as monostable multivibrator
The relay responds to pulses of $>100\,\mu s$ duration, only after a time determined by R and C.

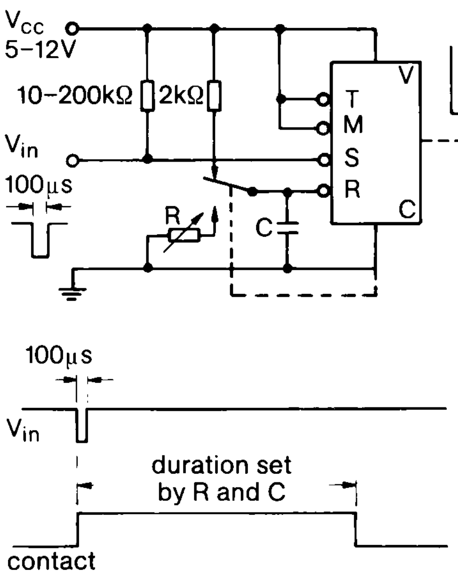
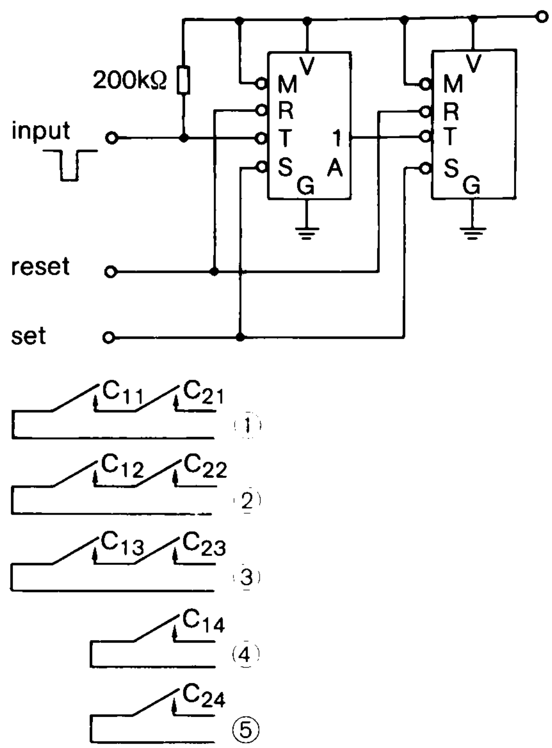


Fig. 252: Use as a monostable multivibrator

In electronics, control signals are becoming shorter on an on-going basis. For the conversion of short output signals of sensors, it is advisable to make use of the response of the IC-relay of 100 µs pulses. Simultaneously very effective electrical isolation of input and output is obtained. Moreover, since the input sensitivity is very high, the relay can be driven directly by sensors themselves without the need for an additional driver.



output control

1	off	off	on	off
2	off	on	off	off
3	on	off	off	on
4	on	off	on	off
5	on	on	off	off

Fig. 253: Multi-stage stepper relay

b) Multi-stage stepper relays (toggle relays)
Multi-stage stepper relays are subject to the following limitations:
- They cannot be brought into the predescribed conditions at any required time.
- The number of steps is fixed.

Where the IC-relay is used, these limitations do not exist. Furthermore, the user obtains the advantages already mentioned, such as low power consumption and high input impedance. Fig. 253 shows the relay in 2-step operation.

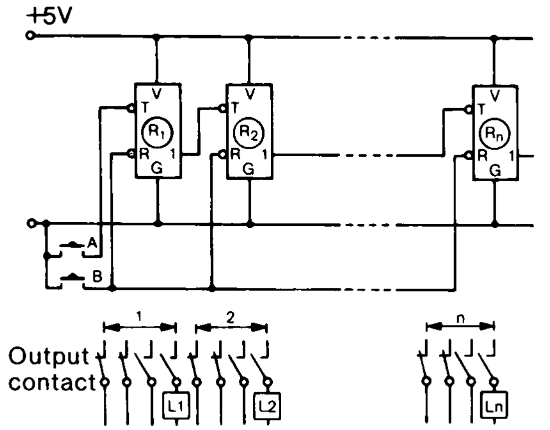
Logic Circuit With IC-Relays

The application of the C3-relay with its functions (bistable, toggle and monostable operation), enables many different logic circuits to be set up. Fig. 254 shows three examples:

a) binary counters
b) sequential set and sequential reset
c) shift registers

Such logic circuits are used in measuring instruments, remote control systems, transport equipment, etc., where the simple construction of logic circuits using the IC-relay, together with its relay functions, provides the following advantages:

a) Binary counter

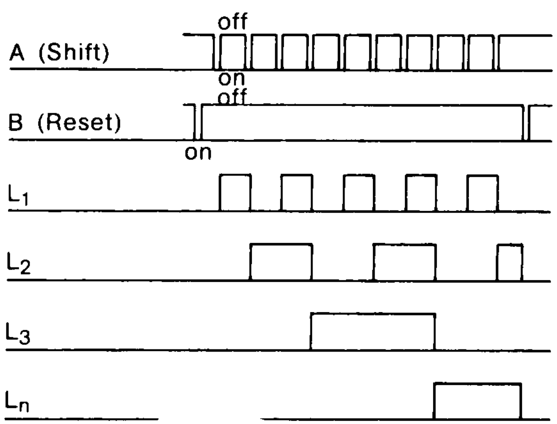


A : Shift switch
B : Reset switch

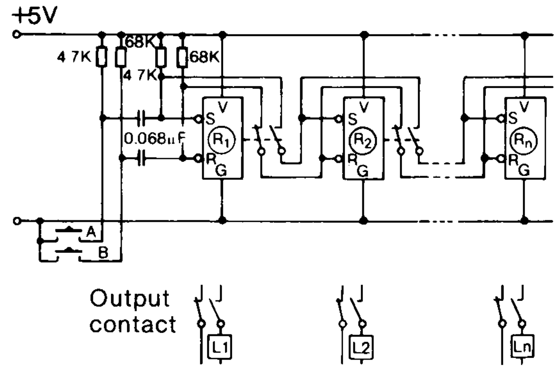
$R_1 \sim R_n$: S2–C3–5V

$L_1 \sim L_n$: Loads

Unused input terminals (S, M) are connected to V_{CC}.



b) Sequential set and sequential reset

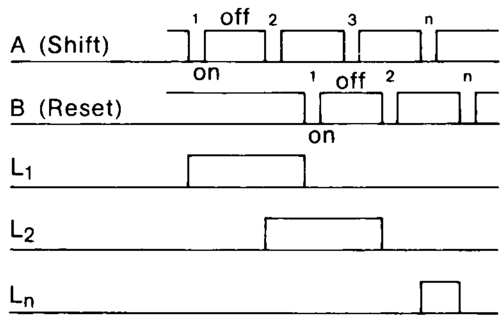


A : Shift switch
B : Reset switch

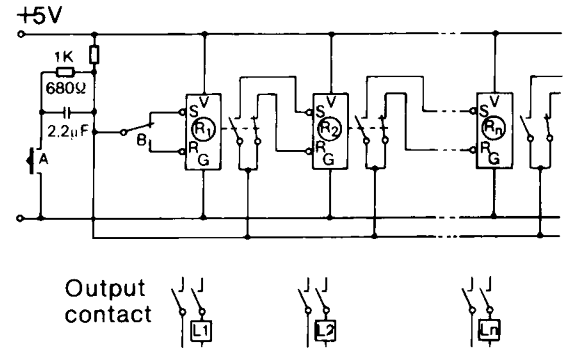
$R_1 \sim R_n$: S2–C3–5V

$L_1 \sim L_n$: Loads

Unused input terminals (T, M) are connected to V_{CC}.



c) Shift register



A : Shift switch
B : Data switch

$R_1 \sim R_n$: S3–C3–5V

Unused input terminals (T, M) are connected to V_{CC}.

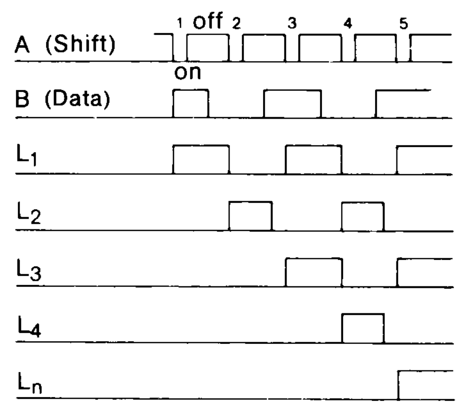


Fig. 254: Example of logic circuit using IC-relays

- simplification of circuits, due to reduction of components;
- smaller dimensions of the printed circuit board;
- power saving;
- cost reduction by virtue of saving on design and assembly times.

Programmable Controls

Since IC-relays are LSI compatible (negative logic operation, H: 2 V, L: 0.8 V), and have the functions of bistable switching, toggle, and monostable operation, they comply readily with the requirements of control systems. No other components are required on the circuit board to switch the relays.

The other features of the built-in IC, such as the suppression of interference pulses and contact bounce, the maintenance of the switched condition on voltage failure, and energy saving, all contribute to simple system building. Together with programmable electronic components, like PLA or PROM, it is easy for the user to design systems with different control programming, without having to know too much about logic design rules.

Together with microprocessors or personal computers, very complex control systems can be accomplished in which the IC-relay, when connected with the bus line of the system, can control several peripherals.

Control Circuits with IC-Relays and PROM

The use of IC-relays together with PROM can give rise to a simple arrangement of programmable control within a very compact unit. Fig. 255 shows a programmable timer for which hitherto cam switchgear or a programming network was used. In this example, programming control consists of a PROM which contains the stored programme and directly drives the IC-relays, as well as an oscillator and counter. The programme is illustrated in the flow diagram.

This example also illustrates that the selective use of different inputs of the IC-relay permits considerable circuit simplification.

In this case, the outputs D_0, D_1 of the PROM go to the inputs, Set and Reset, while signals from D_2 onwards drive the IC-relays at the T inputs.

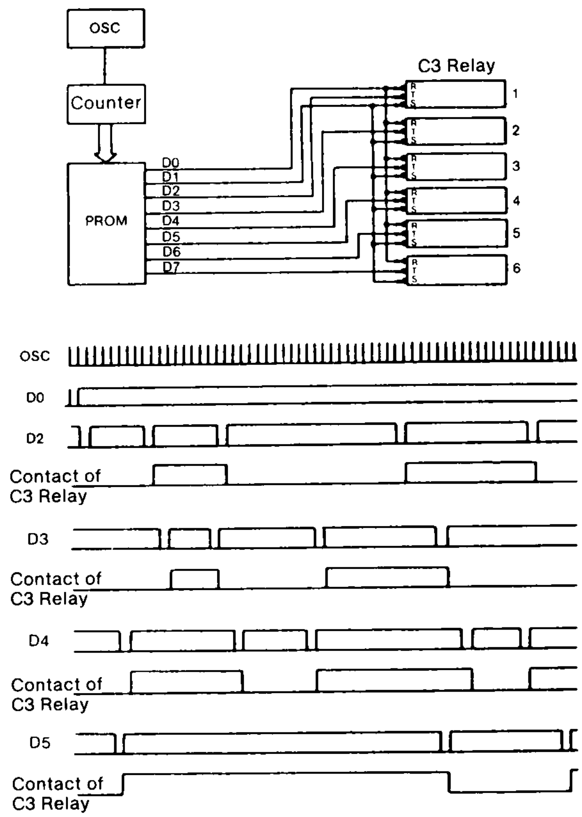


Fig. 255: Programmable timer

The characteristics of such a programmable timer are:

- compact size, energy saving and high reliability;
- programmes can easily be changed (by using an EPROM);
- complicated programme sequences are possible;
- low cost.

Fig. 256 shows a control system for a machine-tool. The outputs of the sensors which are fitted to the various stations of the machine, are connected to the inputs of the PROM. Depending on the input signals, the IC-relays, which are directly connected to the PROM, operate in accordance with the PROM stored programme and control the different functions of the machine.

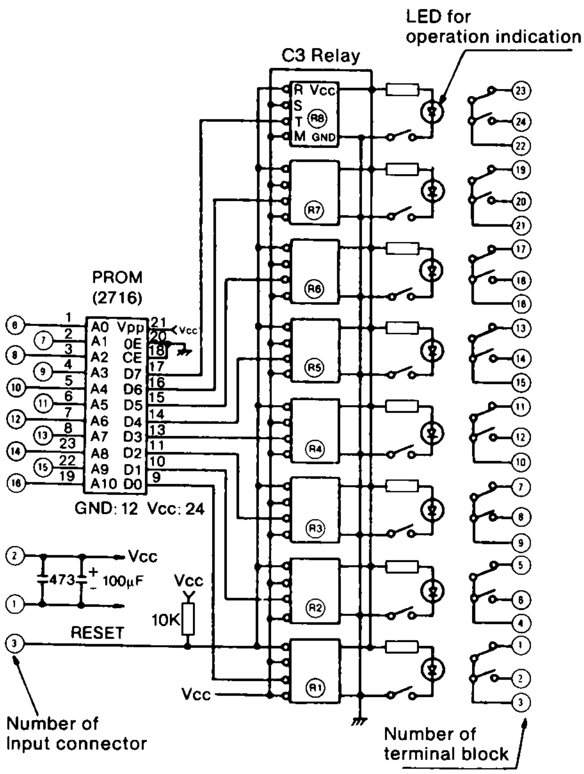


Fig. 256: Machine tool control system

Combination with TTL or PLA

In logic controls, the IC-relay can be connected directly to TTL gates or PLAs, since the output level of the PLA corresponds in principle to that of the TTL.
In production plants, where small quantities of different products are to be manufactured, PLA control circuits are finding increased use. By programming PLAs, it is possible to achieve any required logic function consisting of AND or OR gates. With direct combination of PLA and IC-relays, user programmable logic control systems can be readily constructed.

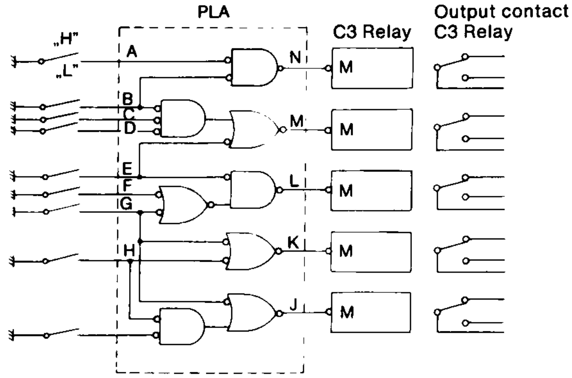


Fig. 257: Example of logic sequence control system

Control Systems with Microprocessors or Personal Computers

Together with microprocessors or personal computers, it is possible to accomplish a broad spectrum of relatively complex control systems in which IC-relays, which are connected with the bus line of the system, switch periphial units. Sequence controls with IC-relays offer basically the same controllability as do the now generally available, programmable controllers. However they are more flexibly adaptable to the user's particular requirements than are P.C. systems. IC-relay control systems distinguish themselves in particular by the following characteristics:

- Possibilities of processing the input signals in real time and to control the IC-relays in accordance with the evaluated results.
- There are now a number of software packages available for the most varied ranges of control requirements, including packages for programmable control systems.
- Flexible programme change or supplementation.
- Design, function, as well as the number and layout of inputs and outputs, can be precisely adapted to the customer's special requirements.

- Lower costs, by reduction of the components which are required for the circuit, and simplification of design and assembly. Saving in wiring due to direct connection to the bus line.
- Selection of suitable output relays from the IC-relay series for different loads (DS, S, ST, SP relays).
- Selective use and combination of four different IC-relay functions (e.g. toggle connection for normal control programme, Set/Reset connection of the same relay for interlocking).
- Low power consumption (due to highly sensitive, polarized relays and by limiting coil current to the pull-in time).
- Compact size.

Application for a Control System with CPU and Bus Line

The application shown in fig. 258 is an example of a complex control system using a microprocessor or personal computer and parallel transfer of data via a bus line. In this application, the address and signal data, which were generated in the CPU system, are parallel transferred via the bus line to the output circuit boards, which consist of decoders and IC-relays.

Fig. 259 shows the layout of such a printed circuit board, on which 8 IC-relays are directly connected to the outputs of a decoder. The noise filters are for the protection of the decoder. The IC-relays have their own protection.

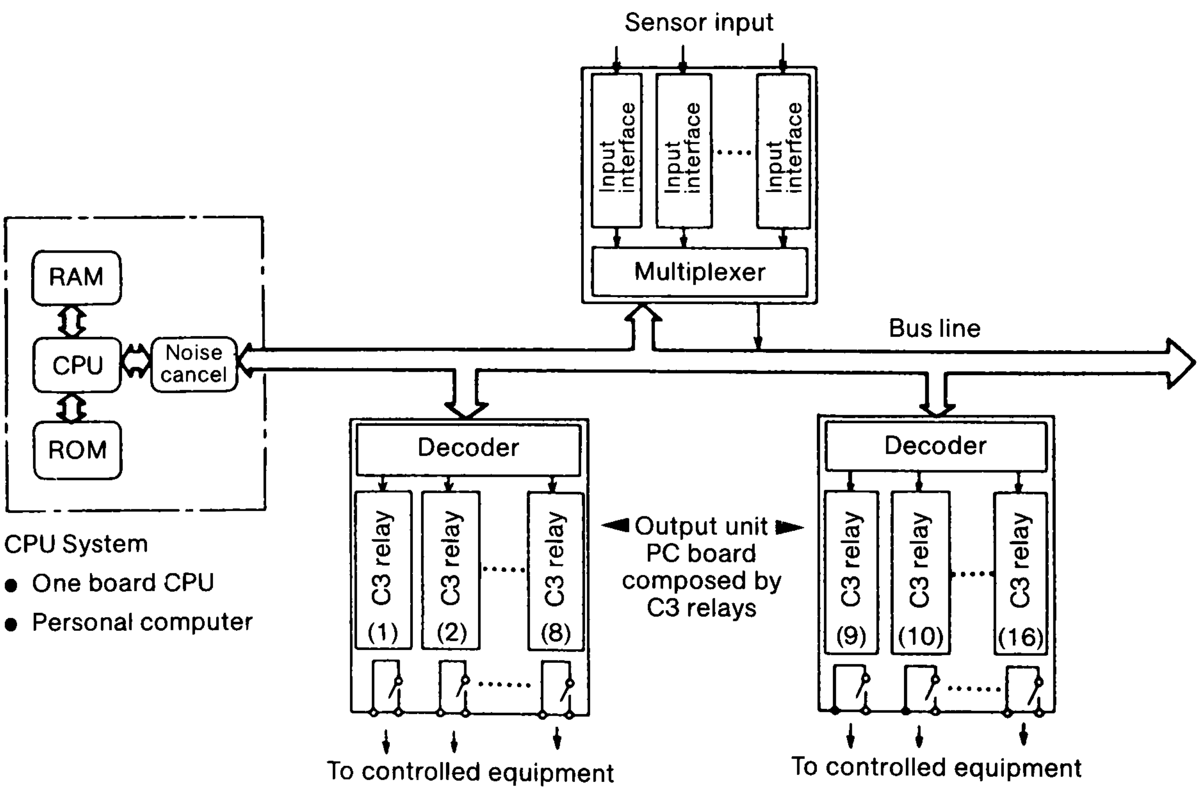


Fig. 258: Block diagram of a parallel transmission control system

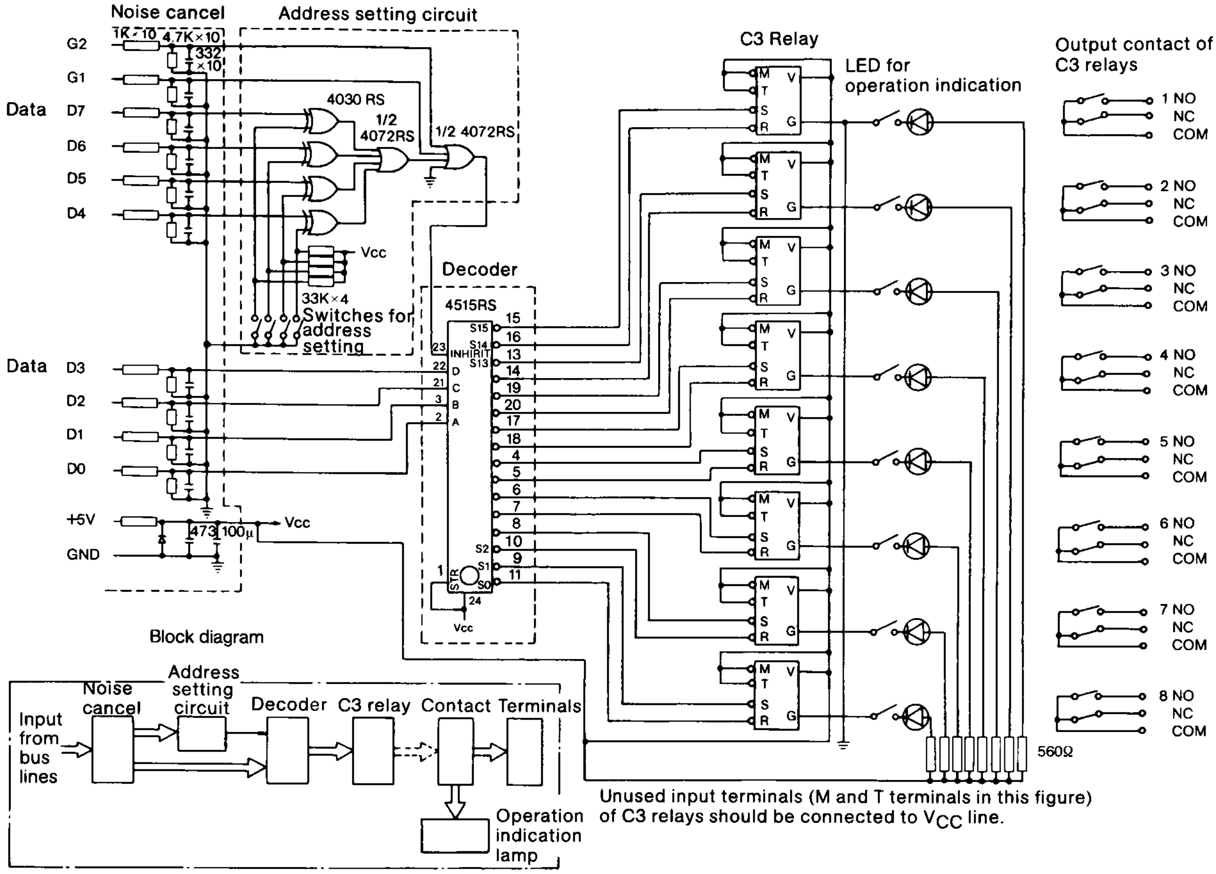


Fig. 259: Output unit pcb for the control system shown in fig. 258

The bus line consists of eight data lines. Four (D4–D7) determine the circuit board address, which is set by the address switches. The signals of the remaining four data lines (D0–D3) control the operations of the IC-relays, in which four bits enable 16 different outputs of the decoder to be addressed. These data lines are linked with the Set or Reset inputs of the relays via the contacts of which the peripheral units are switched. With this system, 128 IC relays can be driven, using only ten lines of bus line.

Based on the circuit shown, three further applications for IC-relay controls are briefly introduced as follows:

Transportation System

The control of transportation systems can be achieved by parallel connected systems via a central processing unit (CPU). IC-relays control the displays, the field winding and the direction of rotation of the motor. The transporting equipment takes the loads to the predetermined destinations and returns to the starting position.

Control System

A security system, a telephone installation and many peripheral units are driven by a central processing unit (CPU) with a bus line via parallel connected transfer systems. The signals of the sensors are processed by the CPU, displayed, and, if appropriate, then trigger the alarm.

Temperature Control System

In order to ensure the specified development of temperature inside a furnace, the values established by the temperature sensors, are processed by the CPU and converted into control pulses for ON and OFF switching of the individual heating elements.

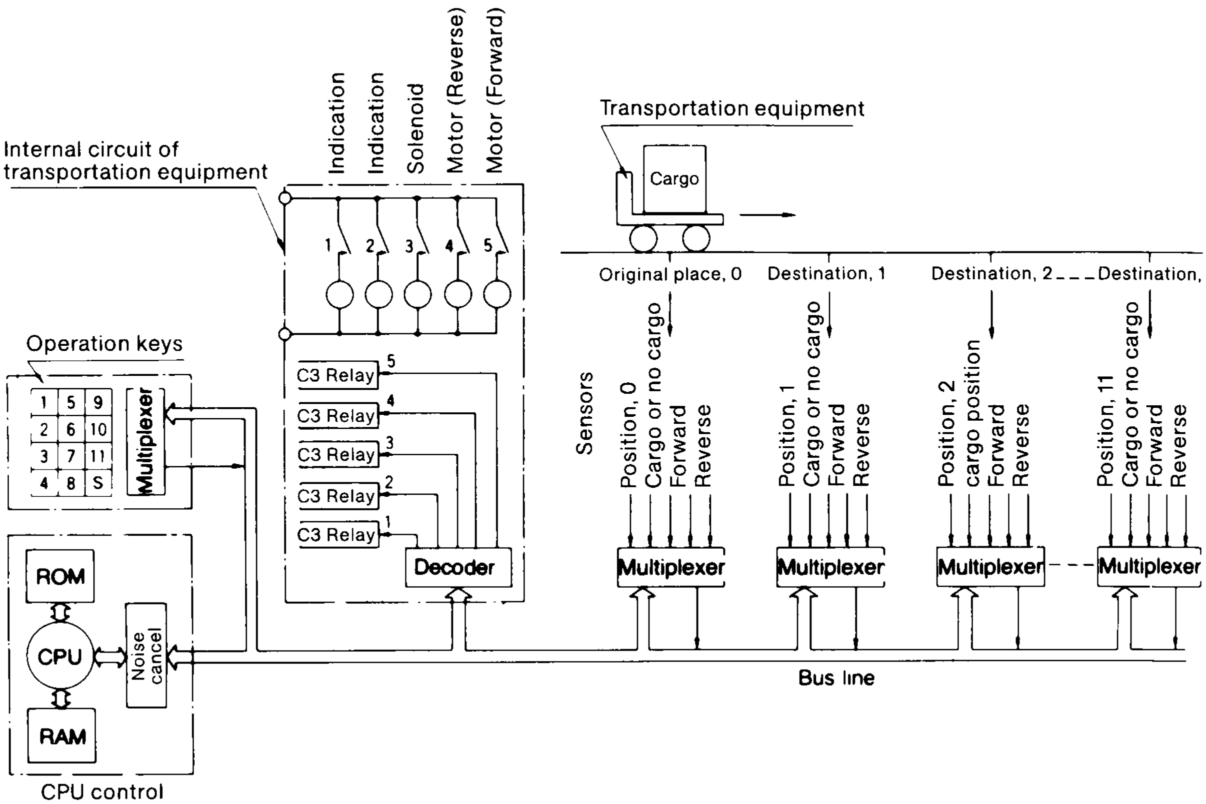


Fig. 260: Transportation control system

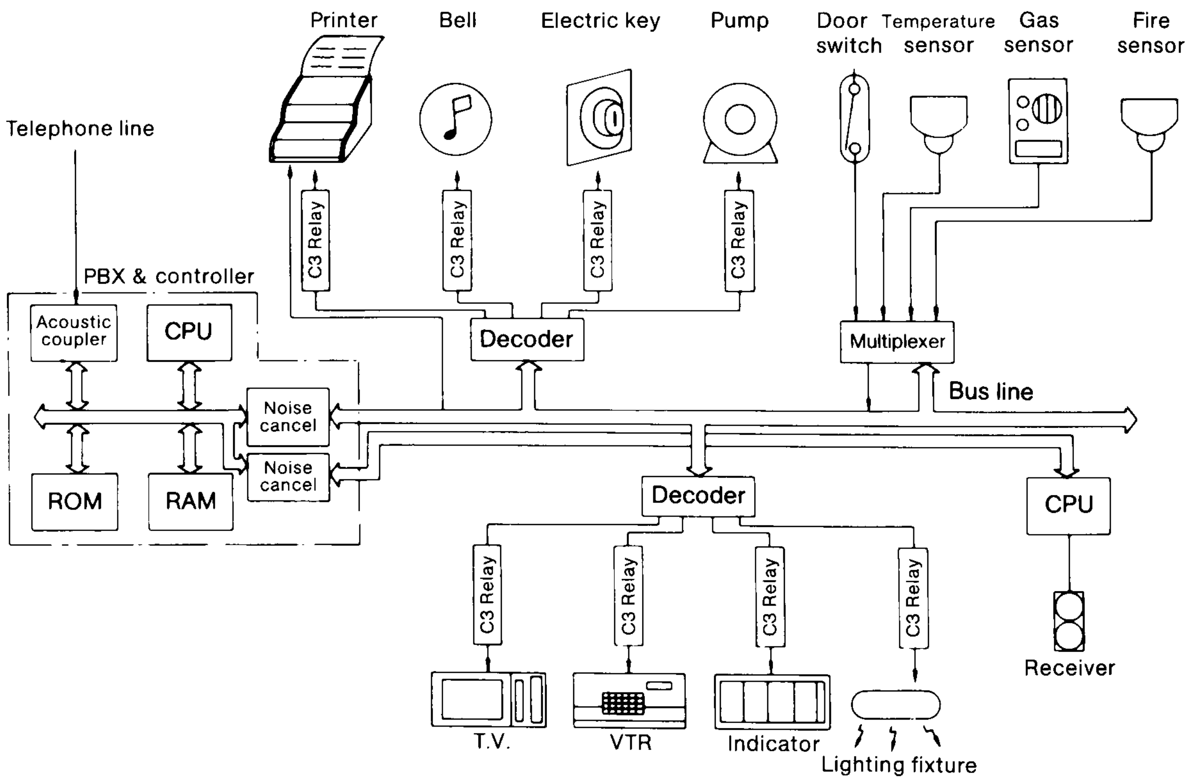


Fig. 261: Control Systems

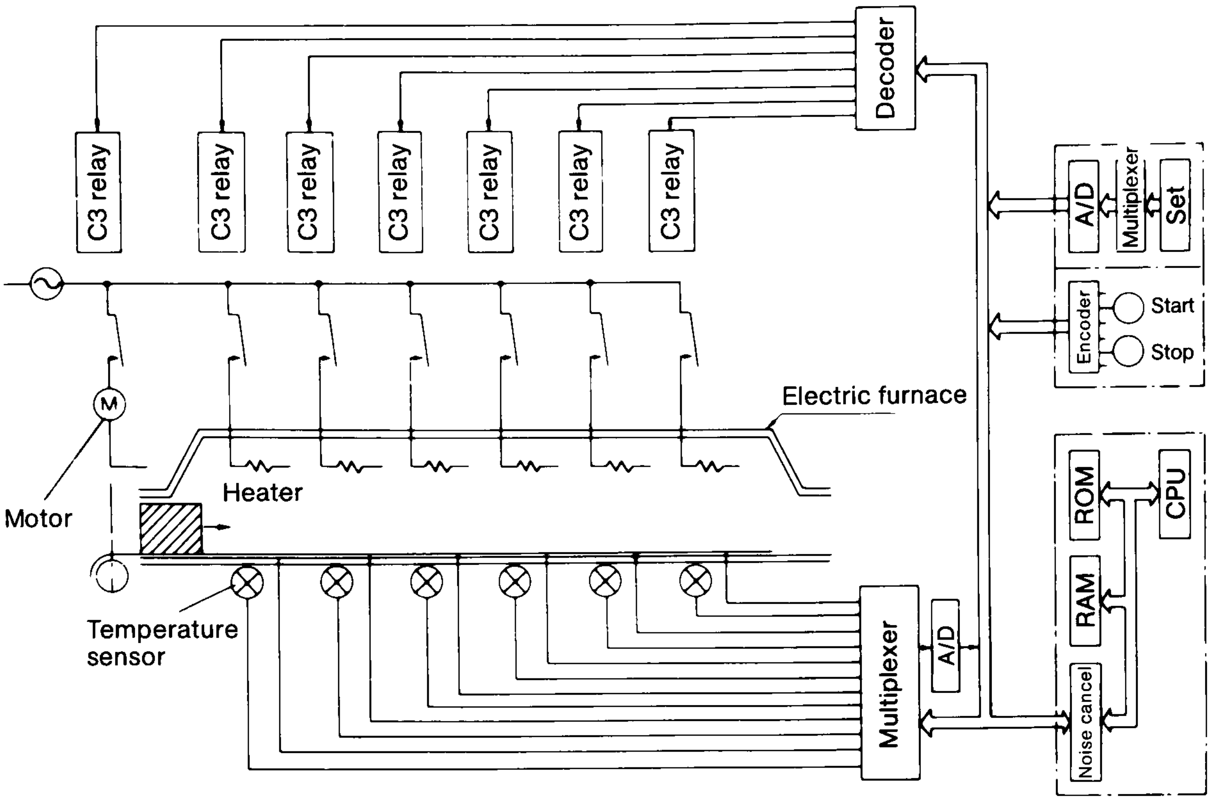


Fig. 262: Temperature control system

4 Relay Tables

with rated technical data, standard prices and sources of supply (a check list for the selection of relays is given in section 3.1)

The purpose of the relay tables is to facilitate the selection of the most suitable relay type for a specific application (pages ■■■).

All major relay manufacturers, as well as their Austrian, British, French, German, Italian, Japanese, Swiss and U.S. representatives have been invited to introduce their products in the relay tables as long as:

a) these relays are like to be available until 1995,
b) at least 50% of the rated data required for the table is available,
c) the ratings, i.e. information provided correspond to the manufacturer's current data sheet or his data sheet valid in January 1984,
d) all data provided by the manufacturer which deviates from the definitions in this book are indicated accordingly.

Since specifications may change, the current manufacturer's data sheet will take precedence over data shown in this book.

Suppliers which did not like to present their prices here, are willing to offer them on request.

For preparation of the relay tables, following guidelines were handed over to the participants:

Purpose of the table

Relay users are provided the opportunity to find a relay suitable for their requirements as rapidly as possible. Therefore, only relays which will be available through 1995 should be included in this table. Relays which have become obsolete for new applications should not be included.

For cost reasons, this book will be printed in several languages. Internationally used formats should be used and the specifications in lines 5 to 29 are to contain no text (figures only). Also they must fit into a quarter, a half, three quarters or a full DIN A5 page (body 125 mm × 180 mm).

Data which are based on test procedures or shown in a format different from that specified in this book are identified with an asterisk. For example, if the insulation resistance is measured at 100 V instead of 500 V, the data will be marked with an asterisk.

All specifications stated in the relay tables have to correspond with the specification sheets, i.e. technical standard which will be current in January 1984. If this data is not available, then a horizontal line is to be inserted in its place.

As previously mentioned in the 1st edition, similar relay type will be listed in consecutive order.

Line 1: A drawing or illustration showing physical dimensions, terminals etc., listings of length, width and height (mm) and volume (cm^3 — excluding terminals), and the relay number (note: this will be inserted by the publisher). If the weight (g) is subject to large fluctuations, the approximate average should be used. For example, 10 grams if the weight varies from 8 to 12 grams.

Line 2 — names the basic relay type, i.e. type TS, a short description of the manufacturer, with the page number on which to find his complete address including telephone number, telex and telefax numbers. (Please submit the complete address which is to be effective January 1984 to the publisher.)

Line 3 — lists the approvals (UL, CSA, VDE, MIL, SEV, etc.) as well as the year of first production. (This date provides information on production quality or stability and to some extent also on the technical standard of the product.)

Line 4 — shows supplementary information highlighting the suitability for special applications (120 characters per quarter page, valid for all languages).

Line 5 — represents the available contact configurations according to table 12.

Line 6 — shows the average contact force, the max. pure contact resistance and the total contact resistance at the terminals (volume resistance). For many applications, it is important to know the pure contact resistance excluding resistance of terminals and other current carrying parts. The volume resistance is measured at 5 V maximum and 0.01 A at the terminal. Resistance of terminals and other current carrying parts, after having been measured once, is substracted from the volume resistance in order to obtain the pure contact resistance. In many cases, however, the volume resistance is sufficient.

Line 7: The bounce time is the elapsed time from initial contact closure to the last intermittant contact opening following the initial closure. Depending on application, maximum or mean or both values may be specified.

Lines 8 to 10: The switching current, switching voltage and switching load ranges refer to a life expectancy of at least 10^5 switching cycles with an expected failure rate of 5% maximum. A failure is defined as the contact resistance exceeding 5% of the load resistance.

Line 11: The maximum inrush current is defined as the current which can be conducted for 200 ms following initial contact closure. The maximum rated current is the current limited by temperature rise of the contacts and all other current carrying parts.

Lines 12 and 13: Pull-in time (delay time) and drop-out time (delay time). Pull-in time:

a) For form A contacts: Elapsed time from energising of coil to first contact closure.
b) For form B contacts: Elapsed time from energising of coil to first contact opening.
c) For form C contacts: Elapsed time from energising of coil to first closure of the form A contact.

Drop-out time:

a) For form A contacts: Elapsed time from de-energising of coil to first contact opening.
b) For form B contacts: Elapsed time from de-energising of coil to first contact closure.
c) For form C contacts: Elapsed time from de-energising of coil to first closure of the form B contact.

Delay time:
The intended extension of pull-in time or drop-out time of a time-delay relay according to the above mentioned definitions.

Line 14: Maximum switching frequency with arc-free load is the maximum number of fully completed switching cycles per second.

Line 15: Mechanical life/life with minimum load (line 10).
Mechanical life: Number of switching cycles that can be performed by a relay without contact load at room temperature with the coil energised with operating power.
Failure criteria:

a) Mechanical life: An increase in pull-in voltage by more than 20% or a decrease in drop-out voltage by more than 50% of the specified values.

b) Life with minimum load: An increase in volume resistance to more than 5% of the load resistance with 5% maximum failure rate. If line 10 shows a minimum load, it is recommended to specify the life expectancy for this load. In practice, this may differ greatly from the mechanical life expectancy.

Line 16: Maximum switching load for $10^8/10^7/10^6/10^5/10^4$ operations is the maximum switching load (in W or VA) for which the specified number of operations can be expected with a maximum failure rate of 5% at an optimum switching frequency and 50% duty cycle. A failure is defined as the contact resistance exceeding 5% of the load resistance. The maximum load has not to be valid for all possible currents and voltages.

Line 17: Pull-in power for 5 and 12 VDC operation. The coil power at which the relay is completely pulled in at 20 to 25 degrees C ambient temperature. Two coil voltages were chosen since more relay types are adjusted more sensitive for 5 VDC coil operation.

Line 18: Nominal power at 5 and 12 VDC operation. Unless otherwise specified, nominal power applies to an ambient temperature of 20 to 25 degrees C and nominal coil voltage. As noted in line 17, some relay types have been designed to operate with lower coil power for 5 VDC nominal applications in order to be compatible with current levels available in integrated circuits.

Line 19: Nominal coil voltages. All available standard coil voltages or a voltage range, i.e. 3...60 V may be specified.

Line 20: Lowest ambient temperature and highest operating temperature (ambient temperature + temperature rise of coil and contacts) at which the relay will continue to operate reliably.

Line 21: Thermal resistance. Temperature rise in Kelvin per watt due to thermal coil dissipation (without contribution of contact dissipation).

Line 22: Thermo-emf at 100% duty cycle is the voltage which is measured at the contact terminals with the coil continually energised at nominal voltage.

Line 23: Dielectric strength is measured at 50 or 60 Hz. AC, applied for at least one minute between open contacts, coil and earth and between contact and earth, without causing breakdown or damage, with a maximum leakage current of 1 mA.

Line 24: Insulation resistance contacts/contact-coil is measured at 500 VDC at 50% relative humidity at 20 to 25 degrees C ambient temperature.

Line 25: Shock and vibration resistance. Shock resistance: g level for the duration specified in IEC 68-2-27 or NARM Std. RS401-A without contact opening longer than 10 µs or mechanical damage. Vibration resistance: Maximum peak to peak g level without contact opening longer than 10 µs or mechanical damage, e.g. 10/2000 means 10 g up to 2000 Hz.

Line 26: Degree of protection IP or MIL-STD or leakage rate (in $cm^3 \times at \times s^{-1}$). The applicable protection types and testing methods are stated in IEC 68.

Line 27: Efficiency η_L at 10^5 switching cycles. The efficiency coefficient is useful as a figure of merit for a certain relay type. The efficiency coefficient is calculated using the following formula:

$$\eta_L = \frac{\text{switching capacity (VA)} \times \text{number of contacts}}{\text{power consumption (Ws)} \times \text{relay volume (cm}^3\text{)}}$$

This is based upon the maximum switching load for 10^5 operations (line 16) with a maximum failure rate of 5% at nominal coil power (line 18) and is duty cycle.

Line 28: Alternate types. Other relay types of same manufacturer which could be applied for the same general applications.

Line 29: The price guidelines are for budgetary calculations.

A check list for the selection of relays based on the ratings stated in these relay tables is given in section 3.1.

5 Translation of Specialist Terminology into German, French and Italian

Relay technology uses words and expressions which often do not appear in technical dictionaries. This book thus has collated such expressions (alphabetically in English) along with the translations in German, French and Italian as an aid for the user.

Opposite each number is an English language expression which is followed by a translation in each of the other languages. Using these numbers and the alphabetical indices permits the user to translate from one language into any of the others.

1 **ability to adsorb**
Adsorptionsvermögen
pouvoir d'adsorption
potere adsorbente

2 **absolute dielectric constant**
absolute Dielektrizitätskonstante
constante diélectrique absolue
costante dielettrica assoluta

3 **absolute permeability**
absolute Permeabilität
perméabilité absolue
permeabilità assoluta

4 **acceptable quality level**
AQL
NQA (niveau de qualité acceptable)
AQL

5 **action quantity**
Wirkungsgröße
grandeur de rendement
grado di rendimento

6 **activated carbon**
Aktivkohle
charbon actif
carbone attivo

7 **active power**
Wirkleistung
puissance efficace
potenza reale

8 **actuating voltage**
Betätigungsspannung
tension de commutation
tensione di attuazione

9 **actuator**
Betätiger, Betätigungsstück, Betätigungsstößel, Betätigungsnocken
commutateur, poussoir, came de commutation
attuatore

10 **adequate make/break of contacts**
Spreizung
dispersion
ampiezza di scostamento, differenza di tempo fra la prima e l'ultima commutazione di un contatto plurilamellare

11 **adhesive**
Klebstoff
adhésif
colla

12 **adjusting method**
Justiermethode
méthode d'ajustage
metodo di taratura

13 **adjusting spring**
Justierfeder
ressort d'ajustage
molla di taratura

14 **adjustment**
Justierung
ajustage
aggiustaggio

15 **to adsorb**
adsorbieren
adsorber
adsorbire

16 **adsorption**
Adsorption
adsorption
adsorbimento

17 **air distance**
Luftstrecke
ligne de fuite aérienne
distanza in aria

18 **air gap**
Luftspalt
entrefer
intraferro

19 **alternating current relay**
Wechselstromrelais
relais à courant alternatif
relé per c. a.

20 **alumina**
Aluminiumoxid (Al_2O_3)
alumine
allumina

21 **A_L-value**
A_L-Wert
coefficient A_L
valore A_L

22 **ambient temperature**
Umgebungstemperatur
température ambiante
temperatura ambiente

23 **american wire gage**
AWG
AWG
American wire gauge

24 **ampere turns, (AT)**
Amperewindungen, AW
ampère tours
amperspire, As

25 **amplitude**
Amplitude
amplitude
ampiezza

26 **anode**
Anode
anode
anodo

27 **antenna-switching relay**
Antennenrelais
relais pour antenne
relé d'antenna

28 **arc**
Lichtbogen
arc
arco elettrico

29 **arc at contact break**
Öffnungslichtbogen
arc de coupure
arco elettrico all'apertura

30 **arc chamber**
Lichtbogenkammer
chambre à arc
camera dell'arco

31 **arc discharge**
Bogenentladung
décharge de l'arc
scarica dell'arco

32 **arc duration**
Lichtbogenverweilzeit
durée d'arc
durata dell'arco

33 **arc extinguishing**
Lichtbogenlöschung
extinction d'arc
smorzamento dell'arco

34 **arc resistance**
Lichtbogenfestigkeit
résistance à l'arc
resistenza all'arco

35 **arc resistant**
abbrandfest
résistant à l'arc
resistenza all'arco

36 **arc resistant metals**
abbrandhemmende Metalle
métaux diminuant l'usure des contacts
metalli che impediscono il logoramento

37 **armature**
Anker
armature
ancora

38 **armature arm**
Ankerarm
bras d'armature
braccio dell'ancora

39 **armature bearing**
Ankerlagerung
palier d'armature
fulcraggio ancora

40 **armature clearance**
Pimpelluft
jeu du doigt de manoeuvre
giuoco dello spinotto

41 **armature holding force**
Haftkraft des Ankers
force de collage de l'armature
forza d'attrazione dell'ancora

42 **armature setting force**
Stellkraft des Ankers
force de réglage de l'armature
forza di movimento dell'ancora

43 **armature stop**
Ankerbegrenzung
butée d'armature
bloccaggio ancora

44 **armature travel**
Ankerweg
course de l'armature
corsa ancora

45 **auxiliary relay**
Hilfsrelais
relais auxiliaire
relé ausiliario

46 **axis**
Drehachse (math.)
axe de rotation
ascisse

47 **axle**
Drehachse (mech.)
arbre de rotation
asse rotante

48 **balanced armature**
Kippanker
armature basculante
ancora basculante

49 **Barkhausen effect**
Barkhausen-Effekt
effet barkhausen
effetto Barkhausen

50 **base plate**
Grundplatte
socle
piastra base

51 **basic grid system**
Rastermaß
grille
reticolo

52 **bearing point**
Lagerung
palier
supporto

53 **bearing stud**
Lagerzapfen
portées de palier
perno del cuscinetto

54 **bias**
Vorspannung (elektr.)
tension de polarisation
tensione di polarizzazione

55 **bifilar resistance**
Bifilarwiderstand
résistance bifilaire
resistenza del bifilare

56 **bifilar winding**
Bifilarwicklung
bobinage bifilaire
avvolgimento bifilare

57 **bifurcated contact**
Doppelkontakt
contact double
contatto sdoppiato

58 **bimetal relay**
Bimetallrelais
relais bimétallique
relé bimetallico

59 **binder**
Bindemittel
liant
legante

60 **bistable**
bistabiles Verhalten
fonctionnement en bistable
funzione bistabile

61 **bit**
Bit
bit
bit

62 **black-and-white circuit**
Schwarz-Weiß-Schaltung
circuit noir et blanc
circuito in bianco-nero

63 **blade contact**
Messerkontakt
contact à lame
contatto a lama

64 **blade spring**
Federband
ressort plat
nastro a molla

65 **blow out magnet**
Blasmagnet
aimant de soufflage
magnete di soffio

66 **blowing of the arc**
Lichtbogenblasung
soufflage d'arc
soffio dell'arco

67 **bobbin**
Spulenkörper
corps de bobine
corpo bobina

68 **bobbin axis**
Spulenkörperachse
axe de bobine
asse del corpo bobina

69 **to bounce**
prellen
rebondir
rimbalzare

70 **bounce time**
Prellzeit
temps de rebondissement
tempo di rimbalzo

71 **bounces**
Prellschläge
rebonds
rimbalzi

72 **break**
öffnen
couper
aprire

73 **break**
Unterbrechung
coupure, interruption
interruzione

74 **break before make**
öffnen vor schließen
couper avant fermer
aprire prima di chiudere

75 **break contact**
Ruhekontakt
contact repos
contatto di riposo

76 **breakdown due to thermal instability**
Wärmedurchschlag
claquage thermique
scarica dovuta al calore

77 **breakdown voltage**
Durchschlagspannung
tension de claquage
tensione di scarica

78 **breakdown voltage**
Spannungsfestigkeit
rigidité diélectrique
resistenza alla scarica

79 **breaking capacity**
Abschaltleistung
pouvoir de coupure
potenza di disinserzione

80 **breaking current**
Abschaltstrom
courant de coupure
corrente di disinserzione

81 **bridge contact**
Kontaktbrücke
pont de contact
ponte dei contatti

82 **bridge rectifier**
Brückengleichrichter
redresseur en pont
raddrizzatore a ponte

83 **bridge transfer**
Brückentransport
transfert de pont
trasferimento a ponte

84 **brown-powder-effect**
Brown-Powder-Effekt
effet Brown-Powder
effetto Brown Powder

85 **can**
Kappe, Gehäusekappe
capot
involucro

86 **capacitor**
Kondensator
condensateur
condensatore

87 **capacity**
Kapazität
capacité
capacità

88 **carbonaceous**
kohlenstoffreich
riche en carbone
ricco di carbone

89 **carrier**
Träger
support
supporto

90 **catalyst**
Katalysator
catalyseur
catalizzatore

91 **cathode**
Kathode
cathode
catodo

92 **center of rotation**
Drehpunkt
centre de rotation
punto di rotazione

93 **change of rotation**
Drehrichtungsumkehr
inversion du sens de rotation
inversione di rotazione

94 **to change-over**
umschalten
commuter
commutare

95 **change-over contact**
Wechselkontakt, Umschalter
inverseur, contact inverseur
commutatore, contatto di scambio

96 **change-over time**
Umschaltzeit
temps de commutation
tempo di commutazione

97 **characteristic impedance**
Wellenwiderstand
impédance caractéristique
impedenza caratteristica

98 **characteristics**
Kenndaten
caractéristiques
caratteristiche

99 **circuit**
Schaltung, Stromkreis
circuit
circuito

100 **circuit diagram**
Stromlaufplan, Schaltbild
schéma électrique
schema di principio, schema elettrico

101 **circuit elements**
Schaltelemente
élément de circuit
elementi di commutazione

102 **clapper type armature**
Klappanker
armature clapet
ancora di rimando

103 **clapper type relay**
Klappankerrelais
relais à armature-clapet
relé ad ancora di rimando

104 **click-stop device**
Rastmittel
dispositif d'encliquetage
pezzo di bloccaggio

105 **closed-circuit current**
Ruhestrom
courant de repos
corrente di riposo

106 **coaxial relay**
Koaxialrelais
relais coaxial
relé coassiale

107 **coefficient of self-inductance**
Induktivitätsfaktor
coefficient d'induction
fattore d'induttanza

108 **coercive force**
Koerzitivkraft
force coercitive
forza coercitiva

109 **coil**
Spule
bobine
bobina

110 **coil wire**
Spulendraht
fil à bobiner
filo

111 **cold solder joint**
kalte Lötstelle
soudure sèche
saldatura fredda

112 **compensating spring**
Ausgleichsfeder
ressort de compensation
molla di compensazione

113 **compound**
Verbindung (chem.)
composé
combinazione (chimica)

114 **conductance**
Leitwert
conductance
conduttanza

115 **constriction resistance**
Engewiderstand
résistance de constriction
resistenza di costrizione

116 **contact area**
Kontaktbereich
zone des contacts
area dei contatti

117 **contact arrangement**
Kontaktanordnung, Kontaktbestückung
configuration de contacts
disposizione dei contatti, tipologia dei contatti

118 **contact assembly**
Federsatz
groupe de ressort
coppia di molle

119 **contact bounce**
Kontaktprellung
rebondissement de contact
rimbalzo dei contatti

120 **contact capacity**
Kontaktkapazität
capacité de contact
capacità dei contatti

121 **contact carrier**
Kontaktträger
porte-contacts
supporto di contatto

122 **contact chamber**
Kontaktraum, Kontaktkammer
chambre de contact
camera dei contatti

123 **contact current**
Kontaktstrom
courant de contact
corrente di contatto

124 **contact force**
Kontaktkraft
force de contact
forza dei contatti

125 **contact gap**
Kontaktabstand
écartements entre contacts
distanza dei contatti

126 **contact interruption**
Kontaktunterbrechung
suppression du contact
interruzione dei contatti

127 **contact load**
Kontaktbelastung
charge de contact
carico sui contatti

128 **contact make**
Kontaktgabe
mise en contact
contattazione

129 **contact making**
kontaktgebend
fermant le contact
contattare

130 **contact material**
Kontaktstoff
matériau de contact
materiale di contatto

131 **contact members**
Schaltstücke
pièces de contact
elementi di commutazione

132 **contact noise**
Kontaktrauschen
bruit de contact
rumore dei contatti

133 **contact opening**
Kontaktöffnung
ouverture de contact
apertura dei contatti

134 **contact overtravel**
Kontaktüberhub
sur-course de contact
corsa ulteriore di contatto

135 **contact point**
Kontaktstelle
point de contact
punto di contatto

136 **contact resistance**
Kontaktwiderstand
résistance de contact
resistenza di contatto

137 **contact spring**
Kontaktfeder
ressort de contact
molla dei contatti

138 **contact surface**
Kontaktoberfläche
surface de contact
superficie dei contatti

139 **contact temperature rise**
Kontakterwärmung
échauffement de contact
riscaldamento dei contatti

140 **contact time**
Kontaktzeit
temps de contact
tempo di contatto

141 **contact touch**
Kontaktgabe
mise en contact
contattazione

142 **contact travel**
Kontaktweg
course de contact
corsa del contatto

143 **contact type**
Kontaktart
type de contact
forma dei contatti

144 **contact wear**
Kontaktverschleiß, Kontaktabbrand
usure de contact
usura di contatto

145 **contact welding**
Verschweißen (Kontakte)
soudure des contacts
incollaggio dei contatti

146 **contacting**
Kontaktierung
fixation des contacts
contattazione

147 **contacting ring**
Kontaktierungsring
anneau de commutation
anello dei contatti

148 **contactless relay**
kontaktloses Relais
relais sans contact
relé senza contatti

149 **contactor**
Schütz
contacteur
contattore

150 **contamination**
Verunreinigung
pollution
contaminazione

151 **to control**
steuern
commander, exciter
pilotare

152 **control energy**
Steuerenergie
énergie d'excitation
energia di comando

153 **control power**
Steuerleistung
puissance d'excitation
potenza di comando

154 **control switch**
Steuerschalter
interrupteur de commande
interruttore di comando

155 **control system**
Steuerung
commande
circuito di comando

156 **core**
Kern
noyau
nucleo

157 **core lamination**
Kernblech
tôles de noyau
lamierino magnetico

158 **counting magnet**
Zählmagnet
aimant de compteur
magnete contatore

159 **counting relay**
Zählrelais
relais compteur
contatore

160 **cover**
Kappe, Gehäusekappe
capot
involucro

161 **cradle relay**
Barrelais
relais Bar
relé a bilanciere

162 **creeping and leakage distance**
Kriech- und Luftstrecke
ligne de fuite superficielle et aérienne
distanza di dispersione e in aria

163 **creeping resistance**
Kriechstromfestigkeit
résistance aux courants de fuite superficiels
resistenza alla corrente di dispersione

164 **cross section**
Querschnitt
section
sezione

165 **crystal-can-relay**
Becherrelais (l·b·h = 20.3·10.2·24.6 mm)
relais scellé
relé a capsula ermetica

166 **crystalline water**
kristallin gebundenes H_2O
eau cristalline
acqua cristallina

167 **Curie point**
Curie-Punkt
point de Curie
punto Curie

168 **current**
Dauerstrom
courant permanent
corrente permanente

169 **current commutation**
Stromkommutierung
commutation en courant
commutazione di corrente

170 **current flow**
Stromfluß
flux de courant
flusso di corrente

171 **current flow loop**
Stromflußschleife
boucle de flux de courant
flusso di corrente di circuito

172 **current impulse switch**
Stromstoßschalter
télérupteur
interruttore ad impulso di corrente

173 **current limit**
Grenzstrom
courant limite
corrente marginale

174 **current path**
Strombahn, Strompfad
cheminement du courant
ramo di corrente

175 **current pulse**
Stromstoß
impulsion de courant
impulso di corrente

176 **current rush**
Stromstoß
impulsion de courant
impulso di corrente

177 **damping**
Schirmdämpfung
atténuation du blindage
smorzamento

178 **damping resistance**
Dämpfungswiderstand
résistance d'amortissement
resistenza di smorzamento

179 **damping winding**
Dämpfungswicklung
enroulement d'amortissement
avvolgimento di smorzamento

180 **decade**
Zehnerpotenz
puissance décimale
potenza decimale

181 **de-energized position**
Ruhelage
position de repos
posizione di riposo

182 **de-gassing**
Ausgasen
dégazer
degassaggio

183 **delay relay**
Verzögerungsrelais
relais temporisé
relé temporizzatore

184 **delay winding**
Verzögerungswicklung
enroulement de temporisation
avvolgimento di ritardo

185 **demagnetization**
Entmagnetisierung
démagnétisation
smagnetizzazione

186 **diamagnetism**
Diamagnetismus
diamagnétisme
diamagnetismo

187 **dielectric constant**
Dielektrizitätskonstante
constante diélectrique
costante dielettrica

188 **dielectric strength**
Spannungsfestigkeit
rigidité diélectrique
resistenza alla scarica

189 **differential relay**
Differenzialrelais
relais différentiel
relé differenziale

190 **differential winding**
Differentialwicklung
enroulement différentiel
avvolgimento differenziale

191 **to diffuse**
diffundieren
diffuser
diffondere

192 **diffusion barrier**
Diffusionsbarriere
barrière de diffusion
barriera di diffusione

193 **diminished pressure**
Unterdruck
dépression
depressione

194 **diode**
Diode
diode
diodo

195 **direction of rotation**
Drehrichtung
sens de rotation
direzione di rotazione

196 **discharge**
Entladung
décharge
scarica

197 **discriminating protective system**
Rückstromauslösung
disjoncteur anti-retour de courant
eccitazione con corrente inversa

198 **discriminating relay**
Wahlrelais
relais de sélection
relé selettore

199 **dissipation factor**
Verlustfaktor
facteur de dissipation
fattore di perdita

200 **distortion**
Verzerrung
distorsion
distorsione

201 **double action switch**
Doppelsprungschalter
commutateur à double action
interruttore a doppio scatto

202 **double make/double break**
Doppelunterbrechung
double coupure
doppia interruzione

203 **double snap action system**
Doppelschnappsystem
système à double action rapide
chiusura a doppio scatto

204 **double throw contact**
Wechselkontakt, Umschalter
inverseur, contact inverseur
commutatore, contatto di scambio

205 **drop-out current**
Abfallstrom
courant de retombée
corrente di caduta

206 **drop-out delay**
Ausschaltverzug
retard à la retombée
ritardo di apertura

207 **drop-out ratio**
Abfallverhältnis
rapport de retombée
rapporto di caduta

208 **drop-out time**
Abfallzeit
temps de retombée
tempo di caduta

209 **drop-out time delay**
Abfallverzögerung
retard à la retombée
ritardo di caduta

210 **drop-out voltage**
Abfallspannung
tension de retombée
tensione di caduta

211 **dry circuit**
Trockenschaltung
circuit sec
circuito dry

212 **duty cycle**
ED, Einschaltdauer
durée de maintient
durata d'esercizio

213 **dwell time**
Verweilzeit
temps de maintien
tempo di attesa

214 **dynamic marginal current**
dynamischer Grenzstrom
courant dynamique limite
corrente marginale dinamica

215 **economical aspects**
wirtschaftliche Aspekte
aspects économiques
aspetti economici

216 **E-core**
E-Kern
noyau en E
nucleo magnetico

217 **eddy current**
Wirbelstrom
courants de Foucault
corrente parassita, corrente di Foucault

218 **effective value**
Effektivwert
valeur efficace
valore effettivo

219 **efficiency**
Effizienz, Gütegrad, Wirkungsgrad
efficience, rendement
efficienza, rendimento

220 **elastic length**
federnde Länge
largeur élastique
lunghezza elastica

221 **electric connection**
elektrische Verbindung
liaison électrique
collegamento elettrico

222 **electric junction**
elektrische Verbindung
liaison électrique
collegamento elettrico

223 **electric time constant**
elektrische Zeitkonstante
constante de temps électrique
costante di tempo elettrica

224 **electrically locked**
elektrisch verriegelt
à verrouillage électrique
interblocco elettrico

225 **electrolytic potential**
elektrolytische Spannungsreihe
tension électrolytique
serie elettrolitica di tensioni

226 **electrolytic series**
elektrolytische Spannungsreihe
tension électrolytique
serie elettrolitica di tensioni

227 **electromagnetic instrument**
Dreheiseninstrument
galvanomètre à palette mobile
strumento a magnete

228 **electromagnetic relay**
elektromagnetisches Relais
relais électromagnétique
relé elettromagnetico

229 **electromotive force**
EMK, elektromotorische Kraft, Urspannung
f.em., force électromotrice
fem, forza elettromotrice

230 **electro-negative gas**
elektronegatives Gas
gaz électronégatif
gas elettronegativo

231 **electronic relay**
elektronisches Relais
relais électronique
relé elettronico

232 **electronic switch**
elektronischer Schalter
commutateur électronique
interruttore elettronico

233 embedding
Umspritzung
enrobage
rivestimento ad estrusione

234 enamelled copper wire
Kupferlackdraht
fil de cuivre émaillé
filo isolante in rame

235 energization
Erregung
excitation
eccitazione

236 energizing power
Erregerleistung
puissance d'excitation
potenza di eccitazione

237 energy
Arbeit
travail
lavoro

238 energy storing
Kraftspeicherung
accumulation d'énergie
immagazzinaggio delle forze

239 enforced mid-position
provozierte Mittelstellung
position intermédiaire forcée
posizione mediana obbligata

240 environmental influences
Umwelteinflüsse
influences de l'environnement
inquinamento

241 equalization
Entzerrung
égalisation
equalizzazione

242 excitation
Erregung
excitation
eccitazione

243 exponential current
Exponentialstrom
courant exponentiel
corrente esponenziale

244 exponential line
Exponentialleitung
ligne exponentielle
linea esponenziale

245 Faston-terminal
Flachsteckeranschluß
sortie Faston
attacco Faston

246 fault-voltage circuit-breaker
Fehlerspannungsschutzschalter
disjoncteur à défaut de tension
dispositivo di protezione tensione di guasto

247 faulty operation
Fehlschaltung
non fonctionnement
commutazione errata

248 ferromagnetism
Ferromagnetismus
ferromagnétisme
ferromagnetismo

249 field of tolerance
Streubreite
longueur de dispersion
campo di tolleranza

250 field of variance
Streukurve
courbe de dispersion
curva variazione

251 film
Fremdschicht
dépôt étranger
strato estraneo

252 film resistance
Fremdschichtwiderstand
résistance du dépôt
resistenza dello strato estraneo

253 filtering
Siebung
filtrage
filtraggio

254 fixed contact
Festkontakt
contact fixe
contatto fisso

255 flange
Flansch
bride, flasque
flangia

256 flash-over voltage
Überschlagspannung
tension de claquage
tensione di scarica

257 flat relay
Flachrelais
relais plat
relé piatto

258 flat spring
Blattfeder
ressort à lames
molla

259 flat tab terminal
Flachsteckeranschluß
sortie Faston
attacco Faston

260 flip-flop circuit
Flip-Flop-Schaltung
circuit Flip-Flop
circuito Flip-Flop

261 force restoring spring
Federkraftspeicher
accumulateur à ressort
accumulatore di forza elastica

262 force storing
Kraftspeicherung
accumulation d'énergie
immagazzinaggio delle forze

263 forced operation
Zwangsführung
manoeuvre forcée
apertura forzata

264 force/travel
Kraft/Weg
force/déplacement
forza/corsa

265 forcibly actuated
zwangsgeführt
à manoeuvre forcée
ad apertura forzata

266 foreign layer
Fremdschicht
dépôt étranger
strato estraneo

267 **form A contact**
Arbeitskontakt, Schließer
contact travail, contact à fermeture
contatto di lavoro, contatto in chiusura

268 **form B contact**
Ruhekontakt
contact repos
contatto di riposo

269 **form C contact**
Wechselkontakt, Umschalter
inverseur, contact inverseur
commutatore, contatto di scambio

270 **forming**
Formierung
formage
formazione

271 **400 cycles relay**
400-Hz-Relais
relais à 400 Hz
relé a 400 Hz

272 **four terminal network**
Vierpol
quadripôle
tetrapolare, quadripolo

273 **frequency band**
Frequenzband
bande de fréquences
banda die frequenza

274 **frequency range**
Frequenzbereich
plage de fréquences
campo di frequenza

275 **frequency relay**
Frequenzrelais
relais de fréquences
relé di frequenza

276 **fritting**
Frittung
frittage
sinterizzazione

277 **galvanometer relay**
Galvanometerrelais
relais galvanométrique
relé galvanometrico

278 **getter**
Getter
getter
Getter

279 **getter material**
Getterstoff
matériaux de getter
materiale del Getter

280 **getter pill**
Getterpille
pastille de getter
pillola Getter

281 **glow discharge**
Glimmentladung
décharge luminescente
scarica luminescente

282 **graphical symbol**
Schaltsymbol, Schaltzeichen
symbole graphique
simbolo di commutazione

283 **guided**
zwangsgeführt
à manoeuvre forcée
ad apertura forzata

284 **guidence**
Zwangsführung
manoeuvre forcée
apertura forzata

285 **half-wave rectification**
Einweggleichrichtung
redressement monophasé
raddrizzatore a semionda

286 **Hall effect**
Hall-Effekt
effet Hall
effetto Hall

287 **heating power**
Heizleistung
puissance calorifique
potenza di riscaldo

288 **heavy duty switch**
Lastschalter
interrupteur de puissance
interruttore di carico

289 **hermetic(al)**
hermetisch
hermétique
ermetico

290 **HF-proof**
HF-dicht
blindé haute fréquence
ermetico all'HF

291 **high speed relay**
Schnellschaltrelais
relais rapide
relé ad intervento rapido

292 **holding winding**
Haltewicklung
enroulement de maintien
avvolgimento di tenuta

293 **hot-wire relay**
Hitzdrahtrelais
relais à fil thermique
relé termico

294 **humidity, relative**
Luftfeuchtigkeit, relative
humidité relative de l'air
umidità relativa

295 **humming**
Brummen
ronflement
fare ronzio

296 **hunting impulse**
Nachlaufimpuls
impulsion de rattrapage
impulso di taratura

297 **hydrocarbon molecule**
Kohlenwasserstoffmolekül
molécule d'hydrocarbure
molecola di carboidrato

298 **hysteresis**
Hysterese
hystérésis
isteresi

299 **hysteresis loop**
Hystereseschleife
boucle d'hystérésis
curva d'isteresi

300 **ignition voltage**
Zündspannung
tension d'allumage
tensione di start

301 **impregnated coil**
imprägnierte Spule
bobine imprégnée
bobina impregnata

302 impulse
Impuls
impulsion
impulso

303 inconstancy
Inkonstanz
inconstance
incostanza

304 indication of operating position
Schaltstellungsanzeige
indication de la position de commutation
indicazione posizione di commutazione

305 inductance
Induktivität
inductivité
induttanza

306 induction
Induktion
induction
induzione

307 inductivity
Induktivität
inductivité
induttanza

308 inequal contact make/ break
Spreizung
dispersion
ampiezza di scostamento, differenza di tempo fra la prima e l'ultima commutazione di un contatto plurilamellare

309 initial capacity
Anfangskapazität
capacité initiale
capacità iniziale

310 initial permeability
Anfangspermeabilität
perméabilité initiale
permeabilità iniziale

311 inrush current
Einschaltstrom
courant de collage
corrente d'inserzione

312 insulating foil
isolierende Folie
feuille isolante
foglio isolante

313 insulation
Isolierung
isolation
isolamento

314 insulation resistance
Isolationswiderstand
résistance d'isolation
resistenza di isolamento

315 insulation varnish
Isolierlack
vernis isolant
vernice isolante

316 interference suppression
Entstörung
déparasitage
eliminazione del guasto

317 intermediate position
Zwischenstellung
position intermédiaire
posizione intermedia

318 interval
Intervall
intervalle
intervallo

319 intrinsic safety
Eigensicherheit
sécurité intrinsèque
sicurezza intrinseca

320 ionization
Ionisation
ionisation
ionizzazione

321 ionization current
Ionisationsstrom
courant d'ionisation
corrente ionizzante

322 iron loss
Eisenverlust
pertes fer
perdite parassite

323 key relay
Tastrelais
relais de manipulation
relé a tasto

324 key switch
Tastschalter
manipulateur
interruttore a tasto

325 knife-edge bearing
Schneidenlagerung
suspension à lame de couteau
fulcraggio a lama

326 knife-edge relay
Schneidankerrelais
relais à armature à lame de couteau
relé ad ancora a lamina

327 latch
Schaltschloß
blocage
interruttore a chiave

328 latching function
bistabiles Verhalten
fonctionnement en bistable
funzione bistabile

329 latching relay
Stromstoßrelais
relais télérupteur
relé ad impulso di corrente

330 leakage flux
Streufluß
flux de dispersion
flusso di dispersione

331 leakage rate
Leckrate
taux de fuite
perdita

332 leakage-current circuit-breaker
Fehlerstromschutzschalter
disjoncteur à courant de fuite
dispositivo di protezione corrente di guasto

333 life expectancy
Lebensdauer
durée de vie
vita

334 line of force
Kraftlinie
ligne de force
linea di forza

335 line resistance
Leitungswiderstand
résistance de ligne
resistenza del filo

336 live-part protection
Berührungsschutz
protection contre les contacts accidentiels
protezione da contatto

337 load
Last
charge
carico

338 load switching range
Schaltlastbereich
plage de pouvoir de coupure
campo di potenza di commutazione

339 locking element
Rastung
encliquetage
arresto

340 loss angle
Verlustwinkel
angle de perte
angolo di perdita

341 magnet armature
Magnetanker
armature d'aimant
ancora del magnete

342 magnet circuit
Magnetkreis
circuit magnétique
circuito magnetico

343 magnet system
Magnetantrieb
entraînement magnétique
sistema magnetico

344 magnetic clamp
Haftmagnetanordnung
système à aimant de collage
funzione del magnete permanente

345 magnetic field
magnetisches Feld, Magnetfeld
champ magnétique
campo magnetico

346 magnetic flux
Durchflutung
flux magnétique
flusso magnetico

347 magnetic latch effect
magnetische Haltewirkung
blocage magnétique
effetto di tenuta magnetico

348 magnetic shielding
magnetische Abschirmung
blindage magnétique
schermatura magnetica

349 main contact
Hauptkontakt
contact principal
contatto principale

350 to make
schließen
fermer
chiudere

351 make before break (mbb)
schließen vor öffnen
fermer avant couper
chiudere prima di aprire (mbb)

352 make contact
Arbeitskontakt, Schließer
contact travail, contact à fermeture
contatto di lavoro, contatto in chiusura

353 make time
Schließzeit
temps de fermeture
tempo di chiusura

354 marginal current
Grenzstrom
courant limite
corrente marginale

355 marginal surface
Grenzfläche
surface limite
superficie marginale

356 materials which create films
fremdschichtbildende Stoffe
matériaux produisant un dépôt
materiali che provocano strati di impurezza

357 max. permeability
max. Permeabilität
perméabilité maxi.
permeabilità max.

358 maximum rating
Belastbarkeit
charge limite
caricabilità

359 mean time of stay
mittlere Verweildauer
temps de maintien moyen
tempo medio di fermata

360 measuring relay
Meßrelais
relais de test
relé di misura

361 measuring unit
Maßeinheit
unités de mesure
unità di misura

362 mercury relay
Quecksilberrelais
relais au mercure
relé a mercurio

363 mercury wetted relays
quecksilberbenetzte Relais
relais mouillé au mercure
relé a bagno di mercurio

364 meter relay
Zählrelais
relais compteur
contatore

365 micro atmosphere
Kleinklima
micro-climat
microclima

366 miniature relay
Miniaturrelais
relais miniature
relé miniatura

367 monitor
Wächter
contrôleur automatique
strumenti di controllo

368 motor driven switch
Motorschalter
interrupteur de moteur
contattore

369 motor reversal
Umkehrantrieb
entraînement reversible
azionamento reversibile

370 motor-protection switch
Motorschutzschalter
disjoncteur de protection pour moteurs
salvamotore

371 mounting plate
Grundplatte
socle
piastra base

372 moving coil relay
Drehspulrelais
relais à bobine mobile
relé a bobina rotante

373 moving-iron instrument
Dreheiseninstrument
galvanomètre à palette mobile
strumento a magnete

374 multivibrator
Multivibrator
multivibrateur
multivibratore

375 mu-metal
Mumetall
Mu-métal
metallo MU

376 mutual induction
Gegeninduktivität
inductance mutuelle
mutua induzione

377 mutual permeability
Scherungspermeabilität
perméabilité au cisaillement
permeabilità da deformazione a taglio

378 NC contact (normally closed contact)
Ruhekontakt
contact repos
contatto di riposo

379 neutral relay
neutrales Relais
relais neutre non polarisé
relé neutro

380 nipple
Pimpel
doigt de manoeuvre
spinotto

381 NO contact (normally open contact)
Arbeitskontakt, Schließer
contact travail, contact à fermeture
contatto di lavoro, contatto in chiusura

382 noise
Rauschen
bruit
rumore

383 no-load switch
Leerschalter
interrupteur à vide, sectionneur
interruttore senza carico

384 nominal coil operating voltage
Spulennennspannung
tension bobine nominale
tensione nominale bobina

385 nominal cross section
Nennquerschnitt
section nominale
sezione nominale

386 nominal current
Nennstrom
courant nominale
corrente nominale di commutazione

387 nominal data
Betriebswert
valeur nominale
valore di esercizio

388 nominal power
Betriebsleistung
puissance de travail
potenza di esercizio

389 nominal switching capacity
Nennschaltvermögen
pouvoir de coupure nominale
potenza nominale di commutazione

390 nominal value
Nennwert
valeur nominale
valore nominale

391 nominal voltage
Betriebsspannung
tension de travail
tensione di esercizio

392 non-inductive coil
induktionsfreie Spule
bobine non inductive
bobina non induttiva

393 non-operate current
Fehlstrom
courant de non functionnement
corrente non operante

394 non-operating temperature
Lagertemperatur
température de stockage
temperatura di magazzino

395 number of operations
Schaltzahl
nombre de manoeuvres
numero di operazioni

396 to operate
betätigen
manoeuvrer
azionare

397 operating force
Betätigungskraft
pouvoir de commutation
forza di attuazione

398 operating position
Betriebsstellung
position de travail
posizione di lavoro

399 operating temperature
Betriebstemperatur
température de travail
temperatura di esercizio

400 **operating temperature range**
Arbeitstemperaturbereich
plage de température de travail
campo di temperatura di lavoro

401 **operation**
Schaltspiel
manoeuvre
ciclo

402 **operational data**
Betriebsdaten
caractéristiques de service
dati di esercizio

403 **optoelectronic coupler**
Optokoppler
opto-coupleur
accoppiatore optoelettronico

404 **optoelectronic separator**
Optokoppler
opto-coupleur
accoppiatore optoelettronico

405 **outgassing**
Ausgasen
dégazer
degassaggio

406 **overcurrent relay**
Überstromrelais
relais par surintensité
relé di sovracorrente

407 **overcurrent release**
Überstromauslösung
déclenchement de surintensité
protezione di cortocircuito

408 **overheating**
Überhitzung
surchauffage
sovrariscaldo

409 **overload**
Überlastung
surcharge
sovraccarico

410 **overload safety device**
Überlastungssicherer
protection contre les surcharges
sicurezza di sovraccarico

411 **overvoltage relay**
Überspannungsrelais
relais à maximum de tension
relé di sovratensione

412 **parasitic oscillation**
Störschwingung
oscillation parasite
vibrazione di disturbo

413 **partial pressure**
Partialdruck
pression partielle
pressione parziale

414 **pawl**
Sperrklinke
cliquet de verrouillage
nottolino di arresto

415 **pcb**
Leiterplatte
platine à circuit imprimé
circuito stampato

416 **p/c-board**
Leiterplatte
platine à circuit imprimé
circuito stampato

417 **p/c-board connection**
Leiterplattenverbindung
connexion pour CI
collegamento sul c. s.

418 **p/c-board relay**
Kartenrelais
relais carte
relé piatto, relé cartolina

419 **performance standard**
Güteklasse
classe de qualité
classe di efficienza

420 **permanent magnet**
Dauermagnet
aimant permanent
magnete permanente

421 **permanent magnet attractive force**
dauermagnetische Anzugskraft
force d'attraction de l'aimant permanent
forza di attrazione del magnete permanente

422 **permeability**
Permeabilität, Induktionskonstante
perméabilité, constante d'induction
permeabilità

423 **permissible ambient temperature**
zulässige Umgebungstemperatur
température ambiante admissible
temperatura ambiente ammessa

424 **phase angle**
Phasenwinkel
angle de déphasage
angolo di fase

425 **phase sensitive relay**
Phasenwächter
relais de surveillance de phase
relé di fase

426 **phase shift**
Phasenverschiebung
déphasage
spostamento di fase

427 **photoelectric element**
Fotoelement
élément photoélectrique
fotoelemento

428 **photoelectric relay**
fotoelektrisches Relais
relais photoélectrique
relé fotoelettrico

429 **pick-up voltage**
Ansprechspannung, Anzugsspannung
tension de collage
tensione di attrazione

430 **piezoelectric effect**
Piezo-Effekt
effet piézoélectrique
effetto piezoelettrico

431 **pin**
Stift
broche
pin

432 **pin**
Anschluß
broche
attacco

433 **pivot**
Drehachse (mech.)
arbre de rotation
asse rotante

434 **pivot**
Zapfen
pivot
perno

435 **pivoted**
drehbar gelagert
tournant
rotante

436 **plug**
Steckanschluß
raccordement à fiche
attacco inseribile, attacco per c.s.

437 **plug connector**
Steckverbinder
connecteur à fiche
connettore

438 **plunger relay**
Tauchankerrelais
relais à armature plongeante
relé a nucleo mobile

439 **polarity inversion**
Wendebetrieb
inversion de polarité
inversione di polarità

440 **polarized relay**
gepoltes Relais, polarisiertes Relais
relais polarisé
relé polarizzato

441 **pole area**
Polfläche
surface polaire
superficie del polo

442 **pole piece**
Polblech
tôle polarisée
lamiera del polo

443 **pole shoe**
Polschuh
pièce polaire
scarpa polare

444 **pollutant**
Schadstoff
pollutant
materiale dannoso

445 **pollution**
Verunreinigung
pollution
contaminazione

446 **polymers**
Polymerisate
polymérides
polimeri

447 **potential barrier**
Potentialwall
barrière de potentiel
barriera di potenziale

448 **power**
Arbeit
travail
lavoro

449 **power source**
Spannungsquelle
source de tension
sorgente di tensione

450 **precious metal**
Edelmetall
métal précieux
metallo prezioso

451 **pre-contact**
Vorkontakt
pré-contact
precontatto

452 **pressure change**
Druckunterschiede
variation de pression
differenze di pressione

453 **pressure range**
Druckbereich
plage de pression
campo di pressione

454 **pressure reduction**
Druckabsenkung
chute de pression
riduzione della pressione

455 **pre-tension**
Vorspannung (mech.)
pré-contrainte
presollecitazione

456 **pre-tensioned**
vorgespannt
pré-contraint
pretensionato

457 **primary circuit**
Primär-Seite
circuit primaire
circuito primario

458 **processing unit**
Steuerorgan
organe de commande d'excitation
organo di pilotaggio

459 **protective gas**
Schutzgas
gaz protecteur
gas protettivo

460 **protective relay**
Schutzrelais
relais de protection
relé di protezione

461 **protective switch**
Schutzschalter
interrupteur de protectio
interruttore di protezione

462 **protective system**
Schutzart
type de protection
tipo di protezione

463 **pull-in bounces**
Einschaltprellungen
rebondissement au collage
rimbalzi all'inserzione

464 **pull-in delay**
Einschaltverzug, Ansprechverzögerung
retard au collage
ritardo all'inserzione

465 **pull-in power**
Ansprechleistung
puissance de collage
potenza di attrazione

466 **pull-in time**
Ansprechzeit, Anzugszeit
temps de collage
tempo di attrazione

467 **pull-in values**
Ansprechwerte
caractéristiques de collage
valori di attrazione

468 **pull-in voltage**
Ansprechspannung, Anzugsspannung
tension de collage
tensione di attrazione

469 **quality and life tester**
Prüfgerät für Qualität und Lebensdauer
dispositif de test de qualité et de durée de vie
tester per prove di qualità e durata

470 **quality test**
Qualitätsprüfung
contrôle de qualité
test di qualità

471 **quartz**
Quarz
quartz
quarzo

472 **radical**
Radikal
radical
radicale

473 **radio interference**
Funkstörung
parasites radio-électriques
interferenza radiofonica

474 **radio interference suppression**
Funkentstörung
anti-parasitage
schermatura contro radiointerferenze

475 **rail**
Schiene
rail
guida

476 **ratchet relay**
Fortschaltrelais
relais pas-à-pas
relé passo-passo

477 **ratchet relay**
Rastrelais
relais à cliquet
relé a rimanenza

478 **rated current**
Dauerstrom
courant permanent
corrente permanente

479 **ratio of pull-in to drop-out**
Halteverhältnis
rapport maintien coupure
rapporto di tenuta

480 **reactive power**
Blindleistung
puissance réactive
potenza apparente

481 **recovery time**
Erholzeit
temps de repos
tempo di ripristino

482 **reed**
Reedzunge
lame de relais reed
linguetta reed

483 **reed armature**
Zungenanker
armature à lame
ancora a linguetta (reed)

484 **reed relay**
Reedrelais
relais reed
relé reed

485 **reed resonance relay**
Zungenresonanz-Relais
relais reed à résonance
relé di risonanza reed

486 **relay diagram**
Relaisdiagramm
diagramme de relais
diagramma relé

487 **relay operating coil**
Erregerspule des Relais
bobine d'excitation du relais
bobina del relé

488 **relay specifications**
Relaisvorschriften
spécifications du relais
prescrizioni sui relé

489 **relay times**
Relaiszeiten
temps de relais
tempi del relé

490 **relay winding**
Erregerspule des Relais
bobine d'excitation du relais
bobina del relé

491 **release time**
Abfallzeit
temps de retombée
tempo di caduta

492 **reliability**
Zuverlässigkeit
fiabilité
affidabilità

493 **reliability characteristics**
Zuverlässigkeitsmerkmale
caractéristiques de fiabilité
caratteristiche di affidabilità

494 **reliability test methods**
Zuverlässigkeitsprüfmethode
méthode contrôle de fiabilité
metodo di misura dell'affidabilità

495 **remanence**
Remanenz
rémanence
rimanenza

496 **remanent relay**
Remanenzrelais
relais rémanent
relé a rimanenza

497 **reset spring**
Rückstellfeder
ressort de rappel
molla di ritorno

498 **reset time**
Rückfallzeit
temps de retour
tempo di caduta

499 **residual air gap**
Restluftspalt
entrefer résiduel
intraferro residuo

500 residual plate
Trennblech
tôle de séparation
lamiera di separazione

501 resolving power
Auflösungsvermögen
pouvoir de résolution
potenza di risoluzione

502 resonance frequency
Resonanzfrequenz
fréquence de résonance
frequenza di risonanza

503 resonance relay
Resonanzrelais
relais à résonance
relé a risonanza

504 resonant circuit
Schwingkreis
circuit oscillant
circuito di risonanza

505 rest position
Ruhelage
position de repos
posizione di riposo

506 reversal
Drehrichtungsumkehr
inversion du sens de rotation
inversione di rotazione

507 reverse current protection
Rückstromauslösung
disjoncteur anti-retour de courant
eccitazione con corrente inversa

508 reversing contactor
Wendeschütz
contacteur à inversion
teleinvertitore

509 ripple
Welligkeit
ondulation
ondulazione (ripple)

510 rotating armature
Drehanker
armature tournante
ancora rotante

511 safety electrical low voltage
Sicherheitskleinspannung
basse tension de sécurité
bassa tensione di sicurezza

512 safety grounding
Schutzerdung
prise de terre de protection
protezione di terra

513 saturation
Sättigung
saturation
saturazione

514 screw mounting
Schraubbefestigung
fixation à vis
fissaggio a vite

515 screw terminal
Schraubanschluß
raccordement à vis
attacco a vite

516 sealed
gekapselt
scellé
incapsulato

517 sealed relay
Becherrelais (l·b·h = 20.3·10.2·24.6 mm)
relais scellé
relé a capsula ermetica

518 selector switch
Wahlschalter
sélecteur
selettore

519 self-cleaning contacts
selbstreinigende Kontakte
contacts autonettoyants
contatti autopulenti

520 self-inductance
Selbstinduktivität
inductance propre
autoinduttanza

521 sensitivity
Empfindlichkeit
sensibilité
sensibilità

522 separator
Trennblech
tôle de séparation
lamiera di separazione

523 sequence
Spreizung
dispersion
ampiezza di scostamento, differenza di tempo fra la prima e l'ultima commutazione di un contatto plurilamellare

524 sequence action changeover contact
Folgewechselkontakt
inverseur séquentiel
contatto di scambio di seguenza

525 series voltage
Reihenspannung
tension en série
tensioni in serie

526 shielding
Abschirmung
blindage
schermatura

527 shock resistance
Schockfestigkeit
résistance aux chocs
resistenza agli urti

528 short-circuit
Kurzschluß
court-circuit
cortocircuito

529 short-circuit current
thermischer Grenzstrom
courant maxi-thermique
corrente limite termica

530 short-circuit ring
Kurzschlußring
bague de court-circuit
anello di cortocircuito

531 short-circuit withstand
Kurzschlußfestigkeit
résistance aux courts-circuits
resistenza al cortocircuito

532 signal relay
Melderelais
relais de signalisation
relé di segnalazione

533 silicate
Silikat
silicate
silicati

534 silicone
Silikon
silicone
silicone

535 single action system
Einfach-Sprungsystem
système à simple action
sistema a singolo scatto

536 single break
Einfachunterbrechung
coupure simple
semplice interruzione

537 skin effect
Hauteffekt
effet de peau
effetto pelle

538 snap action
Sprungvorgang
fonctionnement à déclic
scatto

539 snap action element
Sprungglied
déclic
elemento di scatto

540 snap action mounting
Schnappbefestigung
fixation à cliquet
fissaggio a scatto

541 snap action switch
Schnappschalter
commutateur à déclic
interruttore a scatto

542 snap in mounting
Schnellbefestigung
monture instantanée
fissaggio rapido

543 socket
Sockel, Steckfassung
socle, support
zoccolo

544 softening voltage
Entfestigungsspannung
tension de plastification
tensione di plastificazione

545 solder
Lötmittel
flux de soudage
stagno

546 solderability
Lötbarkeit
soudabilité
saldabilità

547 soldering
Löten
soudage
saldare a stagno

548 solenoid
Solenoid
solénoïde
solenoide

549 solid-state electronics
Halbleiterschaltungen
circuit à semi-conducteur
circuito a semiconduttori

550 spark suppression
Lichtbogenunterdrükkung, Funkenlöschung
suppression d'arc
soppressione dell'arco

551 specification
Lastenheft, Vorschrift
cahier des charges, spécification
specifica, prescrizione

552 specification dimension drawing
Maßbild
plan coté
disegno dimensionale

553 spring
Feder
ressort
molla

554 spring force
Federkraft
force élastique
forza elastica

555 spring load characteristic
Federkennlinie
courbe caractéristique du ressort
curva delle forze elastiche

556 spring thickness
Federstärke
épaisseur du ressort
spessore della molla

557 sprung
gefedert
suspendu
elastico

558 standards and definitions for electric relays
Normen und Bestimmungen für elektrische Relais
normes et spécifications pour relais électriques
norme e prescrizioni per relé elettrici

559 start-up time
Anlaufzeit
temps de démarrage
tempo di avviamento

560 station protective switch
Stationsschutzschalter
disjoncteur de protection de station
sezionatore stazionale

561 stationary contact
Festkontakt
contact fixe
contatto fisso

562 steatite
Steatit
stéatite
steatite

563 step-by-step switches
Schrittschaltwerke
sélecteur pas-à-pas
organo di passo passo

564 stepping relay
Fortschaltrelais
relais pas-à-pas
relé passo-passo

565 sticking
Kleben
coller
incollare

566 stop spring
Rastfeder
ressort cliquet
molla di bloccaggio

567 **storage relay**
Speicherrelais
relais de mémoire
relé di memoria

568 **storage temperature**
Lagertemperatur
température de stockage
temperatura di magazzino

569 **stud**
Zapfen
pivot
perno

570 **supply voltage**
Versorgungsspannung
tension d'alimentation
tensione di alimentazione

571 **supporting spring**
Stützfeder
ressort de suspension
molla di supporto

572 **switch**
Schalter
commutateur
interruttore

573 **to switch off**
ausschalten
couper
disinserire, aprire

574 **switch off arc**
Ausschaltlichtbogen
arc de coupure
arco di apertura

575 **switch off current**
Abschaltstrom
courant de coupure
corrente di disinserzione

576 **to switch on**
einschalten
coller
inserire

577 **to switch over**
umschalten
commuter
commutare

578 **switched state**
Schaltzustand
état de commutation
stato di commutazione

579 **switching behaviour**
Schaltverhalten
comportement en commutation
tipo di commutazione

580 **switching capacity**
Schaltvermögen
pouvoir de coupure
potenza di commutazione

581 **switching chamber**
Schaltkammer
chambre de commutation
camera di commutazione

582 **switching characteristics**
Schaltverhalten
comportement en commutation
tipo di commutazione

583 **switching current**
Schaltstrom
courant de commutation
corrente di commutazione

584 **switching current consumption**
Stromaufnahme während des Schaltens
courant consommé pendant la manoevre
assorbimento di corrente di commutazione

585 **switching cycle**
Schaltspiel
manoeuvre
ciclo

586 **switching device**
Schaltgerät
appareil de commutation
commutatore

587 **switching element**
Schaltglied
élément de commutation
organo di commutazione

588 **switching frequency**
Schaltfrequenz, Schalthäufigkeit
fréquence de commutation
frequenza di commutazione

589 **switching interval**
Umschaltzeit
temps de commutation
tempo di commutazione

590 **switching load**
Schaltlast
pouvoir de coupure
carico di commutazione

591 **switching operation**
Schaltvorgang
manoeuvre
operazione di commutazione

592 **switching over by clocked impulses**
getaktete Umschaltung
commutation cadencée
commutazione a impulsi

593 **switching point**
Schaltstelle
point de commutation
punto di commutazione

594 **switching pulse**
Schaltimpuls
impulsion de commutation
impulso di commutazione

595 **switching relay**
Schaltrelais
relais de commutation
relé di commutazione

596 **switching reliability**
Schaltungssicherheit
fiabilité de commutation
sicurezza di commutazione

597 **switching voltage**
Schaltspannung
tension de commutation
tensione di commutazione

598 **symmetrical windings**
symmetrische Wicklungen
enroulements symétriques
avvolgimenti simetrici

599 **synchronization**
Synchronisierung
synchronisation
sincronizzazione

600 **telegraph relay**
Telegrafenrelais
relais télégraphique
relé telegrafico

601 **temperature**
Temperatur
température
temperatura

602 **temperature gradient**
Temperaturgefälle
gradiant de température
caduta di temperatura

603 **temperature level**
Temperaturniveau
niveau de température
livello di temperatura

604 **temperature limitation**
Grenztemperaturbereich
plage de température limite
campo di temperatura limite

605 **temperature rise**
Erwärmung
échauffement
riscaldamento

606 **temperature scale**
Temperaturskala
echelle de température
scala di temperatura

607 **terminal**
Anschluß
broche
attacco

608 **test voltage**
Prüfspannung
tension de test
tensione di prova

609 **thermal balance**
thermisches Gleichgewicht
equilibre thermique
equilibrio termico

610 **thermal limiting current**
thermischer Grenzstrom
courant maxi-thermique
corrente limite termica

611 **thermal resistance**
thermischer Widerstand
résistance thermique
resistenza termica

612 **thermistor**
Heißleiter
thermistance
termistore

613 **thermo electromotive force**
Thermospannung
tension thermique
tensione termoelettrica

614 **thermo-electric relay**
Thermorelais
relais thermo-électrique, relais thermique
relé termico

615 **throw-over relay**
Kipprelais
relais basculant
relé basculante

616 **time constant**
Zeitkonstante
constante de temps
costante di tempo

617 **time of stay**
Verweilzeit
temps de maintien
tempo di attesa

618 **time-delay relay**
Zeitrelais
relais temporisé
relé a tempo

619 **toggle operation**
Schrittschaltverhalten
functionnement pas-à-pas
funzionamento passo passo

620 **toggle relay**
Stromstoßrelais
relais télérupteur
relé ad impulso di corrente

621 **torque**
Drehmoment
couple
coppia

622 **torr**
Torr
Torr
Torr

623 **total off time**
Gesamtausschaltzeit
temps total de coupure
tempo totale dell'interruzione

624 **total on time**
Gesamteinschaltzeit
temps total de collage
tempo totale dell'inserzione

625 **Townsend discharge**
Townsend-Entladung
décharge Townsend
scarica Townsend

626 **track**
Schiene
rail
guida

627 **transfer time**
Umschlagzeit
durée d'inversion
tempo di spostamento

628 **transformation ratio**
Übersetzungsverhältnis
rapport de transformation
rapporto di trasformazione

629 **transformer**
Transformator
transformateur
trasformatore

630 **transistor**
Transistor
transistor
transistor

631 **transistor relay**
Transistorrelais
relais à transistor
relé a transistor

632 **transit time**
Umschlagzeit
durée d'inversion
tempo di spostamento

633 **travel**
Betätigungsweg, Hub
course du contact
corsa dell'attuatore

634 **travelling time**
Hubzeit
temps d'attraction
tempo della corsa

635 trigger
Triggerung
déclenchement
trigger

636 tunnel effect
Tunneleffekt
effet tunnel
effetto tunnel

637 twin contact
Zwillingskontakt
contact jumelé
contatto gemello

638 two-step relay
Stufenrelais
relais à étape
relé passo passo

639 ultrasonic bath
Ultraschallbad
bain d'ultra-son
bagno ad ultrasuoni

640 ultra-sound
Ultraschall
ultra-son
ultrasuoni

641 ultra-violet radiation
UV-Strahlung
radiation ultra-violette
raggi ultravioletti

642 undercurrent release
Unterstromauslösung
déclenchement pour courant minimum
protezione di bassa corrente

643 undervoltage release
Unterspannungsauslösung
déclenchement à minimum de tension
protezione di bassa tensione

644 undervoltage tripping
Unterspannungsauslösung
déclenchement à minimum de tension
protezione di bassa tensione

645 universal relay
Allstromrelais
relais universel
relé universale

646 unprotected contacts
luftoffene Kontakte
contacts non protégés
contatti aperti in aria

647 vacuum relay
Vakuumrelais
relais à vide
relé di vuoto

648 varistor
Varistor
varistance
varistore

649 vibration resistance
Vibrationsfestigkeit
résistance aux vibrations
resistenza alle vibrazioni

650 virgin curve
jungfräuliche Kurve
courbe de première aimantation
curva vergine

651 voltage break capacity
Abschaltspannung
tension de coupure
tensione di disinserzione

652 voltage breakdown
Spannungsdurchschlag
perforation électrique
scarica di tensione

653 volume resistance
Durchgangswiderstand
résistance de passage
resistenza di passaggio

654 water glass
Wasserglas
verre soluble
vetro solubile

655 wear volume
Abbrandvolumen
volume d'usure
volume di logoramento

656 welding
Schweißen
soudage
saldatura

657 Wheatstone bridge
Wheatstonesche Brücke
pont de Wheatstone
ponte di Wheatstone

658 white noise
weißes Geräusch
bruit blanc
rumore bianco

659 wide-band capacitor
Breitbandkondensator
condensateur à large bande
condensatore a nastro largo

660 winding
Wicklung
enroulement
avvolgimento

661 wiping contact
Wischkontakt
contact bref
contatti autopulenti

662 wiping relay
Wischrelais
relais à contact bref
relé wiping, relé a contatti striscianti

663 wiring
Verdrahtung
câblage
cablaggio

664 work
Arbeit
travail
lavoro

665 yoke
Joch
carcasse
giogo

5.1 Alphabetical index: German

5.2 Alphabetical index: French

5.3 Alphabetical index: Italian

6 References

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7 Addresses of companies, the names of which appear in the relay tables

AMF Deutschland GmbH
Potter & Brumfield Div.
Postfach 5607, 6200 Wiesbaden 1, Tel. (06121) 718061, Tlx. 4186157

Aromat Corporation
250 Sheffield Street, Mountainside, N. J. 07092, USA,
Tel. (201) 232-4260, FAX (201) 232-1325 or (201) 232-5366

Bach GmbH + Co.
KACO-Elektrowerk
Postfach 2405, 7100 Heilbronn, Tel. (07131) 502-0, Tlx. 728631

Brown, Boveri & Cie AG
Postfach 101680, 6900 Heidelberg 1, Tel. (06221) 701-1, Tlx. 461827

C. P. Clare Elektronik GmbH
Postfach 1167, 6070 Langen, Tel. (06103) 23051, Tlx. 415000

Elfein GmbH
Wiener Straße 120, 6000 Frankfurt/Main 70, Tel. (069) 655061, Tlx. 414317

W. Günther GmbH
Postfach 820149, 8500 Nürnberg 82, Tel. (0911) 6552-0, Tlx. 622351

LRE Relais + Elektronik GmbH
Postfach 370266, 8000 München 37, Tel. (089) 52302-0, Tlx. 522190

Schaltbau Gesellschaft mbH
Postfach 801540, 8000 München 80, Tel. (089) 9251-0, Tlx. 523156

Schleicher GmbH & Co. Relais-Werke KG
Postfach 200253, 1000 Berlin 20, Tel. (030) 33005-1, Tlx. 182950

Schrack Schaltgeräte Vertriebs GmbH
Salzschlirfer Straße 21, 6000 Frankfurt/Main 61, Tel. (069) 41007-1, Tlx. 412076

SCHRACK ELEKTRONIC AG
Pottendorfer Straße 25–27, A-1121 Wien, Tel. (0222) 85010, Tlx. 131591
FAX (0222) 8501-4686

SDS-Relais AG
Fichtenstraße 3–5, 8024 Deisenhofen, Tel. (089) 6104-0, Tlx. 529253
FAX (089) 6104-59
from Oct. 1986: Tel. (089) 613004-0
FAX (089) 613004-59

Steinecker Elektronik GmbH
Postfach 1454, 6052 Mühlheim/Main, Tel. (06108) 2057, Tlx. 4185824

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To the reader of this technical guide.

In the not too distant past, many of the evolutionary developments discussed in this guide were considered to belong to the realms of Utopia. That they could be put into practice is due in large part to the efforts of the co-authors listed on page 12 and to the users of modern relays who showed great co-operation by testing the new products and by making valuable suggestions.

The importance of co-operation between manufacturer and user of modern relays becomes more obvious when it is noted that the near perfect 2nd generation relay technology is now already well established in the world-wide market place. Further, the new 3rd generation programmable IC-relays are proving to have been technically well conceived and are finding a rapidly increasing market acceptance. As a consequence the last 12 years can be considered as having seen a greater evolutionary development than did the previous 120 years.

As a result of user acceptance, new devices incorporating these developments have been produced, resulting in an enormous economic benefit to society as a whole. We ask that you continue to challenge us in future, so that your suggestions can be taken into account when the 3rd edition of this book is published and thus be of benefit to the rest of society.

Hans Sauer

Fichtenstraße 5
D-8024 Deisenhofen

Tel. (089) 6104-10
FAX (089) 6104-59
Tlx. 529253
from Oct. 1986:
Tel. (089) 613004-10
FAX (089) 613004-59