6. A small microprocessor-based relay can replace a whole set of standard electromechanical relays. In the first place, this applies to complex distance protections. Thus you can save expensive space occupied by cabinets with relay protection.

It is true that complex microprocessor relays occupy smaller areas of mounting by five to ten times less than a set of standard relays with similar functions. It is also true that boards with microprocessor-based protections occupy less space by several times than conventional ones, but the tricky question is: What part of space of the power station or substation can one actually save if one replaces electromechanical relays with microprocessor-based ones? One hundred thousandth? Or one millionth?

7. Microprocessor-based relays are more sensitive to emergency modes than electromechanical ones.

This is also absolutely true, as all the arguments considered above given by advocates of microprocessor-based relays. The question is whether such high sensitivity and accuracy are really required in relay protection of power units. For example, let us take microprocessor-based frequency relays picking up when frequency diverts by 0.005 Hz, and standard analog electronic relays with a pick-up accuracy of 0.01 to 0.05 Hz (for different models). The author wonders if anywhere in the world there is a power station or substation with frequency relays performing some operations in the power system at a frequency error of 0.005 Hz from the nominal value? In many cases, even sensitivity of standard electromechanical or analog electronic relays is excessive and one has to coarsen it artificially. Can relay protection of power units face the problem of low sensitivities of the relay?

8. Higher reliability of static microprocessor-based relays in comparison with electromagnetic relays containing elements moving mechanically.

At first sight it may really seem uncontestable that a static device without movable elements is much more reliable than a complex mechanism with numerous interacting elements, but only on the face of it. On closer examination it appears that things are not so simple.

First, the number of pick-ups (that is the movements of movable elements) of electromechanical protective relays is paltry in comparison with their service life. Referring to his personal experience, the author can say that he has come across such cases when relays with original (factory) defects have been exploited for more than 10 years. The fact that these defects have not been discovered for 10 years proves that during all this time the relay never picked up (and also that it is inadmissible to check relays so rarely!). Is it really worth speaking about mechanical wear in such cases?

Second, the number of elements from which a microprocessor-based relay is constructed is by hundreds and thousands times more than the number of elements from which an electromechanical relay is made. The reliability theory says that there is an inversely proportional dependence between the number of elements and the reliability of complex systems. As far as reliability of the elements is concerned, everything is also not as simple as that. In the electromechanical relay affected by external factors capable of causing damage, there are only coils of electromagnets and insulation of internal installation wires. These are very reliable and stable elements, but if it was a question of improving their reliability, the coils could be impregnated with epoxide resin in vacuum and internal wiring in Teflon insulation could have been used. In microprocessor-based relays, practically all electronic elements are affected by the supply voltage, and a part of them by input current or voltage. Some elements are constantly in the mode of generating signals. Some components (electrolytic capacitors, for example) wear considerably under constant exposure to working voltage. As far as integral circuits (IC — basic active elements of microprocessor-based relays) are concerned, they are the main cause of relay malfunctions (Figure 15.5 – Matsuda T., Kovayashi J., Itoh H., Tanigushi T., Seo K., Hatata M., Andow F. Experience with maintenance and improvement in reliability of microprocessor-based digital protection equipment for power transmission systems. Report 34–104. SIGRE Session, 30 August–5 September 1992, Paris). One of the major problems of complex electronic devices is aging of their components, bringing on changes in their parameters, during their lifetime. As a rule, the lifetime of such devices usually does not exceed 10 to 15 years. At about that time we begin to encounter various failures, malfunctions, and disturbances that are sometimes very difficult to locate in such complex devices (such as in the microprocessor relays, for example), and even if we do successfully diagnose a malfunction, it is not always possible to repair it (continuing with the above example, printed circuit boards on the surface mounting microelements for instance — standard technology for microprocessor relays). In such situation, it is possible to replace

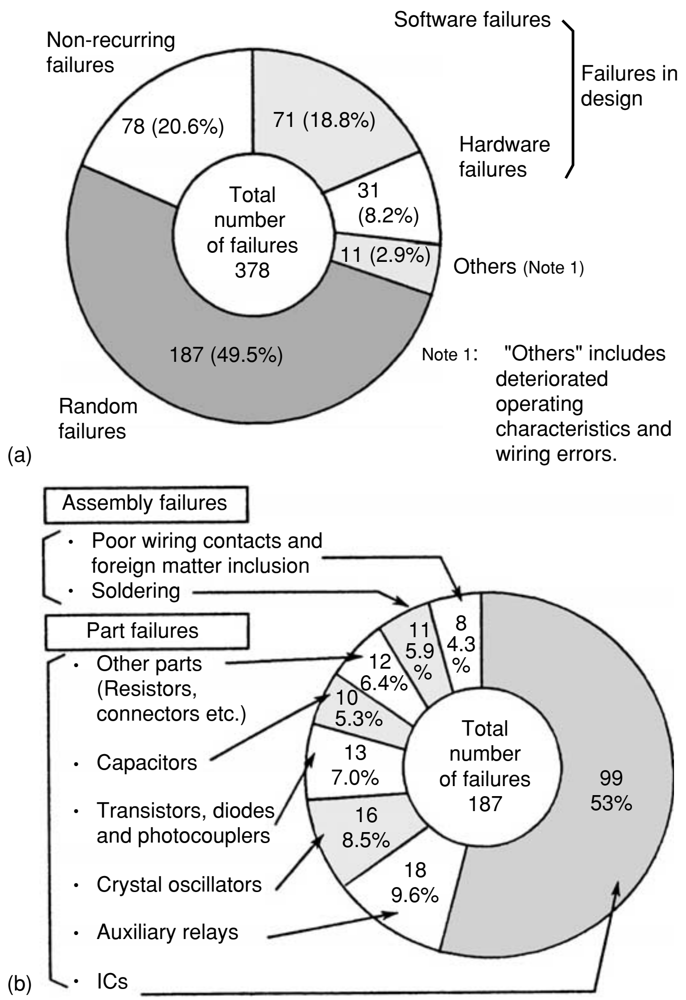


FIGURE 15.5
Statistics of malfunctions of 378 microprocessor-based relays produced by leading Japan companies. (Matsude T., Repart 34–104, SIGRE, Session 30).

damaged PCB only entirely, which cost sometimes makes a significant part of relay cost. With all due respect to our new and modern technologies, it should be noted here that previously far more ''simple'' electromechanical protection relays, some produced as many as 40 and 50 years ago from materials and according to technologies of that time, continue to work reliably today in many power systems (in Russia, for example).

Mass maintenance of microprocessor relays presents many problems, with their built-in switching power supply. Such power supplies recomplex devices (see Figure 15.6, for example) and with the addition heavy duty, continuous work, and exposure to spikes, harmonics, etc., they often fail.

Power supplies of microprocessor devices frequently create problems that designers did not foresee at all when developing these devices. The author experienced such a problem when a breakdown of one of the minor elements of a microprocessor device produced a short circuit of power supply. The microprocessor instantly gave a set of uncoordinated commands, which led to simultaneous disconnecting of all the power transformers of a large class 161 kV substation. Analysis of the reasons for this failure established that the short circuit of the power supply had come in the current limiting mode, as is necessary for high-grade power supplies. Current limitation is provided by fast decrease of output voltage level so that the output current does not exceed the maximal value allowed for the power supply. In the presence of large-capacity capacitors in the power supply, this voltage reduction occurred relatively slowly: during 0.5 to 1 sec. During this time the microprocessor, whose voltage supply had essentially been reduced, started to ''go around the bend'' and have sufficient lengthy time to give out complete commands, causing and leading to the serious failures.

FIGURE 15.6
Built-in switching power supply of a REL-316 type microprocessor relay (ABB), dimensions: 270×230 mm.

In order to prevent this, in our opinion, power supplies for microprocessor devices must be completed with so-called ''crowbar protection'' — a simple circuit (a thyristor, for example) which provides instantaneous short circuiting of the output of the power supply, whenever the emergency mode is enacted.

Protection functions of the important object (high-voltage line, power transformer, bus bar system, and generator on power plant) have been divided between five and six separate relays till an era of microprocessor devices. Failure of one relay yet did not lead to malfunction of all protection system completely. In one microprocessor device, functions of many relays are concentrated. For example, only the microprocessor device such as REG-216 carries out functions: differential protection, inverse-time overcurrent, negative phase-sequence, overvoltage, distance protection, underimpedance, overload, overtemperature, frequency, rate-of-change frequency, overexitation, etc. In such device failure of any common element, for example, the power supply, the microprocessor or its auxiliary elements leads to malfunction of protection system completely.

One of the serious problems which have been found out by the author that discrepancy between switching capabilities of subminiature electromagnetic relays (using as output elements in microprocessor protection devices [Figure 15.7]) and real conditions. Researches executed by the author have shown, that as output elements of the microprocessor protection devices produced by all leading companies are used subminiature electromagnetic relays which are not intended for switching inductive loading with currents about 2 to 5 A (coils trip of high-voltage circuit breakers or auxiliary lockout relay) at 125 and the more so 250 V DC. These subminiature relays work with a huge overload and can be damaged at any moment.

Internal constant monitoring of the condition of main units, even separate important elements of microprocessor protection device promoted by manufacturers as great progress in protection technique allowed the maximum protection reliability. Actually, the statement that internal self-diagnostics of microprocessor relays allows increasing reliability of relay protection is not correct. There is no connection between failure intensity of elements of microprocessor relays and the information on happened failures. The actual fact appears no more than an advertizing gimmick.

For example, in protection device MiCOM P437 constant monitoring serviceability of each of output electromagnetic relays (so anyway, the manufacturer asserts) is available. But who can explain, how (even only theoretically) it is possible to supervise serviceability

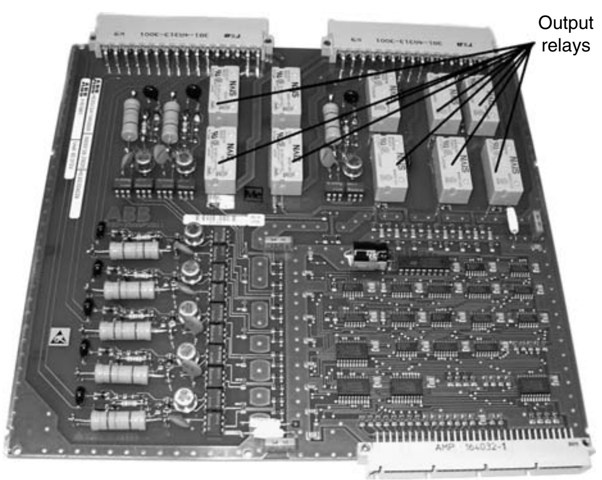


FIGURE 15.7
Input/output board of microprocessor protection device with subminiature electromagnetic relays as output elements.

(that is ability to close normally open contact when control current pass across the coil) or absence of the welding of normally closed contact of the relay without its pick-ups? As a more detailed consideration of this question, it appears that continuity of the coil is constantly only supervised (by passing through them weak pulses of a current which are not causing operations of the relay). What can happen with no energized coil? For what is such monitoring necessary?

That is why it is only natural that research performed by the Research and Development Division of the Israel Electric Corp. (Aspects of Digital Protective Relaying. RE-626, 1991) led to the following conclusion:

> Microprocessor relay reliability is lower than that of electromechanical and static relays: Microprocessor relay components tend to fail more often than those of conventional relays. This disadvantage is not compensated by a self-monitoring function, especially in unmanned substations. Maloperation or a failure to operate as a result of an internal relay failure may occur before the arrival of staff, after receiving an alarm signal.

The experience in this area of such a huge country as the former Soviet Union and present Russia is very interesting. More than 1.6 million relay protection and automation devices, mostly Russian made electromechanical relays (Electrical Devices Plant in Cheboksary), are installed in the Russian power supply system which is one of the oldest and biggest in the world. Of those, microprocessor protection systems constitute less than 1%. Even in the Moscow power system — one of the most advanced and well provided power systems — microprocessor devices amount to only 3,000 out of a total of 170,000 relay protection devices used there, which is at the most 2%.

Moreover, according to specialists' evaluations, about 80% of the relay protection devices in Russia have been operating for 20 years, and some relays even for over 50 years, while their service life should not exceed 15 years. It is worth mentioning that with all of this going on, the true response factor of this protection remains stable, and is over 99%! This fact suggests that Russian electromechanical protection relays are highly reliable and that even in the 21st century such protection can be successfully used in the world's largest power supply system. Such situation is characteristic not only for Russia, but also for other old power systems. In spite of the fact that microprocessor relays exist in the market any more for the first 10 years, rates of replacement of electromechanical or old static relays remain, on the average, very low. According to the publication of Basler Electric Co. (Johnson G., Thomson M. *Reliability Considerations of Multifunction Protection*), it will take about 70 years to replace all the predecessor relays with modern microprocessor.

Yet it is clear that the life-time of the major part of the protection relays has expired and they are called for replacement. Because of aging of bronze and brass subjected to permanent mechanical stress, and pealing of the insulation material of relay wires, they are only microns far from short circuit. At the same time, the opinion of many Russian specialists in the field of power engineering says that the total replacement of traditional Russian electromechanical relays by compatible digital parts made in Europe and U.S.A. will result in a drastic increase of emergency cases in power supply systems. Moreover, unlike their Western colleagues, the Russian manufacturers of low voltage equipment advance a sound belief in rational implementation of technical innovations in such specific fields as relay protection. They believe that in the next 3 to 5 years, all of the obsolete equipment should be replaced with traditional time-proved electric equipment, and only then should carefully planned installation of digital devices begin in power installations. This should be done selectively rather than totally, and moreover that the microprocessor relays be backed up with new generation electromechanical protection systems.

Leading manufacturers of microprocessor devices, such as ABB, Siemens, and Alstom have successively penetrated the Russian market, however, at the moment even they show certain caution, taking into account the scale of the Russian power system and the possible loss in case of a major crash. ABB, for example, purchased in Russia sets of microprocessor protection relays for its project at one of the biggest power stations in Kyrgyz, and then connected them in parallel with its own (Russian) electromechanical relays. A similar solution was used in some other objects, for example, at the Zubkovsky substation at the center of Moscow.

In spite of such very careful treatment of microprocessor protection devices in Russia and their very limited use, the rate of these device failures in the Russian power supply system still turned out to be twice as high as that of the traditional protection devices. (Based on material of the 15th Scientific and Technical Conference, ''Relay protection and automation of power supply systems''). The following data were brought up: Within 3 years, from 1999 to 2001, 100 out of 23,264 operations of relay protection devices at the Novosibirsk power system were false responses. Part of these false responses occurred with modern equipment that was only put into operation late. In another case, false responses of Siemens microprocessor devices at one of the thermal power stations of the Moscow power system ''Mosenergo'' resulted in disconnection of all of these protection systems, which remained unconnected for more than 2 years. At another substation of the same power system, microprocessor relays were damaged by a stroke of lightning. At a power station in Kostroma-microprocessor device failures were triggered by static voltage from synthetic carpets.

Taking into account that safe operation of the entire power supply system depends on the relay protection system, the above-mentioned cases are more than just unfortunate incidents. This is a problem that needs to be immediately addressed. Moreover, it is clear that as a result of such incidents which occurred within the last few years, the excitement about implementation of intellectual digital technology in Russia has declined. At present, 70% of the Russian low voltage industrial equipment market (which also includes relay protection devices) belongs to foreign companies. Because of serious accidents that occurred in the Western power supply systems, this fact does not inspire the Russian specialists: They ''do not want to repeat somebody else's mistakes,'' as mentioned in one of the publications.

These were some of the so-called ''advantages'' of microprocessor-based protective relays. Let us take a look at their disadvantages.

15.3 Disadvantages of Microprocessor-Based ''Relays''

1. Impact of electromagnetic disturbances from the power supply network on the operation of the relay.

Blackout

A blackout results in the total loss of utility power.

- Cause: Blackouts are caused by excessive demand on the power network, lightning storms, ice on power lines, car accidents, construction equipment, earthquakes, and other catastrophes.
- Effect: Current work in RAM or cache is lost. Total loss of data stored on ROM.

Noise

More technically referred to as electromagnetic interference (EMI) and radio frequency interference (RFI), electrical noise disrupts the smooth sine wave one expects from utility power.

- Cause: Electrical noise is caused by many factors and phenomena, including lightning, load switching, generators, radio transmitters, and industrial equipment. It may be intermittent or chronic.
- Effect: Noise introduces malfunctions and errors into executable programs and data files.

Sags

Also known as brownouts, sags are short-term decreases in voltage levels. This is the most common power problem, accounting for 87% of all power disturbances according to a study by Bell Labs.

- Cause: Sags are usually caused by the startup power demands of many electrical devices (including motors, compressors, elevators, and shop tools). Electric companies use sags to cope with extraordinary power demands. In a procedure known as rolling brownouts, the utility will systematically lower voltage levels in certain areas for hours or days at a time. Hot summer days, when air-conditioning requirements are at their peak, will often prompt rolling brownouts.
- Effect: A sag can starve a microprocessor of the power it needs to function, and can cause frozen keyboards and unexpected system crashes, which result both in lost or corrupted data. Sags also reduce the efficiency and life span of electrical equipment.

Spikes

Also referred to as an impulse, a spike is an instantaneous, dramatic increase in voltage. A spike can enter electronic equipment through AC, network, serial, or communication lines and damage or destroy components.

- Cause: Spikes are typically caused by a nearby lightning strike. Spikes can also occur when utility power comes back online after having been knocked out in a storm or as the result of a car accident.
- Effect: Catastrophic damage to hardware occurs. Data will be lost.

Surge

A surge is a short-term increase in voltage, typically lasting at least 1/120 of a second.

- Cause: Surges result from presence of high-powered electrical motors, such as air conditioners. When this equipment is switched off, the extra voltage is dissipated through the power line.
- Effect: Microprocessors and similar sensitive electronic devices are designed to receive power within a certain voltage range. Anything outside of expected peak and RMS (considered the average voltage) levels will stress delicate components and cause premature failure.

Many cases of malfunctions and even damages of microprocessors caused by spikes and surges are described in literature. For example, mass malfunctions of microprocessor-based time relays occurred in nuclear power plants in the U.S.A. (Information Notice No. 94–20: *Common-Cause Failures Due to Inadequate Design Control and Dedication*, Nuclear Regulatory Commission, March 17, 1994). A review of these events indicated that the microprocessor-based timer or relay failed as a result of voltage spikes that were generated by the auxiliary relay coil controlled by the timer or relay. The voltage spikes, also referred to as ''inductive kicks,'' were generated when the timer or relay time-delay contacts interrupted the current to the auxiliary relay coil. These spikes then arced across the timer or relay contacts. This arcing, in conjunction with the inductance and wiring capacitance generated fast electrical noise transients called ''arc showering'' EMI. The peak voltage noise transient changed as a function of the breakdown voltage of the contact gap, which changed as the contacts moved apart and/or bounced. These noise transients caused the microprocessor in the timer or relay to fail.

The organization of the supply system of relay protection is also very important. Power units are supplied by powerful accumulator batteries with a constantly connected charger, or by an uninterrupted power supply (UPS) cushioning the negative impact of the factors listed above, however, the same system supplies driving gears of power switches and many other devices, causing spikes. Besides, investigations of UPS systems (*The Power Protection Handbook* — APC, 1994) have shown that at certain conditions noise spikes and high harmonics can get into microprocessors through grounded circuits and neither UPS nor filters can prevent this. In addition, UPS devices have their own changeover times. Usually specifications for UPS indicate a switch delay time of 3 to 5 msec, but in fact under certain conditions this time may increase by a factor of more than 10. In a normal mode, the load in some types of UPS devices (''OFF-line'' types) is usually feed through a thyristor switch (bypass) which must become enabled when voltage diverts below 190 or above 240 V. After that the load is switched to the output of the inverter supplied from the accumulator battery. The time of disabling of the thyristor switch is summed up from the time of decrease of current flowing through the thyristor to the zero value t_0 and turn-OFF time t_q, after which the thyristor is capable of withstanding the voltage in the closed (OFF) position. For different types of thyristors $t_q = 30$ to 500 μsec, and t_0 depends on the proportion of induction and pure resistance of the circuit of the current flowing through the disabled thyristor (if the circuits break). As a result of switching OFF of the input circuit breaker or pulling out of the UPS supply cable from the terminal block $t_0 = 0$ to 5 msec, which will provide very high performance, however, at actual interruption of supply a break usually occurs in circuits of a higher voltage level, and not in the circuit for 120/220/380/400 V. The thyristor switch is then shorted to the second winding of the network transformer and the load connected to it. If the beginning of the supply interruption coincides with the conductivity interval of the thyristor, the duration of the process of current decaying may exceed 400 msec, and changeover to reserve power supply (inverter) may be delayed for inadmissibly long times. If the beginning of supply interruption coincides with the no-current interval, switching requirements are similar to those at input cable break. It follows that at interruptions of supply and voltage falls-through coinciding with the interval of current flowing, the working source will changeover to the reserve supply for inadmissibly long times (Dshochov B.D. Features of electrical power supply of means of computer networks. *Industrial Power Engineering*, 1996, N2, p. 17–24). The user who sets up and checks the UPS usually reaches conclusions about its serviceability by switching the input circuit breaker OFF. As shown above, this does not always correspond to conditions of actual transient processes (short circuiting of the input to the induction shunt), which creates the possibility that after installation and successful check of the UPS by switching OFF of input circuit breaker, some voltage falls-through (coinciding with intervals of current flowing) may lead to disabling (''suspension'') of the microprocessors. That is why in some types of UPS of the ''OFF-LINE'' category in order to provide high performance during change-over in the short-circuit mode, high-speed electromechanical relays instead of thyristor ones are used.

To determine the actual time of changeover of the UPS one should make an experiment imitating short circuits of the working source, to inductively active a shunt while a special measuring system records the transient processes. But who runs such experiments and where?

Thereupon, another aspect of the problem gains our attention: suspensions and malfunctions of the operation of the microprocessor of the UPS in emergency modes on high-voltage circuits. When the control microprocessor malfunctions, alternation of switching-ON and switching-OFF of power semiconductor elements of the inventor may be disturbed and short-circuit loop making, followed by automatic switching-OFF of the input circuit breaker of the UPS. This same phenomenon can happen to automatic chargers whose microprocessors are supplied from an external auxiliary UPS. Such incidents quite often occur in practice, but nobody yet has concerned himself with a serious analysis of the reasons. It is quite possible that the reasons for such emergency switching of UPS, and of the chargers, are similar to those for the case considered above.

2. Microprocessor-based relay protections, especially complex ones such as distance protections, do not always operate adequately in complex breakdowns or on boundaries of protection zones and cannot always trace transient processes correctly and in proper time. In practice, one often comes across breakdowns and malfunctioning of complex microprocessor-based protections in exploitation conditions. If the relay is tested on a standard laboratory test bench with standard signals at its inputs, it will operate precisely and reliably. The problem is that it is impossible to simulate all possible combinations and signal distortions that may take place in real situations on a test bench. It is also impossible to foresee all such situations when the relay is designed. This situation is similar to when a properly functioning powerful PC equipped with an undamaged powerful software shell (such as Windows®) suddenly buzzes at a certain instruction set, or if several programs run simultaneously. In most cases, it is impossible to foresee and prevent such situations. The working group of the U.S.A. and Canada has published the report on the reasons of well-known accident (August 14, 2003) in which it is ascertained, that one of the reasons of occurrence of computer ''suspension'' of control system and occurrence of emergencies in a power supply system of the company ''First Energy'' in U.S.A. In electromechanical relays, such situations are impossible. Therefore, many researchers insist that at the further wide introduction of digital techniques in protective relaying, it is necessary to provide additional independent (reserved) not digital protection relays for emergency modes.

3. A strange phenomenon exists whereby high-speed microprocessor-based protections respond to the emergency mode much more slowly than electromechanical ones. In one of the power systems, for reliability improvement microprocessor-based and electromechanical distance relays are switched in parallel. When emergency situations were analyzed, more than once it turned out that the electromechanical relay had picked up and tripped the circuit breaker before the microprocessor-based relay responded. This may be explained by the fact that unlike an electromechanical or analog electronic relay, the microprocessor-based relay operates with input values discretely. It ''picks'' current

values of input quantities and copies them into the buffer, then picks another set of input values in a certain time interval and compares them with those stored in the buffer. If the second set is identical to the first, the input values are directed to the microprocessor for processing. In general, for pick-up of an electromechanical or instantaneous electronic relay 10 to 15 msec are enough, while for a microprocessor-based relay 30 to 40 msec are required. Actually full operating time of microprocessor relay frequently reaches up to 50 to 80 msec for complex failures. So it often turns out that the superior performance of the microprocessor-based relay indicated in the advertisement of the producer is not provided in practice. In transient emergency modes, the microprocessor has to process great sets of information in a real-time mode, accompanied by quick and considerable changing of input signals. For this, it requires certain time (sometimes hundreds of milliseconds). Moreover, if after the starting of the microprocessor, the situation changes (for example, a single phase short circuit to the ground turned to the two-phase and then to the three-phase one), the starting process of calculation is interrupted and all calculations must be performed from the very beginning.

4. There are essential differences in operation of electromechanical and microprocessor-based relays caused by their different susceptibility to harmonics, saturation, and other wave distortions.

It is well known that at great ratios of short-circuit currents, current transformers considerably distort the curve of the output current applied to the relay. The problem of deterioration of accuracy is relevant for all types of relays, including electromechanical ones. Electromechanical relays produce torque that is proportional to the square of the flux produced by the current. These relays respond to the current squared or to the product of the currents produced by the input quantities. Since root-mean-square (rms) is defined as the average of the integral of the square of the current, these relays are said to be rms responsive. For most microprocessor relays, all quantities other than the fundamental component are noise. These relays used digital filters to extract only the fundamental, and either attenuate or eliminate harmonics (Zocholl S.E. and Benmouyal G. how microprocessor relays respond to harmonics, saturation, and other wave distortions. Meta world Schweitzer Engineering Laboratories, Inc., Summer 2003). The fast fourier transformation (FFT) is a very useful tool for analyzing the frequency content of stationary processes in microprocessor relays. Protection algorithms based on FFT have serious disadvantages including the neglecting of high-frequency harmonics, when dealing with nonstationary processes (magnetizing inrush and fault currents) for determining the frequency content. Furthermore, different windowing techniques should be applied to calculate the current and voltage phasors and this causes significant time delay for the protection relay. In this case, accuracy is not assured completely. For example, in cases of influence of inrush current on transformer differential relay with harmonic restraint, the relaying information is contained in the system fundamental and the harmonics only interfered. It is somewhat surprising that the digital filter will faithfully extract the fundamental from any waveform that is periodic at system frequency. The distance elements, in another example, did not operate because no voltage depression accompanied the high-current signal. However, sensitive settings caused the negative-sequence directional to identify a forward fault.

5. Considerable complication of exploitation of the protective relay: apparently, testing, and adjustment of microprocessor-based protections with the help of a computer (or even without it) require some new level of training of specialists and more time (what we mean here is that a technician or an engineer does not have to adjust the same relay every day, but they have to learn everything about it from the very beginning and to

gain an understanding of testing methods). It is enough to look through Instruction Manuals of these devices, which are almost as thick as this book, to realize this, and as far as trouble tracing and repair of such devices go, this is practically impossible during the exploitation. An article by John Horak (Basler Electric) ''Pitfalls and Benefits of Commissioning Numerical Relays,'' *Neta World, Summer 2003* tackles the problems arising during testing of microprocessor-based relays. The acceptance test is a step-by-step procedure published in the relay's instruction manual that checks that the relay's measuring elements, timing elements, status inputs, contact outputs, and logic processing system are functional, and that relay performance is within the manufacturer's intended specifications, using settings and logic defined by the manufacturer's test procedure. The test will include calibration checks involving secondary current and voltage injection. The relay is not field calibrated since, generally, only factory processes can calibrate numerical relays. In the process of working through these tests, one will learn a bit about the relay and will perform the value of showing that the relay is functioning correctly. The acceptance test does not make one completely knowledgeable of the relay, so some time should still be set aside for further investigation of the relay as the commissioning program proceeds.

Modern microprocessor-based systems (as line current differential protection, for example) are complex devices that include sophisticated protection algorithms and intense communications. As a result, performance testing of such complex systems may create a problem particularly because expensive and specialized equipment is required. Basic validation testing may be performed using phasors and test sets as far as the protection functions are considered; and a local loop-back procedure as far as the communications are considered. True performance testing requires either a real-time digital simulator or a playback system capable of driving several sets of three-phase currents and voltages (two- and three-terminal testing).

Testing the communication channels for high noise, bursts, channel asymmetry, channel delay, etc., is a field that does not belong to traditional relay testing. This requires new expertise and specialized test equipment. Due to the complexity of modern current differential relays, it is highly beneficial, if not crucial, to conduct performance tests involving both protection and communication functions particularly if difficult system conditions or poor communication channels are anticipated.

The increasingly large weight of the ''human factor'' in the operation of microprocessor relays created many more opportunities for additional mistakes, particularly during the programming and testing stages of the relay. Many interrelated functions and parameters controlled by one microprocessor-based relay lead to the necessity of artificial coarsening and even to entire disabling of some functions to test the other ones. After testing, one should not forget to input the previous settings of the relay. Such problems do not exist in electromechanical relays. In instruction manuals for many such relays, it is indicated that the settings of the relay may be changed during testing of the relay, which is why after that one should carefully check them.

In addition, the interfaces of many modern programs are often not too friendly, and the internal logic that works with them can sometimes warrant anguish! Many new programs (including from some very well-known companies!!) are simply ''raw'' and contain a lot of bugs. Who can know what will occur if even one bug starts to control relay protection?

6. Information redundancy. Many digital relays have too many variants of parameters for setting such which are not unequivocally necessary for relay functioning. Especially it concerns the devices with complex functions, such as distance protection with their one hundred set parameters. A function for 15 to 20 light-emitting diodes located on the

forward panel of the relay; a degree of brightness of the screen; color of a luminescence of the screen; color of the reports of information display; time of preservation of the data on the screen; and many other parameters with numerous variants which can be chosen from library of parameters. Frequently, these variants are superfluous. For example, in microprocessor protection device MiCOM P437, only the fuse supervision algorithm for voltage transformer can be chosen on four different variants! Such obvious redundancy leads to great number of settings, variants passes for the protection device with complex functions. It increases a error probability because of the ''the human factor.'' The problems pertinent to the human factor grow repeatedly if the same group of people should serve the relay of the different manufacturers having various programs with different interfaces, different principles of a parameter's choice, at times adjustments, even different names and designations of the same main parameters.

7. Possibility of intentional remote actions to break the normal operation of the microprocessor-based relay protection (Electromagnetic Weapons, Electromagnetic Terrorism). The theory behind the E-bomb was proposed in 1925 by physicist Arthur H. Compton not to build weapons, but to study atoms. Compton demonstrated that firing a stream of highly energetic photons into atoms that have a low atomic number causes them to eject a stream of electrons. Physics students know this phenomenon as the Compton Effect. It became a key tool in unlocking the secrets of the atom. Ironically, this nuclear research led to an unexpected demonstration of the power of the Compton Effect, and spawned a new type of weapon. In 1958, nuclear weapons designers ignited hydrogen bombs high over the Pacific ocean. The detonations created bursts of gamma rays that, upon striking the oxygen and nitrogen in the atmosphere, released a tsunami of electrons that spread for hundreds of miles. Street lights were blown out in Hawaii and radio navigation was disrupted for 18 h as far away as Australia. The United States set out to learn how to ''harden'' electronics against this electromagnetic pulse (EMP) and develop EMP weapons.

Now, intensive investigations in electromagnetic weapons field are being carried out in Russia, the U.S.A., England, Germany, and China. In the U.S.A. such research is carried out by the biggest companies of the military–industrial establishment, such as TWR, Raytheon, Lockheed Martin, Los Alamos National Laboratories, the Air Force Research Laboratory at Kirtland Air Force Base, New Mexico, and many civil organizations and universities.

In the 1990s, the U.S. Air Force Office of Scientific Research set up a 5-year Multidisciplinary University Research Initiative (MURI) program to explore microwave sources. One of those funded was the University of New Mexico's Schamiloglu, whose lab is located just a few kilometers down the road from where the Shiva Star sits behind tightly locked doors.

The German company ''Rheinmetall Weapons and Munitions'' has also been researching E-weapons for years and has test versions. The EMP shell was designed following revelations that Russia was well ahead of the West in the development of so-called radio-frequency (RF) weapons. A paper given at a conference in Bordeaux in 1994 made it clear that the Russians believed it possible to use such weapons to disable all of an enemy's electronic equipment. Written by Dr. A.B. Prishchipenko, Deputy Director of Scientific Center ''Sirius,'' member-correspondent of the Russian Academy of Military Sciences (Figure 15.8) and entitled ''Radio Frequency Weapons on the Future Battlefield,'' it described Soviet research dating back to the late forties, provoking near panic among western military planners (A.B. Prishchepenko, V.V. Kiseljov, and I.S. Kudimov, Radio frequency weapon at the future battlefield, Electromagnetic environment and conse-

FIGURE 15.8
Dr A. Prishchipenko, deputy director of Scientific Center ''Sirius,'' member-correspondent of the Russian Academy of Military Sciences.

quences, *Proceedings of the EUROEM94, Bordeaux, France, May 30–June 3*, 1994, part 1, pp. 266–271). It gave credence to the nightmare scenario of a high-technology war in which all the radio, radar, and computer systems on which their weapons depended would be disabled, leaving them completely defenseless. Then 2 years ago, it emerged that the Russians had developed an electromagnetic device, a so-called E-Bomb, capable of disabling electrical and electronic systems, which could be carried in a briefcase. Amid intelligence reports showing that the Irish IRA had discussed the possibility of paralyzing the city of London with an E-Bomb, British research in that technology was stepped up.

Today in Russia electromagnetic weapons are being developed by huge research and production institutions like the Scientific Association for High Temperatures (OIVT), consisting of the following Moscow organizations: the Institute of High Temperatures of Academy of Sciences, the Institute of Thermal Physics of Extremal States, the Institute of Theoretical and Applied Electrodynamics, the Research-and-Development Center of Thermal Physics of Impulse Excitations, and the proving ground in Bishkek, in addition the All-Russian Scientific Research Institute of Experimental Physics in Sarov (Arzamas-16) in the Nizhni Novgorod region, the All-Russian Scientific Research Institute of Technical Physics in Snezhinsk (Chelyabinsk-70). In spite of the economic crisis in Russia and a lack of money for many military programs, the government allocates money to these institutions. For example, recently in Moscow for the Scientific Association OIVT, a new building with an area of 1500 m^2 has been built.

Lately, many projects of past age have been declassified and are freely sold today. For example, the Institute of High-Current Electronics of the Russian Academy of Sciences in Tomsk (HCEI SB RAS) offers at free sale ultra-wideband high-power sources of directional electromagnetic radiation (Figure 15.9). As the technology of military RF weapons matures, such weaponry also becomes affordable and usable by criminals and terrorists. Both cheap low-tech and expensive high-tech weapons exist. High-power sources and other components to build EM weapons are available on the open market and proliferate around the globe (Figure 15.10).

One potential ingredient made available by the military is old radars, sold when facilities close down. Anything that operates between 200 MHz and 4 or 5 GHz seems to be a real problem. The reason they are for sale is that they are not very effective. Radar technology has improved drastically, but the radar does not need to be the newest technology to cause problems to electronic equipment and systems that are not prepared for an intentional EM threat. Intentional EMI includes both pulses and continuous-wave signals, in two basic forms. One is high-power microwave (HPM), a continuous-wave signal at a Gigahertz, like radar. The other is ultra-wideband, which is essentially a fast pulse produced by a radar using pulse techniques rather than a continuous wave. These threats can be packaged in a mobile van or even a suitcase. The effective ranges decrease with size, but even a suitcase-sized threat is widely available. According to Peter Cotterill, managing director of MPE Ltd (Liverpool, U.K.), an electromagnetic bomb in a

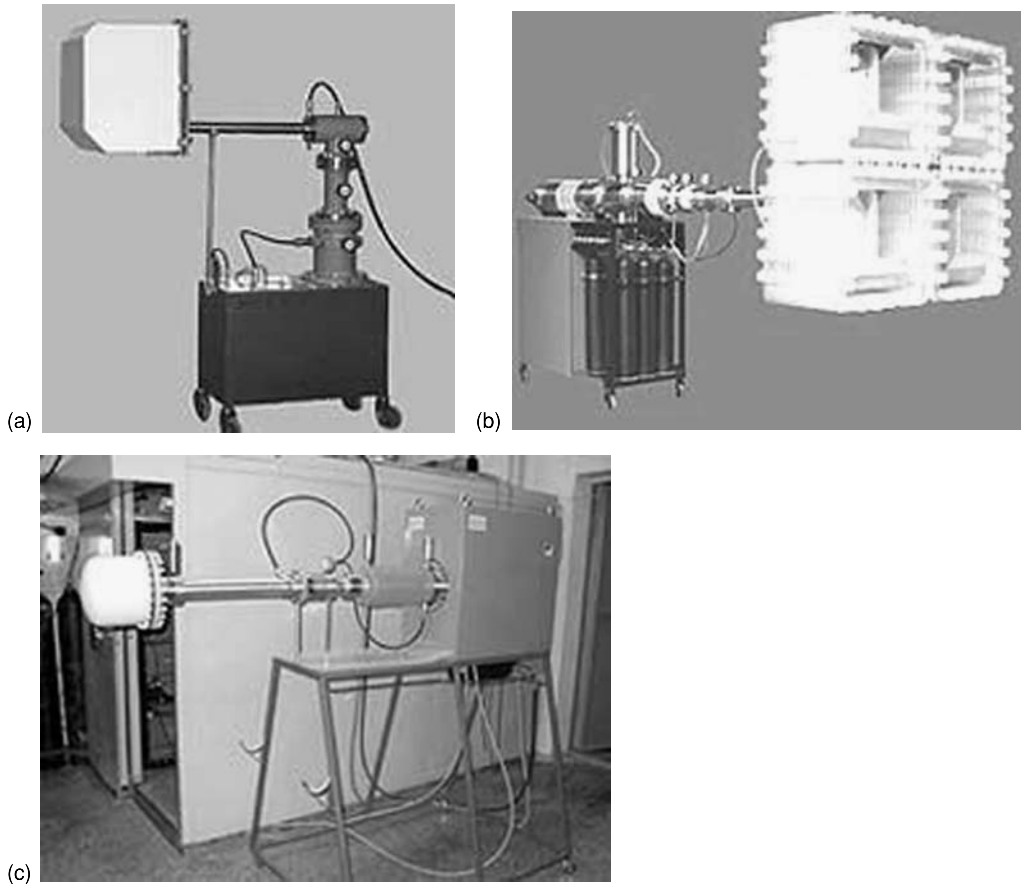


FIGURE 15.9
Compact ultra-wideband generators of directional pulse electromagnetic radiation with power output of 100 to 1000 MW (Institute of High-Current Electronics, Russia).

suitcase with a range possibly as high as 500 m can be purchased on the Internet at the cost of only $100,000. Terrorists could use a less expensive, low-tech approach to create the same destructive power. ''Any nation with even a 1940s technology base could make them,'' says Carlo Kopp, an Australian-based expert on high-tech warfare. The threat of E-bomb proliferation is very real. *Popular Mechanics* estimates a basic weapon could be built for $400.

Nowadays there are no measures preventing the distribution of electronic weapons. Even if agreements on limitation of distribution of electromagnetic weapons are reached, they will not be able to solve the problem of accessibility of required materials and equipment. One cannot rule out the possibility of leakage of electromagnetic weapons technology from countries of the former U.S.S.R. to third world countries, or to terrorist organizations, as the former really face great economic difficulties. The danger of distribution of electromagnetic weapons is quite real.

Today it is possible to find finished drawings and descriptions of generators of directional high-frequency radiation based on household microwave ovens on the Internet (see: www.powerlabs.org, www.voltsamps.com, etc).

Problems of ''electromagnetic terrorism'' capable of causing man-caused accidents on a national scale similar to that which happened in New York in August 2003, were formu-

(a)

(b)

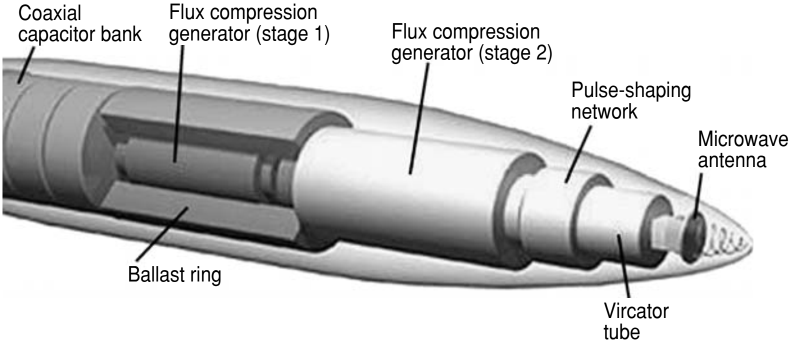


FIGURE 15.10
(a) Russian GPS-guided KAB-500S type electromagnetic bomb (right); (b) Typical construction of an E-bomb.

lated in an article by Manuel W. Wik (now chief engineer and strategic specialist on future defense science and technology programs at the Defence Materiel Administration, Stockholm) ''Electromagnetic terrorism — what are the risks? What can be done?,'' Published in 1997 in the *International Product Compliance Magazine*. Here is what that article says on the subject:

> Although electromagnetic terrorism is not often discussed in public, as it is potentially an extremely sensitive issue, there needs to be wider public awareness of the threats posed and a better understanding of the consequent risk-management strategies required. Nevertheless, with the gradual development of smaller equipment that can be used to produce short, intense EMPs capable of damaging the controls of much electronic equipment, electromagnetic terrorism is increasingly something that needs to be considered during the compliance-planning route. Thus, although it is important that neither the details of electromagnetic (EM) interaction with particular systems nor specific vulnerabilities should be made public, public awareness of the potential threats and, indeed, a better understanding of the relevant risk-management strategies need to be more widely disseminated. Electromagnetic terrorism (EM terrorism) is the international, malicious generation of electromagnetic energy, introducing noise or signals into electric and electronic systems, thus disrupting, confusing or damaging these systems for terrorist or criminal purposes. EM terrorism can be regarded as one type of offensive information warfare. EM terrorism needs to be considered more carefully in

> the future because information and information technology are increasingly important in everyday life.

Electronic components and circuits, such as microprocessors, are working at increasingly higher frequencies and lower voltages and thus are increasingly more susceptible to EMI. At the same time, there have been rapid advances in RF sources and antennae and there is an increasing variety of equipment capable of generating very short RF pulses that can disrupt sophisticated electronics. Intentional EMI poses a significant threat worldwide. Until recently, industry has been resistant to addressing the issue, but the International Electrotechnical Commission (IEC) is beginning to develop methods to fight criminal EMI.

The possibility of intentional EMI has come under the scrutiny of the United States Congress. Representative Jim Saxton of New Jersey and Representative Roscoe Bartlett of Maryland have held several investigations concerning this threat and have lobbied Congress for funds for appropriate research. As early as February 1998, Saxton began holding hearings on the proliferation and threat of RF weapons.

The issue of intentional EMI has also begun to be addressed at international conferences. The 1999 International Zurich Symposium on EMC held the first workshop on intentional EMI, with nearly 200 people in attendance. The 2001 Zurich Symposium was the culmination of several years of work in the field of intentional EMI. This symposium included the first refereed session on intentional EMI. The threat of intentional EMI is not limited to RF energy. Most of the emphasis in this area has been on RF fields but the issue of injecting directly into power and telecom systems has been overlooked. Yuri Parfenov and Vladimir Fortov, of the Russian Academy of Sciences Institute for High-Energy Densities, recently experimented with injection of disturbances into power lines outside a building and found that the signals penetrate very easily and at a high-enough voltage to cause damage to computers inside the building. Additionally, radiated fields often become a conducted threat due to coupling of RF energy to exposed wires.

It is astonishing that numerous research projects devoted to EM terrorism are concerned with the EMI impact on such objects as communication systems, telecommunications, air planes, computers, but there are practically no projects devoted to investigation of resistance of microprocessor-based relays to EMI, malfunctioning of which can lead to high consequences. However, it is obvious without any investigations that microprocessor-based relays are more prone to EMI impact than electromechanical and even analog electronic ones.

In addition, it turns out that ''electromagnetic terrorism'' is not the only form of modern remote terrorism to which microprocessor-based relays are prone. There are also electronic intrusions called cyber-attacks. A cyber intrusion is a form of electronic intrusion where the attacker uses a computer to invade electronic assets to which he or she does not have authorized access. The IEEE defines electronic intrusions as:

> Entry into the substation via telephone lines or other electronic-based media for the manipulation or disturbance of electronic devices. These devices include digital relays, fault recorders, equipment diagnostic packages, automation equipment, computers, PLCs, and communication interfaces.

A cyber-attack can be an intrusion as described above, or a denial of service attack (DOS) where the attacker floods the victim with nuisance requests and/or messages to the extent that normal services and functions cannot be maintained. A DOS attack is also called a flood attack. A distributed DOS attack (D-DOS) is a flood attack launched simultaneously from multiple sites.

Tools for attacking computer-based control equipment by telephone and network connection are free and widely available over the Internet. There are literally dozens of Websites devoted to hacking, usually providing downloadable programs or scripts to help the novice hacker get started.

Nowadays hackers' attacks are becoming terrorist weapons. Real cases of terrorist attacks of this kind are usually kept secret, but some are already known. For example, an attempt to damage the Israeli power system with the help of a hacker's attack was prepared by the ''Special Services'' of Iran for several months in 2003. Fortunately, the security service of the Israel Electric Corp. managed to block these attacks. As attacks of this kind to the main national computer systems of Israel have become more frequent, within Israeli Counter-Intelligence and Internal Security Service (SHABAK) there is a special subdivision for counteraction to such attacks.

But this problem is not only actual for Israel. The North American electric power network is vulnerable to electronic intrusions (a.k.a. cyber-attacks) launched from anywhere in the world, according to studies by the White House, FBI, IEEE, North American Electric Reliability Council (NERC), National Security Telecommunications Advisory Committee (NSTAC) KEMA, Sandia National Laboratories. At the heart of this vulnerability is the capability for remote access to control and protection equipment used by generation facilities and Transmission and Distribution (T&D) utilities. Remote access to protective equipment historically has been limited to proprietary systems and dedicated network connections. Now, however, there is an increased use of public telephone services, protocols, and network facilities, concurrent with a growing, more sophisticated, worldwide population of computer users and computer hackers which is why special services of many countries had to create special subdivisions to fight this dangerous phenomenon. In Russia, in particular, it is the Federal Agency of Governmental Communication and Information (FACI) and ''Atlas'' Scientific-Technical Center of Federal Security Service (FSB) that tackles these problems.

Is there a solution for this situation?

Probably yes, if:

- We completely replace all electric wires connected to microprocessor relays, including current and voltage circuits, with nonconductive fiber-optical wires.
- Use opto-electronic CT and VT, instead of traditional instrument transformers.
- Provide full galvanic separation from the power electric network by using a power supply of microprocessor relays to carry through the unit ''motor generator.''
- The relay should be placed in a completely closed metal case made with a special technology, used for ultrahigh frequencies in which there are no other kinds of the electric equipment.

This is the price necessary to pay for progress in the field of relay protection.

15.4 Summing Up

Some conclusions in brief:

1. Did microprocessor-based relays introduce any new functions for relay protection that were unknown before or impossible to implement with the help of traditional relays? On closer examination, it appears that the answer is NO.

Microprocessor-based relays only combined features of some relays adding some functions that used to be carried out by registration devices.

2. Do microprocessor-based relays provide a higher level of reliability of power supply? NO!
3. Did microprocessor-based relays make the work of the maintenance staff simpler? Obviously NO!
4. Do microprocessor-based relays have any uncontestable advantages? Again the answer would appear to be NO! Microprocessor relays have appeared as a result of developments in microcontrollers and not in order to improve conventional (static or electromechanical) relays. The behavior of conventional relays in operation continues to be excellent. Why do we need to make our life more complicated by using microprocessor-based relays, which on the one hand have no essential advantages in comparison with traditional ones, and on the other hand have many of their own unsolved problems?

It turns out that there is an important reason to use microprocessor-based relays, however it does not lie in the power industry field, but in the field of relay production (Schleithoff F.S. *Statischer Schutz im Mittelspannungsnetz*, ''Elektrizitatswirtschaft,'' 1986, 85, No. 4, pp. 121–124). It appears that it is much more profitable to produce microprocessor-based relays than electromechanical or even analog electronic ones. This is explained by the possibility of complete automation of all technological processes and production and control of parameters of microprocessor-based relays. The following question is to the point here: Where do problems of producers concern development of correct technical politics in the power industry field? In fact, the largest international concerns, such as ABB, General Electric, Siemens, Alstom have become ''trendsetters'' in the power industry and now determine main tracks of development not only of relay protection, but also of the whole power industry. If in some years these companies stop producing all other types of relays except for microprocessor-based ones (and this is the main tendency today), this fact will not justify uncontestable advantages of such relays from the point of view of interests of power suppliers and of the whole society.

5. The transition to microprocessor relays (if inevitable!) should be complete, that is excluding teamwork with electromechanical relays, such transition should be carried out together with the replacement of traditional instrument transformers to optical, and full replacement of all electric wires connected to the relay to isolated optical wires. Microprocessor relays should be mounted in closed metal cases made with use of high-frequency technology. Relay power supplies should be carried out through the unit's ''motor generator.''

To neglect these requirements could lead to serious problems in the electric power industry in the near future. So we can see that indeed there are many new problems still not known in world of electromechanical relays.

16

Special Relays

16.1 Polarized Relays

A polarized relay is a sort of direct current (DC) electromagnetic relay with an additional source of a permanent magnetic field affecting the relay armature. This additional source of the magnetic field (called ''polarizing'') is usually made in the form of a permanent magnet.

Polarized relays have been known since the time of the first sounders (Figure 16.1). Peculiarities of polarized relays are, first, polarity of the winding switching and, second, very high sensitivity. The latter can be explained by the fact that the permanent magnet creates a considerable part of the magnetic flux required for the relay pick up, which is why the relay winding causes only a small additional magnetic flux, which is much less than in standard relays. Some types of polarized relays *can pick up from a signal of a few millionths Watts.*

The magnetic circuit of the polarized relay is, of course, more complex than the magnetic circuit of a standard electromagnetic relay (Figure 16.2), and such a relay is also more expensive than a standard one.

The magnetic flux (ϕ_m) of the permanent magnet passes through the armature of the relay branches into two parts: the flux (ϕ_1) passes through the left working gap and the flux (ϕ_2) passes through the right working gap. If these are the only magnetic fluxes (and there is no current in the coil), the armature of the relay will be to the left or to the right of the neutral position, since a neutral position is not stable in such a magnetic system.

When current appears in the windings w_1 and w_2, an additional magneto-motive force and the working magnetic flux (ϕ) both pass through the working gap. The force affecting the armature depends on:

- The current value in the winding
- The power of the magnet
- The initial position of the armature
- The polarity of the current in the winding
- The value of the working gap

At certain combinations of these parameters the armature of the relay turns to a new stable state, closes the right contact and the relay picks up.

There are several types of magnetic systems of polarized relays. The two most popular today are the *differential* and *bridge* types (Figure 16.3). In a relay with a differential magnetic system, the magnetic flux of the permanent magnet passing through the

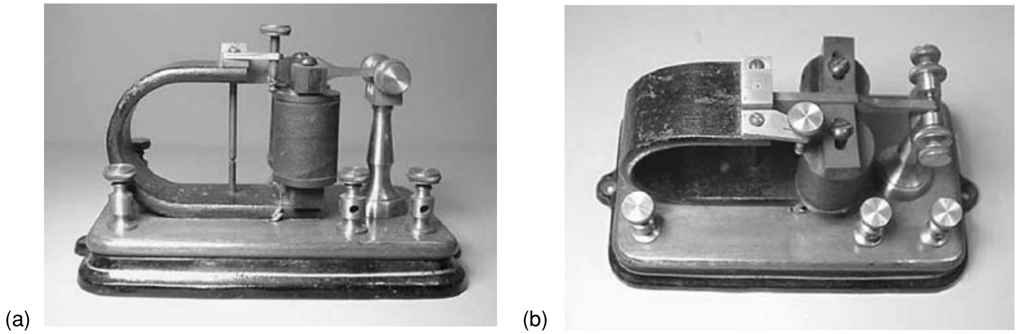


FIGURE 16.1
An ancient polarized relay of high sensitivity with a horseshoe-shaped permanent magnet (year approximately 1900).

armature of the relay is divided into two fluxes in such a way that in the left and in the right part of the working gap these magnetic fluxes are directed to opposite sides, that is the armature is affected by the difference of these two fluxes.

In the bridge magnetic system, the magnetic flux of the permanent magnet is not divided into two fluxes in the area of the working gap and the armature, but has only one direction. The field created by the coil is divided into two fluxes, which have opposite signs in the working gap area.

The first type of this magnetic system was widely used in polarized relays of normal size (Figure 16.4).

A later and modernized construction of this relay, produced in the 1970–80's, is shown in Figure 16.5.

There were also a lot of relays with bridge magnetic systems (Figure 16.6). One can affect the relay by adjusting the initial position of the armature of the polarized relay. The polarized relay is usually adjusted by screws with which one changes the position of the stationary contacts (Figure 16.7), and therefore the armature.

At neutral adjustment of the relay, when there is no current in the winding, the armature (together with the movable contact) remains in the position it has taken at pick up of the relay, that is in the right or left position. To switch to initial position one

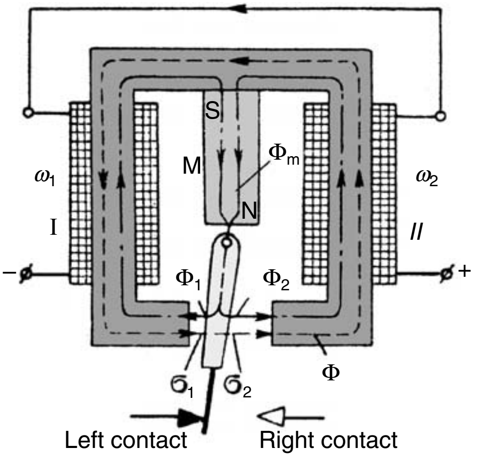


FIGURE 16.2
Simplified magnetic circuit of a polarized relay. M — Permanent magnet; ϕ_m — polarizing magnetic flux of the permanent magnet; ϕ_1 — magnetic flux of the left gap σ_1 between the armature and the magnetic core; ϕ_2 — magnetic flux of the right gap σ_2.

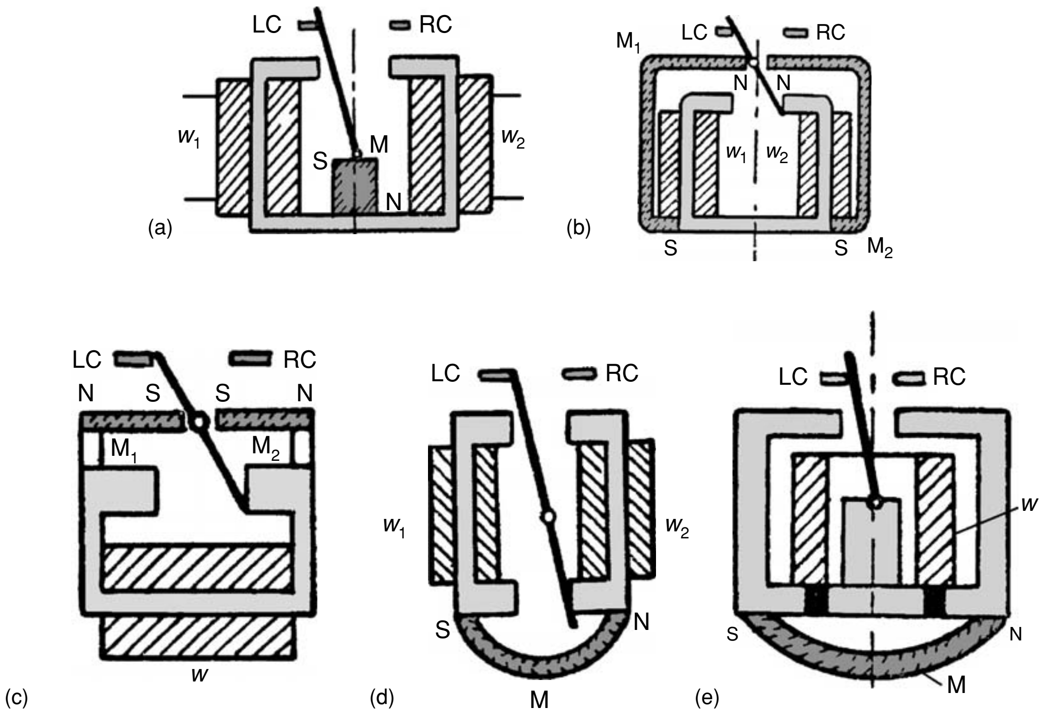


FIGURE 16.3
Schemes of the magnetic circuit of a so-called "differential" (a, b, c) and "bridge" (d, e) type. *w* — Coil; M — permanent magnet; LC — left stationary contact; RC — right stationary contact.

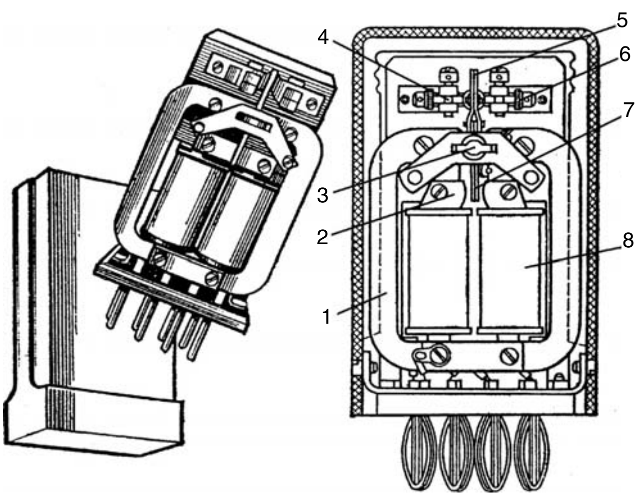


FIGURE 16.4
A polarized relay of the RP series with a differential magnetic system (corresponding to Figure 16.3b), produced in Russia in the 1950s. 1 — One of the two permanent magnets; 2 — pole of the core; 3 — rotation axis of the armature; 4 and 6 — adjusting screws of stationary contacts; 5 — movable contact fixed on the armature; 7 — armature; 8 — coils.

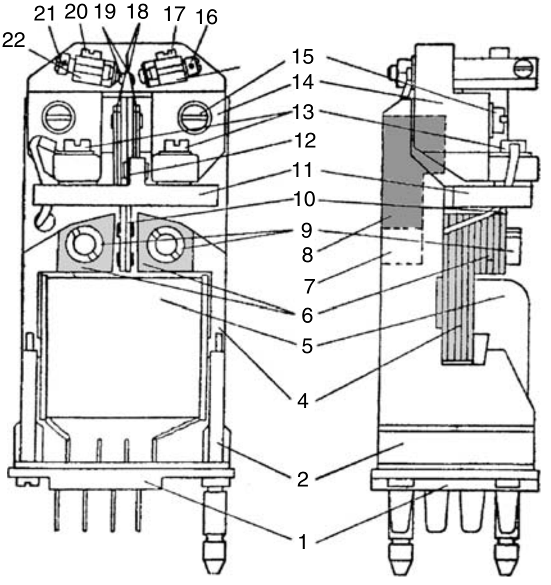


FIGURE 16.5
Construction of a polarized relay of the RP series, produced in 1970–80's (Russia). 1 — Heel piece with outlets of the relay; 2 — case from silumin (aluminum alloy); 4 — magnetic core; 5 — coil; 6 — pole lugs; 7 — steel insert; 8 — permanent magnet; 9 — fastening screws; 10 — armature; 11 — cramp; 12 — plat spring; 13 and 15 — fastening screws; 14 — ceramic board; 16 and 21 — screws adjusting the position of stationary contacts; 17 and 20 — lock screws; 18 — springs of the movable contact; 19 — movable contact.

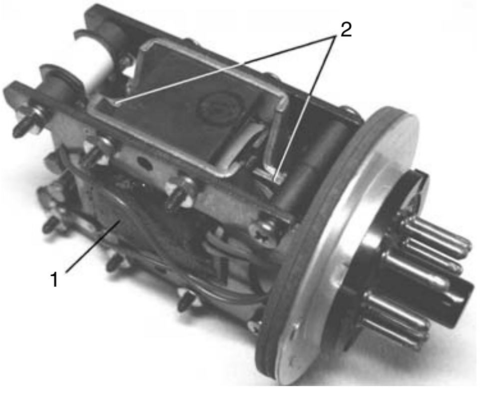


FIGURE 16.6
A relay with an aluminum case (off) produced by Sigma (1960–70's). The magnetic system is of the bridge type (Figure 13.3d). Size: 51 mm in diameter, the full length is 82 mm. 1 — Coil; 2 — armature.

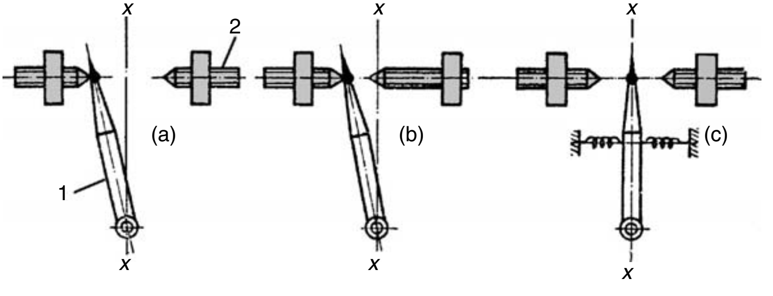


FIGURE 16.7
Types of adjustment of initial position of the armature of the polarized relay: (a) Neutral; (b) with predominance; (c) three-position. 1 — Armature with a movable contact at the end; 2 — adjusting screw with a stationary contact at the end.

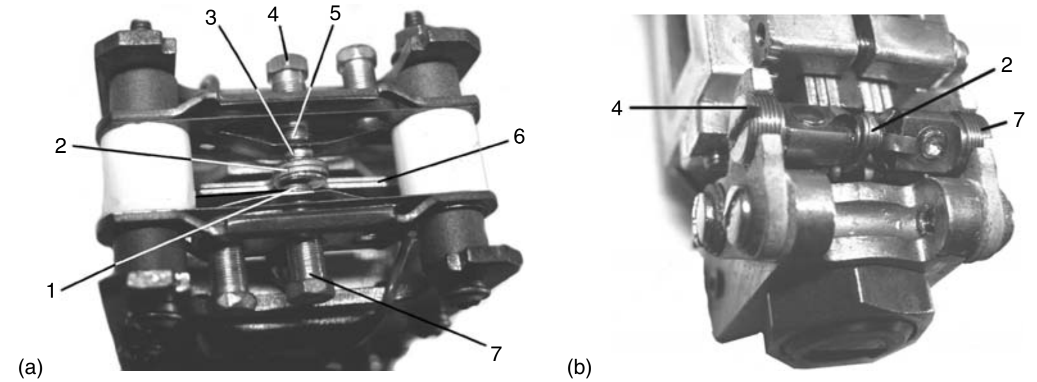


FIGURE 16.8
Construction of adjusting unit (enlarged) of different types of polarized relays, produced by Sigma (1960–70's, U.S.A.). 1 and 3 — Stationary contacts; 2 — movable contact placed on the end of the armature; 4 and 7 — adjusting screws for adjustment of initial position of stationary contacts and the armature; 6 — armature.

must apply voltage of the opposite polarity to the winding (if there is only one winding), or to the second winding (if there is one).

In this modification, there is no need for a restorable spring which also increases sensitivity of the relay. If self-reset of the relay to the initial position is required after the winding supply has been switched OFF, one uses adjustment with predominance to one of the poles by twisting in one of the adjusting screws, shifting the proper stationary contact outside the neutral line (Figure 16.7b).

In relays with three-position adjustment, the armature in the currentless state is retained in the intermediate position between the contacts (the first position) with the help of a spring (Figure 16.7c). When current flows in the winding, the relay switches to the left (the second position) or to the right (the third position), depending on the polarity of the voltage in the winding.

Such principle of adjustment of polarized relays is used by practically all producers of such relays (Figure 16.8). As it can be seen from Figure 16.8, in relays produced by Sigma contacts of the hard type have been used. This is the simplest, but not the only variant of contacts of polarized relays. In such relays they often use contacts of special types (Figure 16.9).

The main purpose for construction of these contacts is suppressing shock of movable contacts to stationary ones, due to the fact that kinetic energy is used for friction of flexible springs. This may be friction of spring ends (a) or of the additional spring covered by

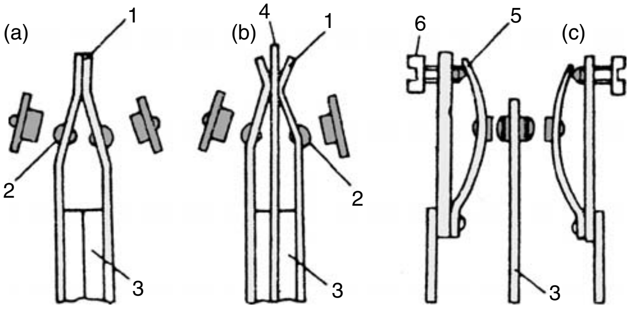


FIGURE 16.9
Contacts of special type, which are frequently used in polarized relays. (a) Flexible movable contact consisting of two springs and rigid stationary contacts; (b) flexible movable contact consisting of three springs and rigid stationary contacts; (c) rigid movable contact and flexible stationary contacts. 1 — Movable contact springs; 2 — contact straps; 3 — the end of the armature; 4 — additional auxiliary spring; 5 — stationary contact springs; 6 — supporting screws.

special material (b) or friction of the spring ends by stationary supporting screws (c) with the help of which the contact system can be adjusted to the moment until the bounce disappears fully.

16.2 Latching Relays

A latching relay is one that picks up under the effect of a single current pulse in the winding, and remains in this state when the pulse stops affecting it, that is when it is locked. Therefore this relay plays the role of a memory circuit. Moreover, a latching relay helps to reduce power dissipation in the application circuit because the coil does not need to be energized all the time (Figure 16.10).

As illustrated in Figure 16.10, the contacts of a latching relay remain in the operating state even after an input to the coil (set coil) has been removed. Therefore this relay plays the role of a memory circuit. As shown in Figure 16.10, the double-coil latch type relay has two separate coils each of which operates (sets) and releases (resets) the contacts.

In latch relays, two types of latching elements are usually used: magnetic and mechanical. A relay with magnetic latching elements is a polarized relay with neutral adjustment (see above). Unlike polarized relays, latching relays are not designed to be used as highly sensitive ones. Sometimes it is impossible to distinguish between a polarized relay and a latching relay, so all relays with a permanent magnet are just called ''polarized relays.''

Perhaps this is not correct, since the main quality of the polarized relays considered above is their high sensitivity. This determines the field of application of such relays. As far as latching relays are concerned, they do not possess extraordinarily high sensitivity (we cannot really speak about high sensitivity meaning the latching contactor capable of

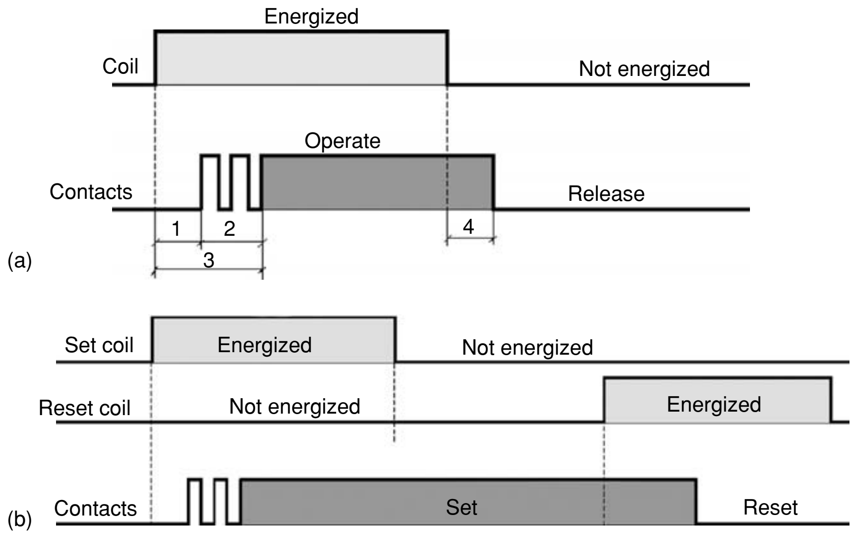


FIGURE 16.10
(a) Time chart of nonlatch relay. 1 — Current-rise time; 2 — bounce time; 3 — full operate time; 4 — release time. (b) Time chart of double coil latch relay.

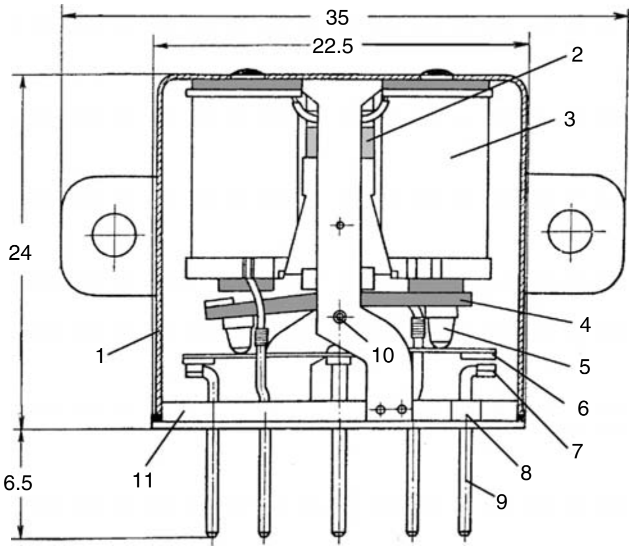


FIGURE 16.11
Construction of a miniature latch relay with magnetic latching of the RPS20 type (Russia). 1 — Hermetic brass case; 2 – permanent magnet; 3 — coil; 4 — flat symmetrical armature; 5 — pushers; 6 — movable contact; 7 — stationary contact; 8 — glass bushing; 9 — output prongs; 10 — rotation axis of the armature; 11 — heel piece.

switching currents of hundreds of Amperes). They are designed to be used when switching circuits affected by single pulse control signals and increased resistance to shocks and vibrations, preventing permanent consumption of energy from the power source, as elements of memory, etc.

In addition, the principle of their operation does not imply only *magnetic latching* of the position, and rules out a considerable part of such relays from the class of polarized relays. Like standard electromagnetic relays, latching relays are produced for all voltage and switched power classes: from miniature relays for electronics, with contact systems and cases typical of standard relays of the same class according to switched power (Figure 16.11 and Figure 16.12), up to high-voltage relays and high-current contactors.

Magnetic systems of latching relays, as mentioned above, are not distinguished by high sensitivity and are constructed in such a way in order to simplify and to minimize the relay (Figure 16.12). Practically, all western companies producing relays also design and produce latching relays (Figure 16.13).

Lately the famous Russian company ''Severnaya Zaria'' has also taken up designing miniature latching relays. Two types of such relays constructed by this company are shown in Figure 16.14. The RPK61 type relay is a double-coil low-profile relay whose dimensions are $19 \times 19 \times 12$ mm. The RPK65 is a single-coil (with changeable polarity) latching relay whose dimensions are $9.53 \times 9.53 \times 6.99$ mm.

The smallest latching relays in the world in standard metal cases of low-power transistors, are produced by the American company Teledyne Relays (Figure 16.15). Latching relays produced by Omron, Deltrol, and some other companies, have similar construction and external design. In these relays another scheme of magnetic circuit with a rocking armature of the clapper type (Figure 16.16) is used. It is frequently applied not only in micro-miniature relays, but also in large-sized relays designed for industrial purposes and for the power industry (Figure 16.17 and Figure 16.18).

Manufacturers have noted that these relays typically have high vibration and shock resistance. The large-sized latching relay produced by ASEA designed for application in power industry is based on a similar principle (Figure 16.18). Recently high power latching relays have become very popular and are produced in great numbers by many companies (Figure 16.19).

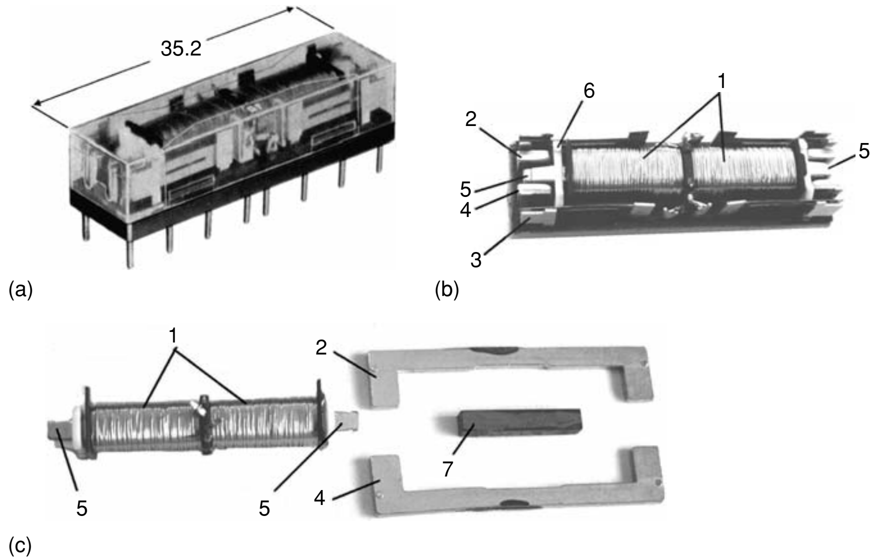


FIGURE 16.12
Construction of a miniature latch relay with a magnetic latching of the DS4 type, produced by Euro-Matsushita. 1 — Set and reset coils; 2 and 4 — plates of the magnetic core; 3 — contacts; 5 — ferromagnetic pole lugs; 6 — plastic pushers put on the pole lugs; 7 — permanent magnet placed in the centre of the coil.

So-called *throw-over relays* are considered to be a variant of latching relays (Figure 16.20). These relays have a scheme unusual for latching relays, of a magnetic circuit with a permanent magnet, but unlike the constructions considered above, they do not require pulse control signals from the control circuits. Current pulses for switching ON and OFF of the relay are formed by the relay itself due to the fact that its coil is supplied through

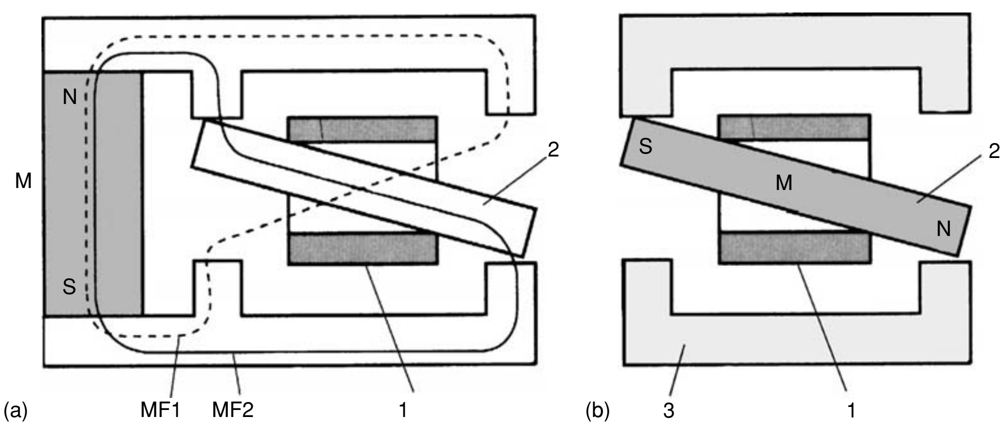


FIGURE 16.13
Popular types of the magnetic system of cheap miniature latching relays, in plastic cases produced by many companies. M — Permanent magnet; MF1 — magnetic flux in first position; MF2 — magnetic flux in second position; 1 — coil; 2 — rotating armature; 3 — yoke.

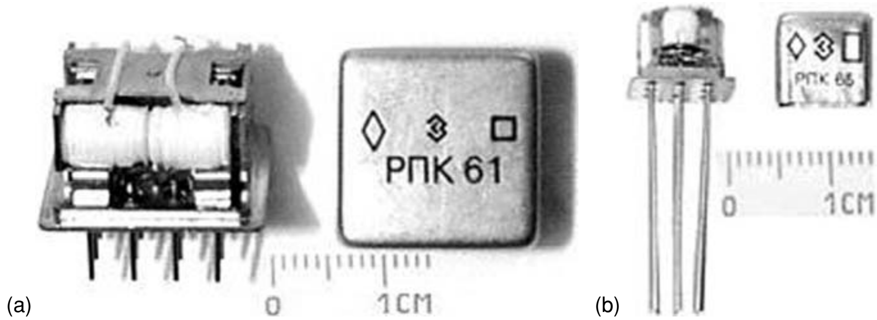


FIGURE 16.14
Miniature RPK61 type (a) and micro-miniature RPK65 type (b) latching relays, produced by the Russian company "Severnaya Zaria."

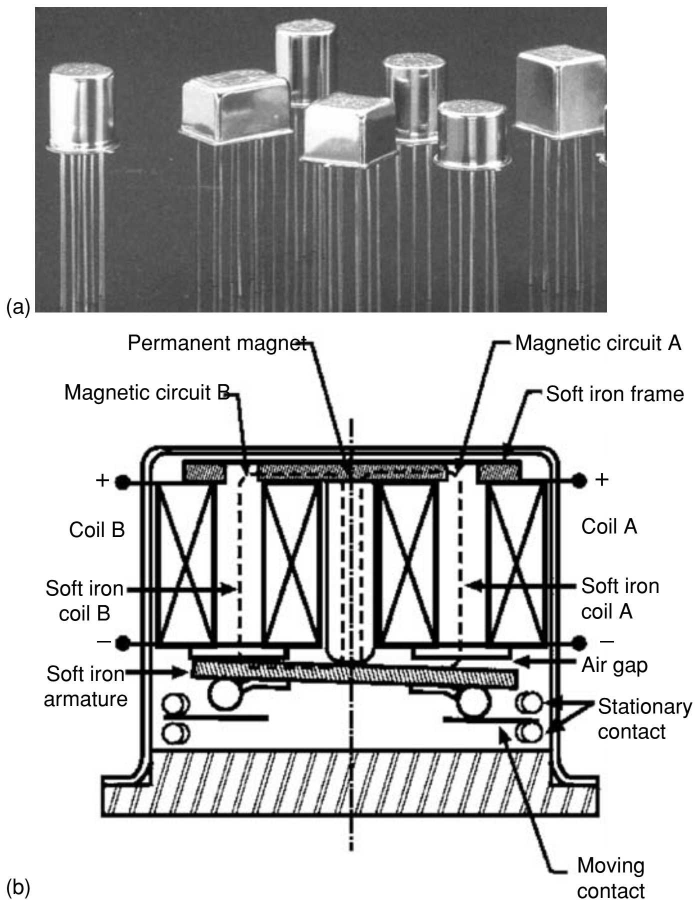


FIGURE 16.15
(a) The smallest latching relays in the world, produced by the American company Teledyne Relays. External design of relays in Centigrid® and TO-5 cases. (b) Construction of miniature latching relays produced by the Teledyne Relays (U.S.A.). (Teledyne 1999.)

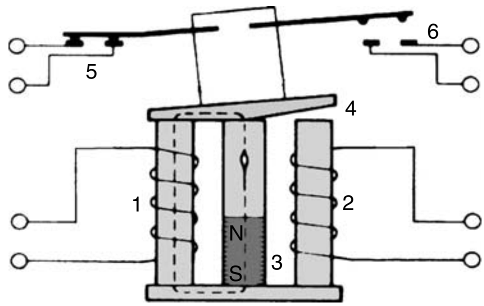


FIGURE 16.16
Variant of a scheme of a magnetic circuit, widely used in production of micro-miniature and also a big-sized relays. 1 and 2 — Coils; 3 — permanent magnet; 4 — armature; 5 — left contacts; 6 — right contacts.

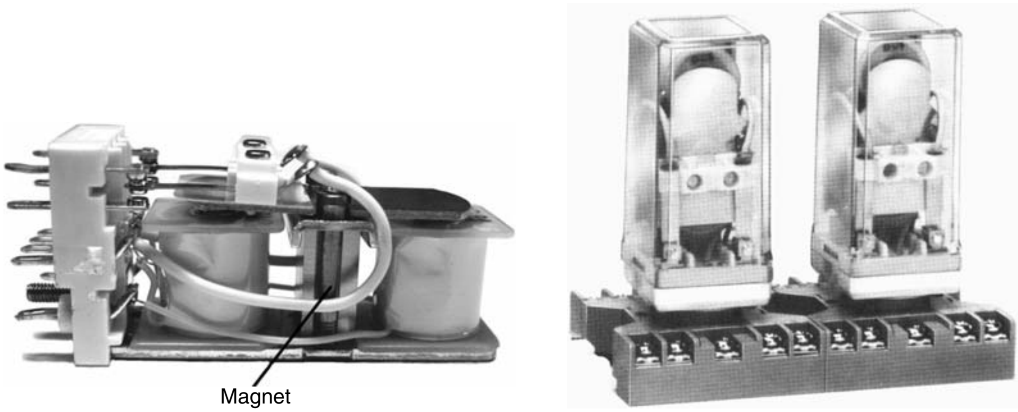


FIGURE 16.17
Industrial latching relays of the RR2KP-U type (Idec Izumi Corp., Japan).

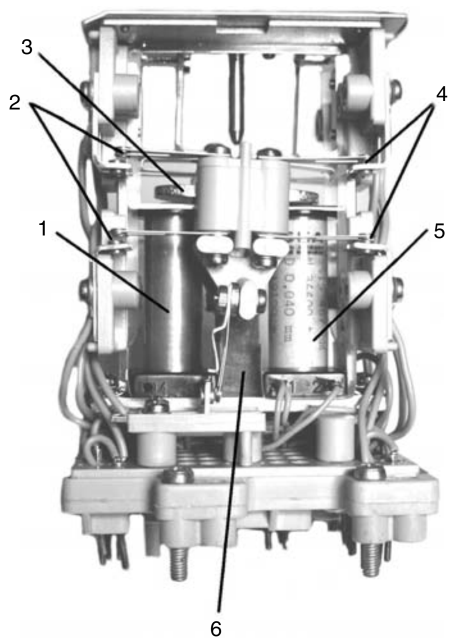


FIGURE 16.18
Large-sized multicontact latching relay of the RXMVB type (with the cover off) designed for application in power industry (ASEA). 1 and 5 — Coils; 2 — left contact system; 3 — armature clapper type; 4 — right contact system; 6 — permanent magnet.

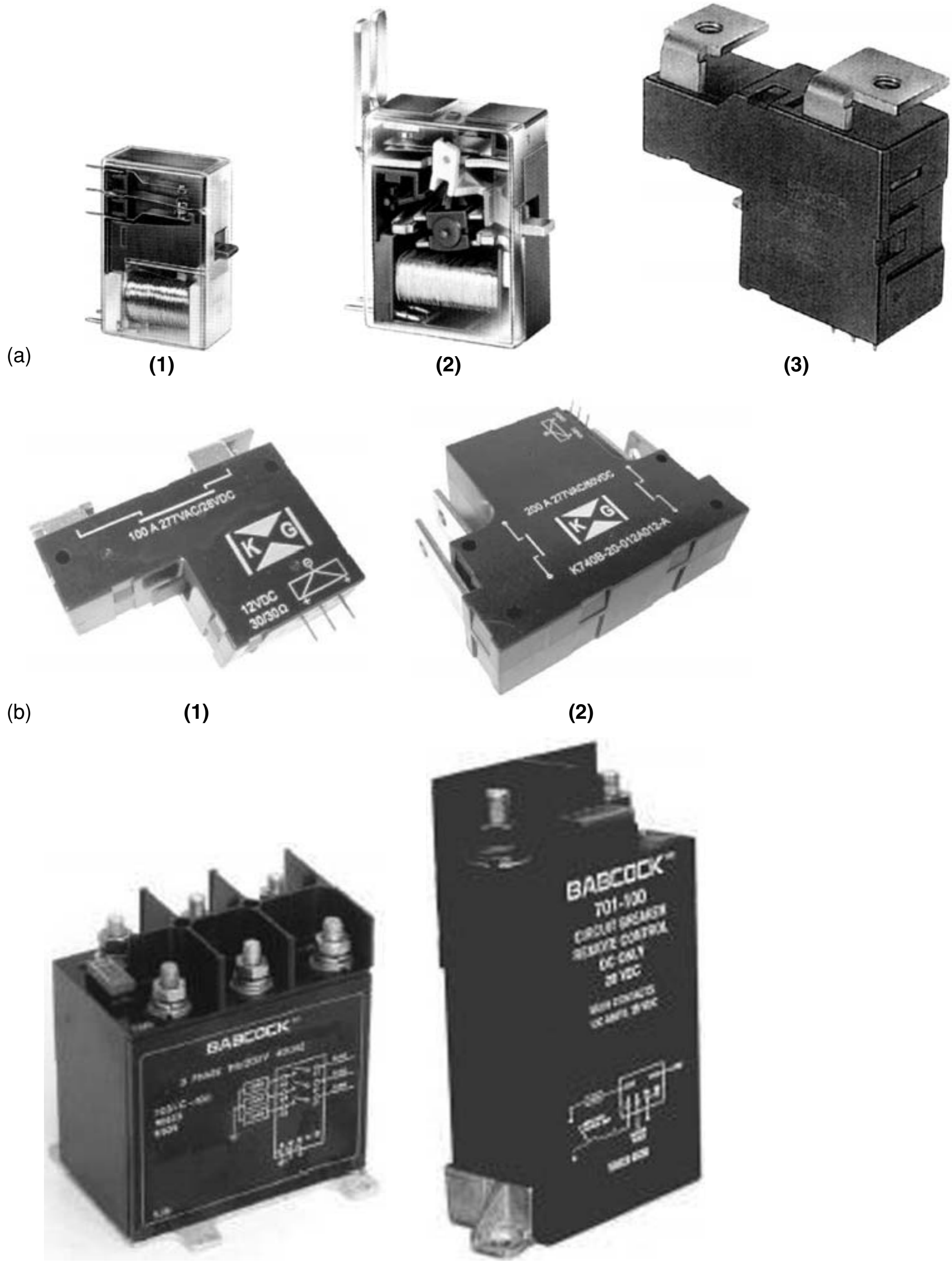
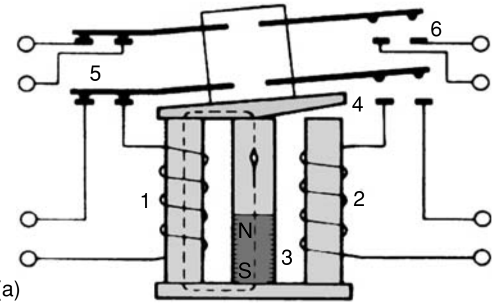
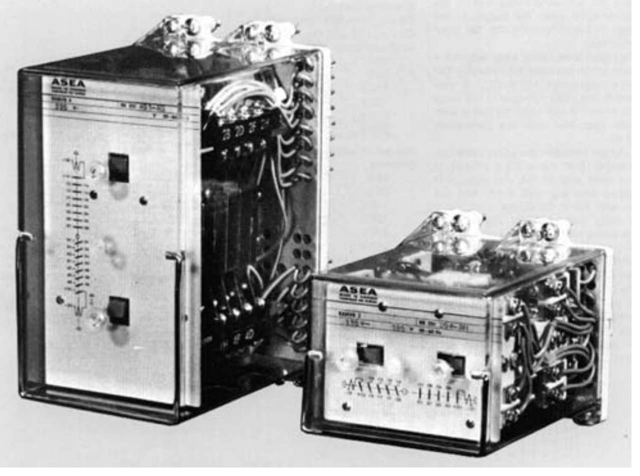


FIGURE 16.19
(a) A power latching relay with the possibility of manual reset for industrial applications, produced by Gruner AG (Germany) for switched currents from 10 to 200 A. (b) A power latching relay produced by KG Technologies (U.S.A.), for switched currents of 100 and 200 A. (c) A power latching relay produced by Babcock (U.S.A.), for nominal switched currents of 100 and 200 A.



(a)



(b)

FIGURE 16.20
Throw-over relays, type RXMVB-2 and RXMVB-4 (ASEA). (ABB 1987 Technical Description B03-1510.)

normally closed (NC) contacts of the relay. As soon as voltage is applied to the input terminals of the relay, as in a standard relay, a current pulse, required for the pick up of the relay, is formed by relay contacts 4 and 5 (Figure 16.20).

After that, the supply circuit of the relay is automatically broken and the relay remains ''ON,'' due to the restraining force of the permanent magnet. Relays type RXMVB-2 and RXMVB-4 are available for both DC and alternating current (AC) supply. The AC relay changes position during the first half cycle when the AC flows in such a direction that the force of the permanent magnet is overcome. The relays have indicating knobs which can also be used to operate the relay position manually.

Another popular type of latching relay with magnetic latching is the so-called *remanence* type. This relay consists of a coil and an armature made of a special ferromagnetic material on a nickel base, with admixtures of aluminum, titanium, and niobium, capable of becoming magnetized quickly under the effect of a single current pulse in the coil, and of remaining in its magnetized state when the pulse stops affecting it.

This type of relay contains a coil with one or two windings wound around it. In the first case, magnetization and demagnetization of the material of the core are carried out by current pulses of opposite polarities, and in the second case — by two different windings on the same bobbin, one of which magnetizes the core while the other one, which demagnetizes it, is a disabling one. The advantage of type of relay is that it does not require any special construction. One has only to make a core in the already existing construction of a standard relay of any type from remanent material, and the latching relay is complete!

This is why these relays typically have very similar designs to standard electromagnetic relays, and actually can exist in the design of any relay — large and small. The only problem that arises in application of such relays is the danger of remagnetization of the

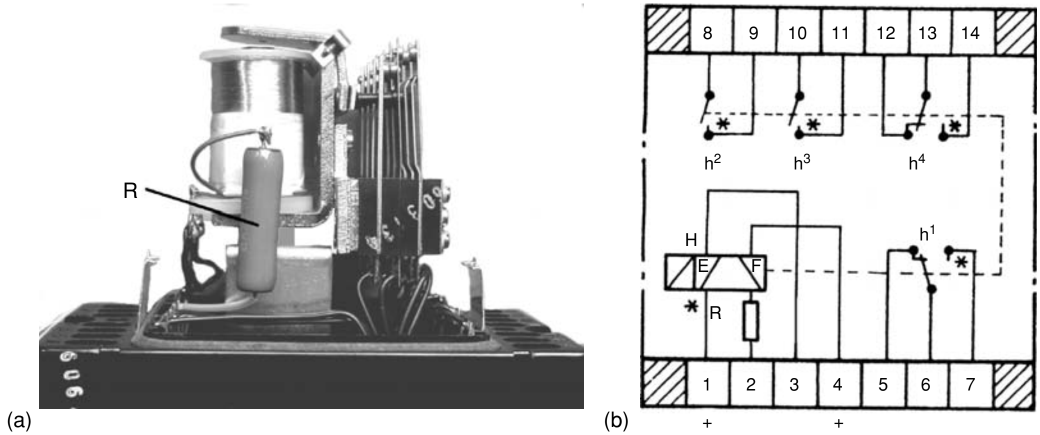


FIGURE 16.21
Remanence relay of the RHH-114 type (cover removed) with additional resistor (R), connected in series with a demagnetized (reset) coil. (AEG Haftrelais RHH-114.)

core by the reset winding if the magnetic field created by it coincides with the field of the set winding by value. In this case, the relay will be switched OFF for a short period of time and then it will be switched ON again.

For normal work it is required that the magnetic field of the reset winding be just strong enough for demagnetization of the core and no more, in order to prevent remagnetization. In order to make application of the relay easier for the user, these windings are made differently, or the reset winding is connected to an additional resistor built-in to the case of the relay (Figure 16.21). In this case at the same voltage value applied to set and reset, windings of different magnetizing forces will affect the core.

Miniature single-coil latching relays for operating voltage of 3 to 5 V are found in many applications, including signal routing, audio, and automotive systems. In these relays coil current must flow in both directions — through a single coil (Figure 16.24a). Current flowing from pin 8 to pin I causes the relay to latch in its reset position, and current flowing from pin I to pin 8 latches the relay in its set position.

A simple integral circuit of the MAX4820/4821 type (+3.3/+5 V, eight-channel, cascadable relay drivers with serial or parallel interface), produced by Maxim Integrated Products Ltd, driving up to four such single-coil (and also four ordinary dual-coil) latching relays, includes a parallel-interface relay driver (UI) with open-drain outputs (Figure 16.24b), and inductive-kickback protection. Latch any of the four relays to their set or reset positions by turning on the corresponding output (OUTX). That output is selected by asserting its digital address on pins A2 to A0 while CS is high. Activate the output by toggling CS. Both devices feature separate set and reset functions that allow the user to turn ON or OFF all outputs simultaneously with a single control line. Built-in hysteresis (Schmidt trigger) on all digital inputs allows this device to be used with slow rising and falling signals such as those from opto-couplers or RC power-up initialization circuits.

The MAX4820 features a digital output (DOUT) that provides a simple way to daisy chain multiple devices. This feature allows the user to drive large banks of relays using only a single serial interface (Figure 16.24c).

The principle of magnetic latching is widely used in many constructions of high- and low-power high-voltage relays (Figure 16.22 and Figure 16.23).

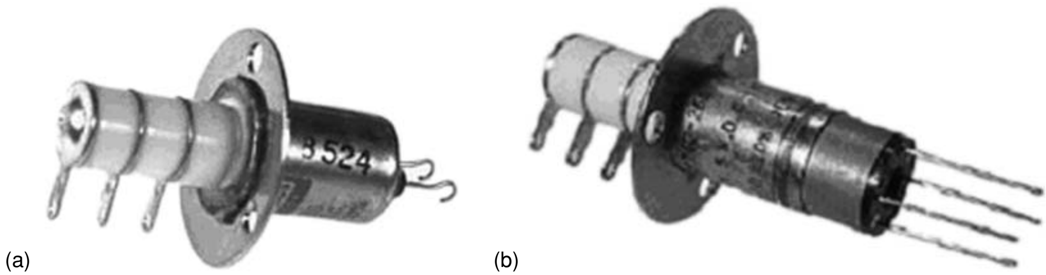


FIGURE 16.22
RFID-26S, 2 kV (a) and RF1J-26N, 4 kV (b) high-voltage relays, by Jennings Co. (U.S.A.).

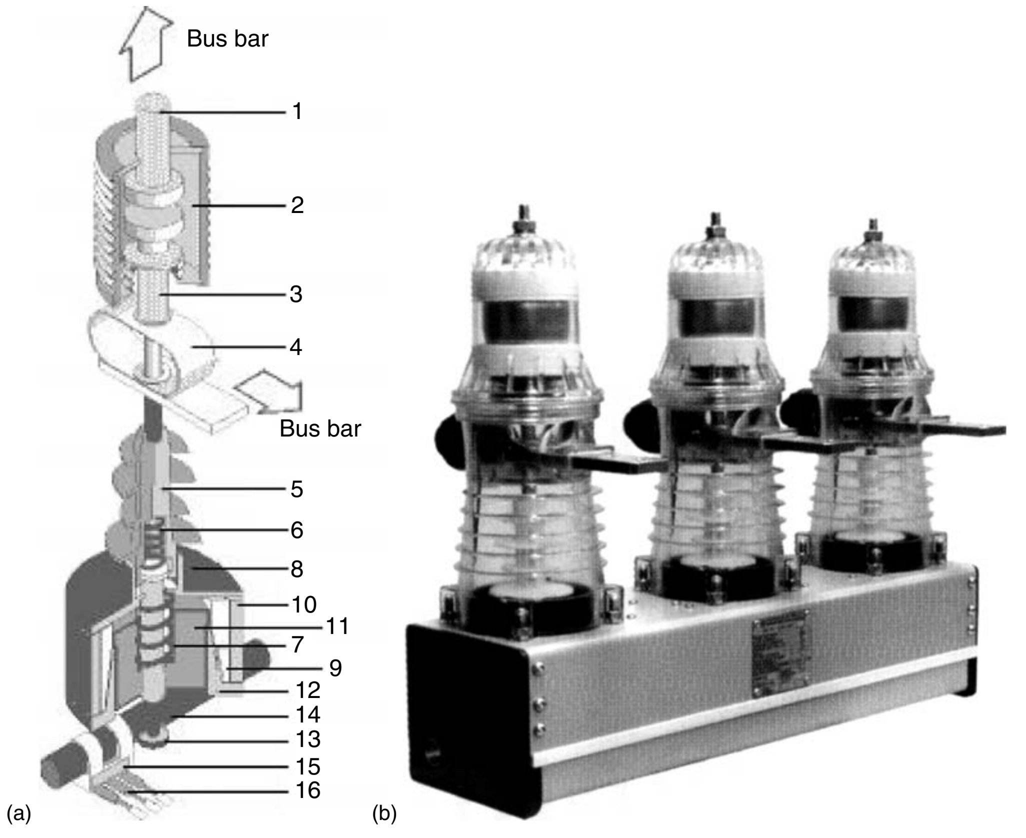
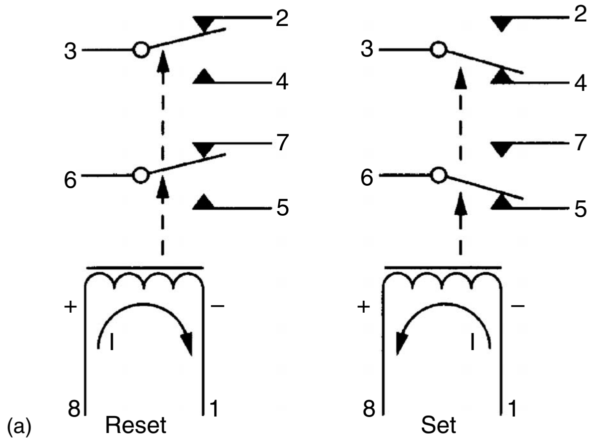
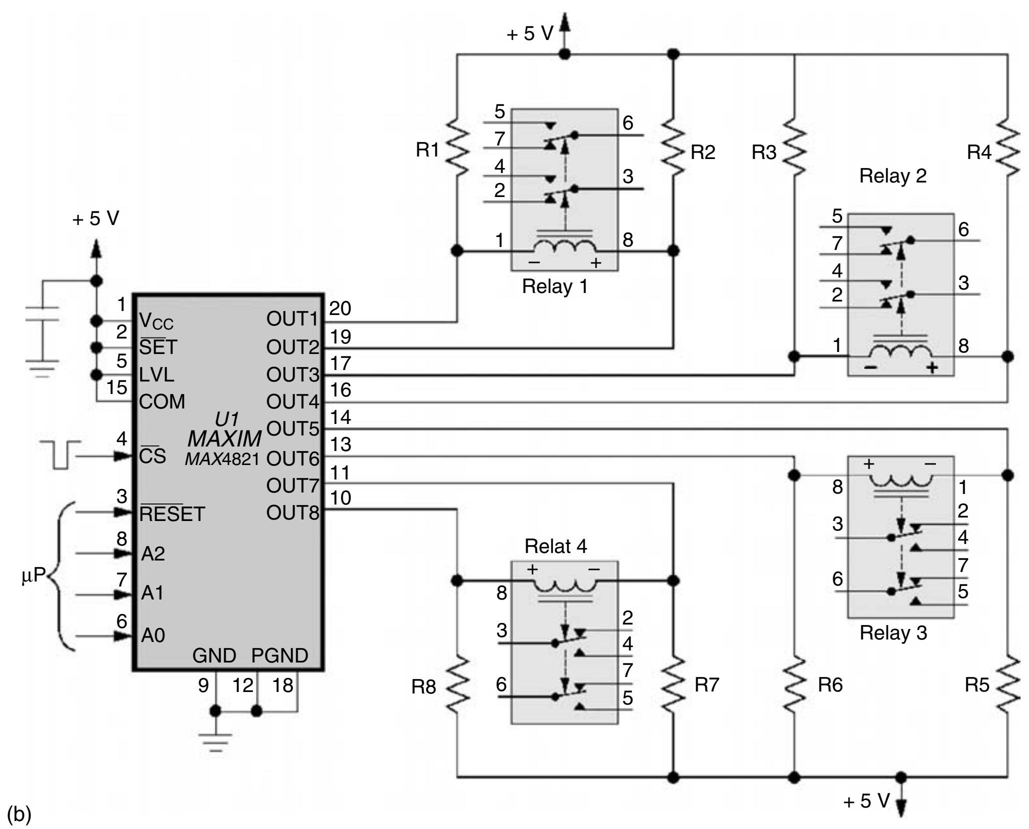


FIGURE 16.23
Magnet-latching power circuit breaker of the BB/TEL type (Tavride Electric, Russia). 12 kV; 1000 A; operating time 25 msec; 1 — stationary contact of the vacuum arc-suppressing chamber; 2 — vacuum arc-suppressing chamber; 3 — movable contact of the vacuum arc-suppressing chamber; 4 — flexible current-carrying bus bar; 5 — traction insulator; 6 — spring of compression; 7 — disabling spring; 8 — upper cover; 9 — coil; 10 — annular magnet; 11 — armature; 12 — lower cover; 13 — plate; 14 — shaft; 15 — permanent magnet; 16 — reed switches.

The suppressing chamber of the circuit breaker (Figure 16.23) is provided due to the fact that the reset spring (7) affects the movable contact (3) through the traction insulator (5). When the "ON" signal is given, the control unit of the circuit breaker forms a voltage pulse of positive polarity, which is applied to the coils (9) of the electromagnets. In the gap of the magnetic system, an electromagnetic attractive force appears and as it increases, it overcomes the power of the disabling spring (7) and the compression spring (6).





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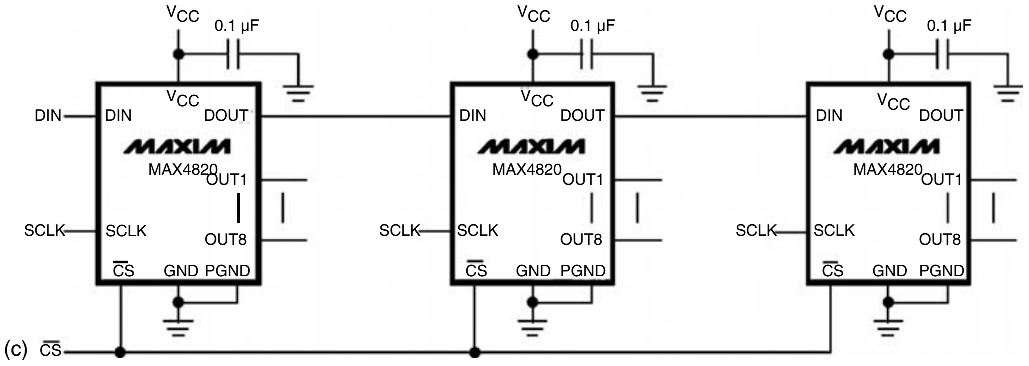


FIGURE 16.24 (*Continued*)
(a) Principle of operation of a miniature single-coil latching relay. The AROMAT AGN210A4HZ relay, for example, has such a principle. (b) The MAX4821 integral circuit easily drives four, single-coil latching relays. (c) Daisy-chain configuration for MAX4820. (MAXIM 2004.)

As a result of the impact of difference of those forces, the armature of the electromagnet (11) together with the traction insulator (5), and the movable contact (3) of the vacuum chamber (2), begins moving in the direction of the stationary contact (1), contracting the disabling spring (7). After the two main contacts close, the armature of the electromagnet continues moving up, contracting the compression spring (6). The movement of the armature continues until the working gap in the magnetic system of the electromagnet equals zero, thus the circuit breaker turns to the magnetic lock. Thus, the control energy for holding contacts 1 and 3 in a closed position is not consumed.

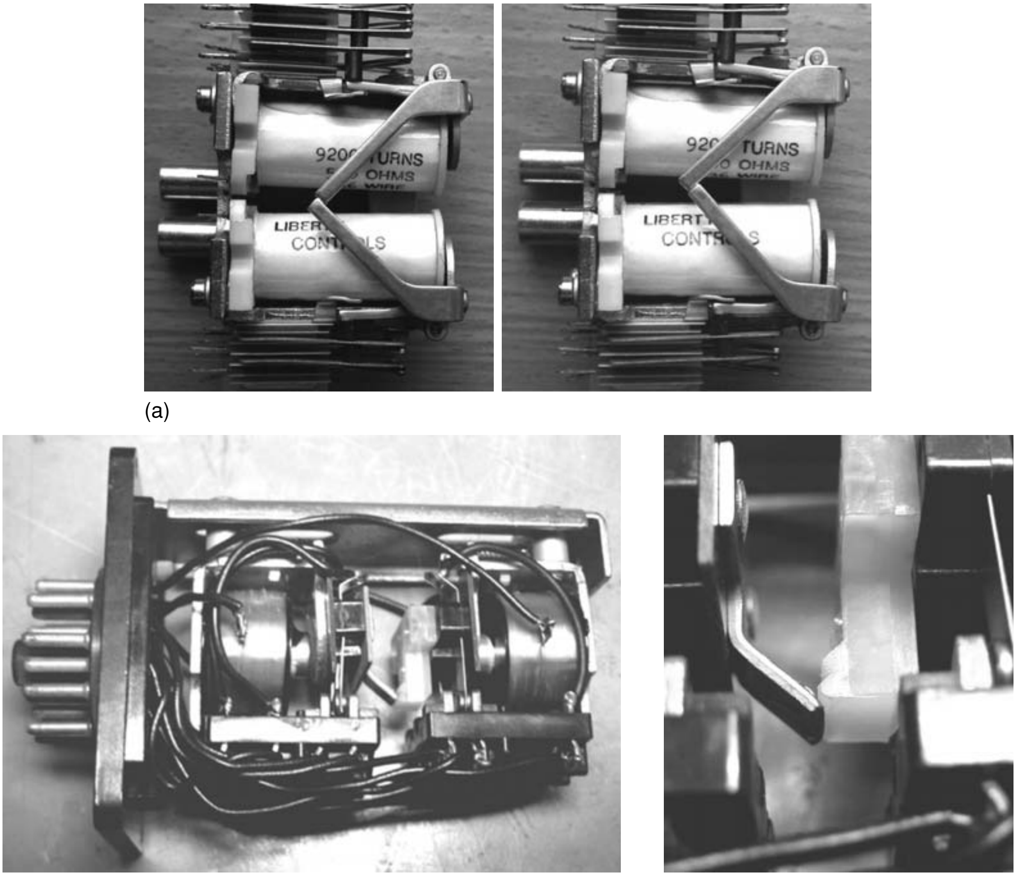
In the process of resetting of the circuit breaker plate 13, fitting the notch of shaft 14, turns this shaft by shifting the permanent magnet (15) installed on it and providing pick up of the reed switches (16), switching external auxiliary circuits.

When the ''OFF'' signal is applied, the control unit forms a current pulse, which has an opposite direction with respect to the making current, and smaller amplitude. The magnet (10) is demagnetized and the drive is unlocked. Affected by the energy accumulated in the disabling spring (7) and the spring of compression (6) the armature (11) moves down, striking the traction insulator (5) connected with the movable contact (3). The contacts 1 and 3 open and the circuit breaker disables the load.

Another variant of latch relays is a relay with mechanical latching. These are not as widespread as relays with magnetic latching, and are considered to be less reliable because of a mechanical unit that can wear out with time and get out of order. Nevertheless such relays are produced by a number of companies. The principle of construction of the mechanical latch is quite simple and sometimes quite original (Figure 16.25).

In Figure 16.25a, a latching relay with mechanical elements of blocking (metal pins) in its two positions is shown. When the relay is switched, the ends of the metal pins connected to the armature of the relay change places. Quite an original solution! In Figure 16.25b, one can see a latching relay with a plastic latch (placed in the center of the relay), made in the form of a tooth into which the curved metal plate jumps as the relay is switched.

The high-voltage latch relay produced by the Ross Engineering Corp. (Figure 16.26) is also made with a mechanical latching. So-called *lock-out relays* (Figure 16.27) are a variant of latching relays with mechanical blocking. The HEA type relays are applicable where it is desired that a number of operations be performed simultaneously. Some of the functions that can be performed by these relays are: tripping the main



(a) (b) (1) (2)

FIGURE 16.25
(a) Principles of construction of latch relays with mechanical latching (Liberty Controls). (b) A latching relay with a plastic latch element (in center of relay) and two coils (for set and reset).

circuit breaker of a system, operating an auxiliary breaker and other relays, which, in turn, perform various functions. Another important use of the HEA type relays is in conjunction with differential relays, which protect transformers, rotating apparatus, buses, etc.

The HEA type relay is a high-speed, multicontact, hand reset auxiliary relay, provided with a mechanical target which indicates whether it is in the tripped or reset position. The HEA63 type hand or electrically reset auxiliary relay has the addition of a rotary solenoid that is used to electrically reset.

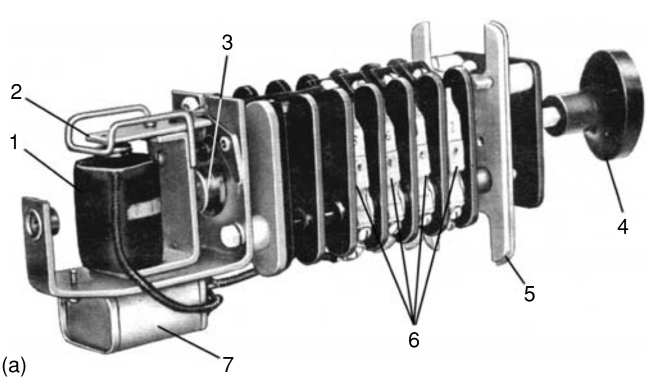
The current closing rating of the contacts is 50 A for voltages not exceeding 600 V. The contacts have a current-carrying capacity of 20 A continuously, or 50 A for 1 min. The interrupting rating of the contacts varies with the inductance of the circuit.

There are also latching relays of electronic types. The simplest type is a thyristor switched to a DC circuit. As has been noted above, this thyristor, opened by a pulse control signal, also remains in the open position after the control signal has stopped to affect it. One can use a solid-state switch — a triac, for work in an AC circuit but in that case it is the control circuit that performs the function of latching. Electronic relays based on this principle are produced by a number of firms (Figure 16.28).

FIGURE 16.26
High-voltage latching relay of the B-1001-E type. (Ross Engineering 2004.)

The NLF Series relays provide a *Flip-Flop* latching function with optical isolation between the solid-state output and the control voltage. This is a solid-state encapsulated relay for switching 1 to 20 A, with up to 200 A inrush current. If voltage to the output is maintained, each time control voltage is applied the output changes state and latches. It is designed for industrial applications requiring rugged reliable operation and long silent operation. The zero voltage switching NLF2 can extend the life of an incandescent lamp up to ten times. The random switching NLF1 is ideal for inductive loads. When fully insulated female terminals are used on the connection wires, the system meets the requirements for touch-proof connections.

The solid-state output is located between terminals 1 and 2 (Figure 16.28a), and is normally open (NO) (or NC) without control voltage applied to terminals 4 and 5. When momentary or maintained control voltage is applied to terminals 4 and 5, the output



(a)


(b)

FIGURE 16.27
(a) A HEA series lock-out relay without cover (General Electric Co.). 1 — Coil; 2 — armature; 3 — latch mechanism; 4 — operating handle; 5 — front support; 6 — contacts; 7 — rectifier and resistor assembly. (b) Lock-out relay of the RDB86 type with a new design. (General Electric Type HEA Auxillary Relays.)

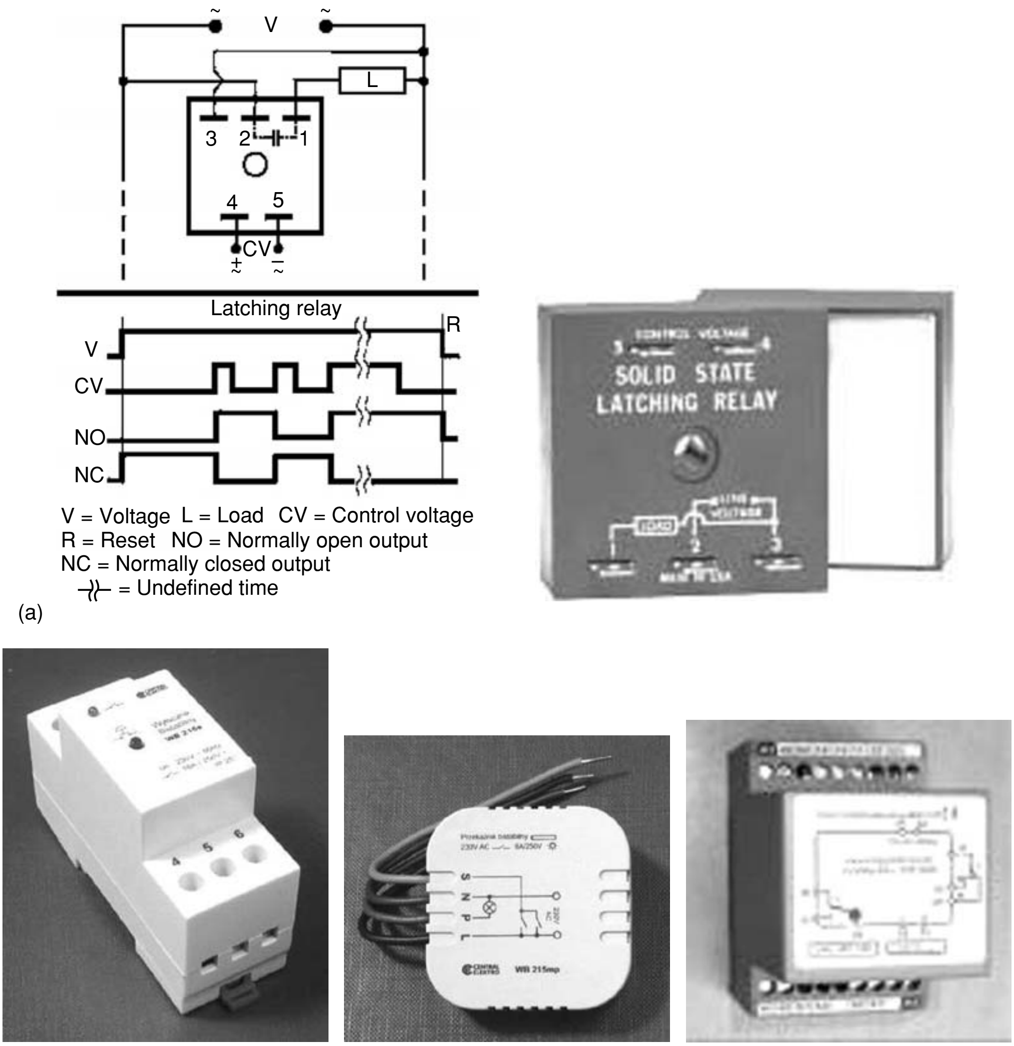


FIGURE 16.28
(a) Solid-state latching relay of the NLF type (ABB). (b) Solid-state latching relays of different types.

closes (or opens) and latches. If control voltage is removed and then reapplied, the output opens (or closes) and latches. The output transfers each time the control voltage is applied. For reset: remove and reapply control voltage. Reset is also accomplished by removing output voltage. Many other companies produce relays of various types (Figure 16.28b).

16.3 Sequence Relays

A sequence relay is sometimes called an *alternator, stepper, step-by-step, flip-flop*, or *impulse* relay. The relay has the ability to open and close its contacts in a preset sequence.

All sequence relays use a ratchet or catch mechanism to cause their contacts to change state by repeated impulses to a single coil. Usually, but not always, one pulse will close a set of contacts, the next will open them, and so on, back and forth. This alternating of open and closed states has many possible uses. A sequence relay requires a pulsed voltage to the coil of approximately 50 msec for each sequence to take place. When the coil is pulsed, the relay armature moves a lever that in turn rotates the ratchet and cams to the first position in the sequence. This position will remain as long as another pulse is not introduced to the coil. The relay is normally comprised of at least two sets of contacts to allow the contacts to alternate in combinations of open and closed states, with each pulse of voltage to the coil. The example of possible two-pole combinations would be where one pole remains open and the other pole is closed with the first pulse applied to the coil.

The second pulse could then reverse the above sequence. The third pulse could have both poles closed and the fourth pulse could open both poles. The above example could also have other sequences, depending upon the amount of teeth in the ratchet and the amount of lobes on the cams. Figure 16.29 shows an example of how cam placement on the contact blades can change the position of the contacts as the cams are rotated by the ratchet gear.

Typical applications of sequence relays (Figure 16.30) are remotely starting and stopping a conveyer from a single momentary push button. Several momentary push buttons might be wired in parallel to control the conveyer from a number of locations. Another

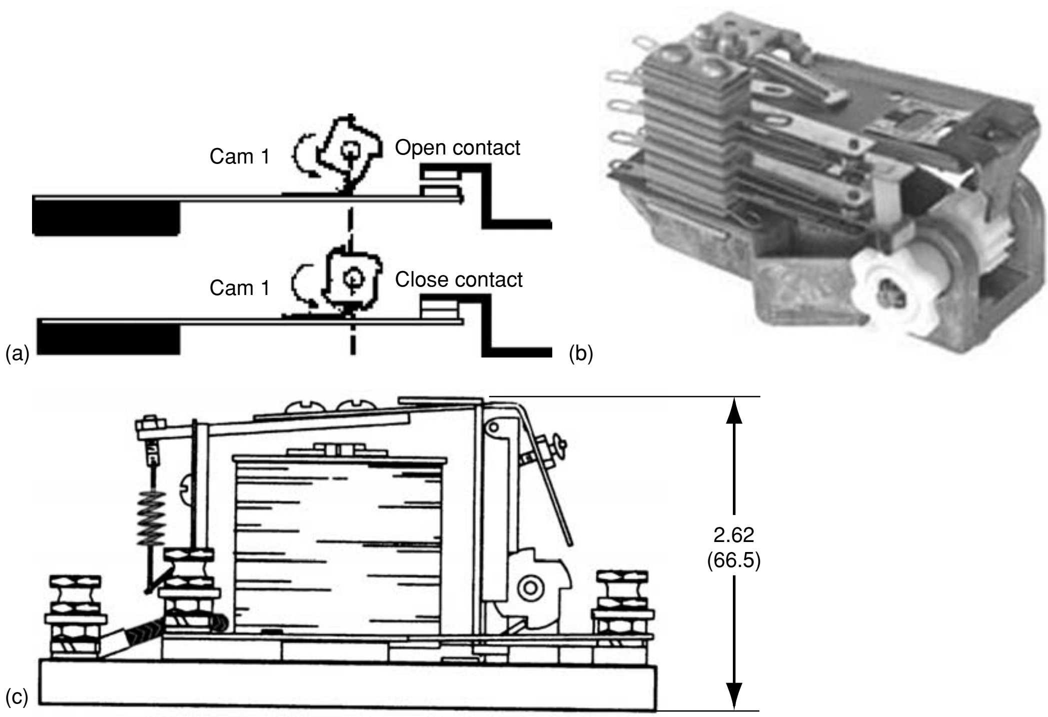


FIGURE 16.29
Operation principle of sequence relay.

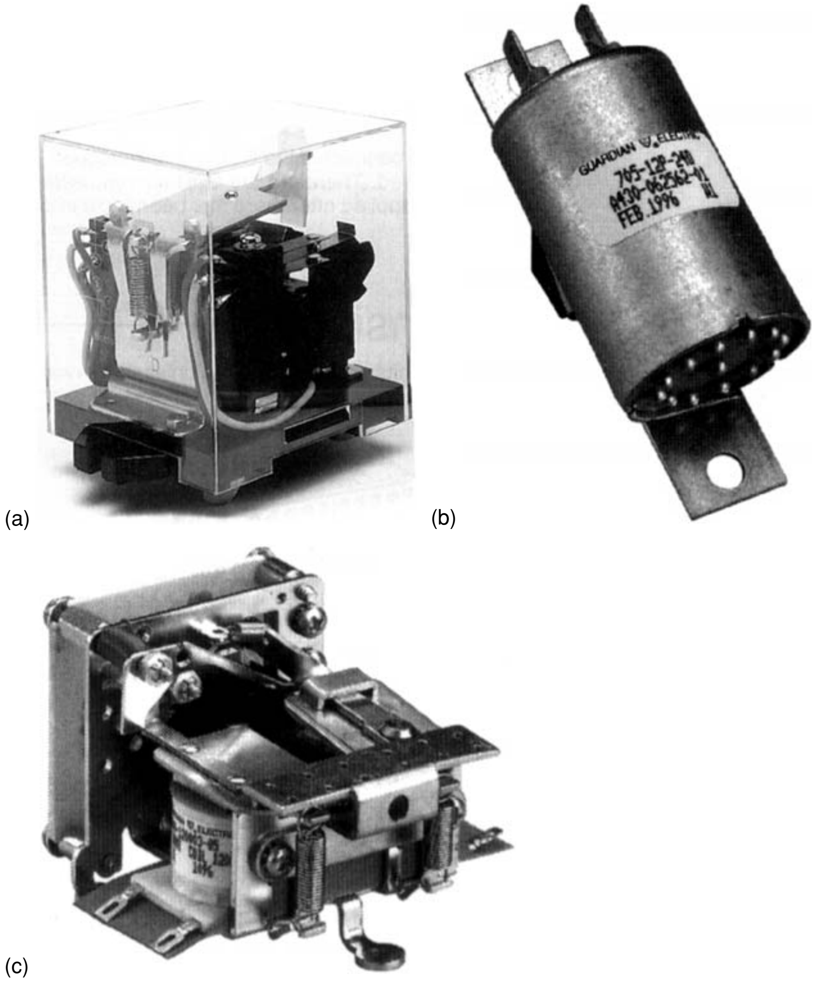


FIGURE 16.30
External designs of sequence relays produced by a number of companies. (a) Ratchet relay G40 type (Omron); (b) stepper relay 705 series (Guardian Electric); (c) stepper relay C85 (Magnecraft).

common use for sequence relays is a cascade starting a multiple HVAC, or other high start-up load systems to limit the high starting current.

One of the variants of sequence relays is a so-called ''*step-by-step selector*'' used in telephone communication for putting through the subscriber of the dialed telephone number. In this device (Figure 16.31) when each pulse is applied to the coil, the contact wipers rotate to one position, closing the corresponding contacts. When one connects the dialer of the telephone, the source of DC voltage and the step-by-step selector, and then if one dials, say ''5,'' five current pulses will be applied to the coil of the step-by-step selector, the contact wipers will make five steps and stop in the position corresponding to the number ''5.''

Dial telephone systems derive their name from the use of a dial, or equivalent device, operated by a subscriber or operator to produce the interruptions of current that direct or control the switching process at the central office. The use of a dial for such purposes, however, is much older than the telephone. It was suggested by

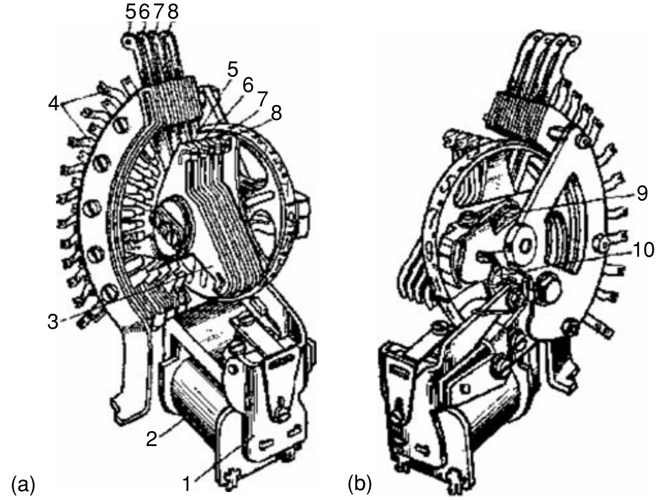


FIGURE 16.31
(a) and (b) Step-by-step selector used in telephone communication. 1 — Armature; 2 — electromagnet; 3 — three-rayed contact wipers; 4 — contact lamellas; 5–8 — inputs of the wipers; 9 — latch; 10 — ratchet gear.

William F. Cooke in 1836 in connection with telegraphy, and first used in Professor Wheatstone's dial telegraph of 1839. In the following years it was subject to many improvements, and was employed not only in dial telegraph systems but in fire alarm and district messenger systems as well. Figure 16.32 shows Froment's telegraph of 1851 transmitting and receiving dials.

The first dial telephone exchange patent, No. 222,458, was applied for on September 10, 1879, and issued on December 9, 1879, jointly, to M.D. Connolly of Philadelphia, T.A. Connolly of Washington D.C., and T.J. McTighe of Pittsburgh (Figure 16.33). Although this first system was crude in design and limited to a small number of subscribers, it nevertheless embodied the generic principle of later dial systems. At each station, in addition to the telephone, batteries, and call bell, were a reversing key, a compound switch, and a dial similar to that employed in dial telegraph systems, and on its face the numbers corresponded to the different stations of the exchange. At the central office were ratchet wheels: one wheel for each station, mounted one above the other on a common vertical shaft and carrying wiper arms which moved with the ratchets. Actuated by the circuit interruptions made by the calling subscriber dial, an electromagnet

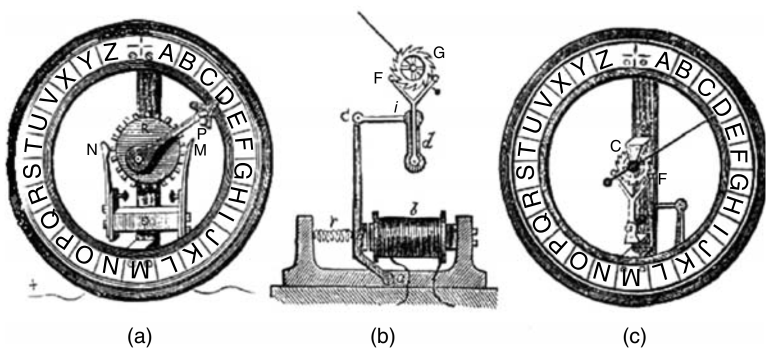


FIGURE 16.32
Transmitting dial (a) and receiving dial (c) used with Froment's alphabetical telegraph system of 1851 together with the electromagnet, ratchet, and pawl arrangement used with the receiving dial (b).

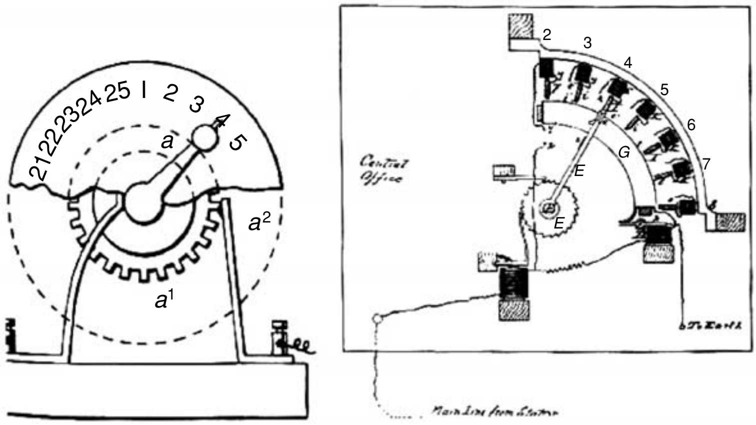


FIGURE 16.33
Fragment of Connolly-McTighe patent No. 222,458 (1879).

stepped the wiper arm around to engage the contact of the called subscriber line. Although the switching mechanism was relatively simple, various manipulations of the reversing key and compound switch were required.

Meanwhile, Almon B. Strowger, (Figure 16.34) Kansas City, U.S. is regarded as the father of automatic switching. Strowger developed a system of automatic switching using an electromechanical switch based around electromagnets and pawls. With the help of his nephew (Walter S. Strowger) he produced a working model in 1888 (U.S. Patent No. 447918, 1891). In this selector, a moving wiper (with contacts on the end) moved up to and around a bank of many other contacts, making a connection with any one of them. Since then, Strowger's name has been associated with the step-by-step selector (controlled directly from the dial of the telephone set), which was part of his idea. But Strowger

FIGURE 16.34
Almon B. Strowger.

was not the first to come up with the idea of automatic switching: it was first proposed in 1879 by Connolly and McTigthe, but Strowger was the first to put it to effective use. The 26 patents on the list that were issued between the Connolly and McTighe patent of 1879 and Strowger's patent No. 447918 of 1891 all related to the operation of small exchanges and for the most part employed complicated electromagnetic step-by-step arrangements, constantly running synchronized clockwork mechanisms, reversals of current direction, changes in current strength, and the like.

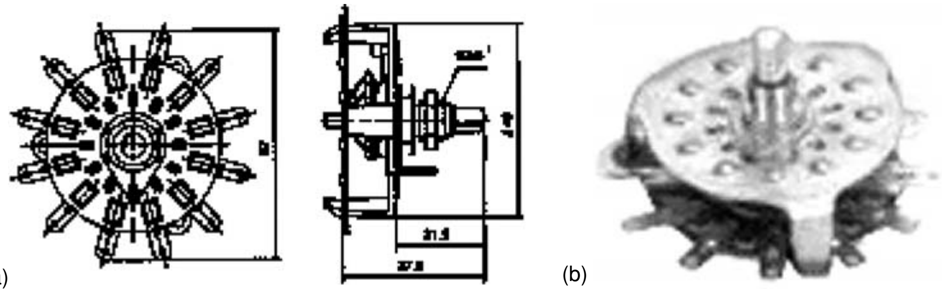
Together with Joseph B. Harris and Moses A. Meyer, Strowger formed his company, the ''Strowger Automatic Telephone Exchange,'' in October 1891. In the late 1890s, Almon B. Strowger retired and eventually died in 1902. In 1901, Joseph Harris licensed the Strowger selectors to the Automatic Electric Co. (AE); the two companies merged in 1908. The company still exists today as AG Communications Systems, having undergone various corporate changes and buyouts.

Later electromagnetic step-by-step arrangements were widely used in many fields of engineering such as measuring engineering (in systems of information acquisition from measured objects), etc. Such devices were also produced in special modification for military purposes. In telephone communication such devices lasted until the 1970–80's, being replaced in recent years by quasi-electronic and then by purely electronic devices.

16.4 Rotary Relays

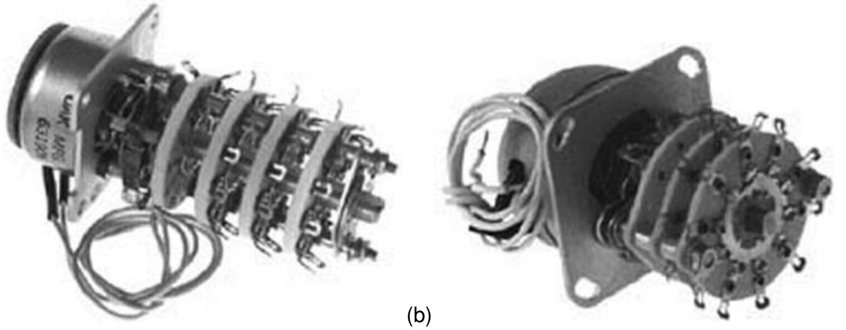
Rotary or *motor-driven* relays are relays in which forward movement of the armature and contacts is replaced by rotary movement. In fact this is a standard multicontact rotor switch with an electromagnetic drive instead of a manual one (Figure 16.35, Figure 16.36).

What is its purpose? The point is that in standard relays movable internal elements (the armature, contacts) may spontaneously shift (and contacts may close) when the relay is affected by considerable accelerations, caused by quick moving in space or by shocks or vibrations of considerable amplitude. Such effects usually take place in airborne military equipment installed in aircraft or in missiles. In addition, there are a number of important surface facilities; the normal functioning of which must be provided with the great ground shaking caused by close explosions or earthquakes. Nuclear power plants also belong to this category of facilities, for example. All equipment for such facilities is built



(a) (b)

FIGURE 16.35
Rotor switch with a manual drive.



(a) (b)

FIGURE 16.36
Rotor relay — is a motor-driven rotor switch.

according to specific requirements. Rotor relays (Figure 16.37, Figure 16.39) are quite frequently used in facilities of this kind.

Rotor relays can be both nonlatching and latching. The nonlatching relay has two coils connected in series inside the relay, which, when energized, rotate the relay rotor shaft, which operates the contacts through a shaft extension. The stator faces and stop ring limit the rotor movement to a 30° arc. Two springs return the rotor to the stop ring and the contacts to their normal positions when the coils are deenergized. The nonlatching MDR series relays have two positions: ''energized'' and ''deenergized'' (Figure 16.38). Each relay in the MDR latching series has two sets of series coils that provide a latching

FIGURE 16.37
Rotor relays of the MDR series (Potter & Brumfield Co.).

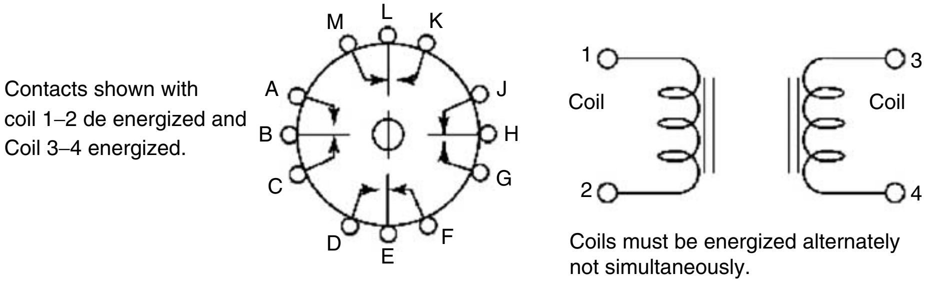


FIGURE 16.38
Circuit diagram of rotary relay.

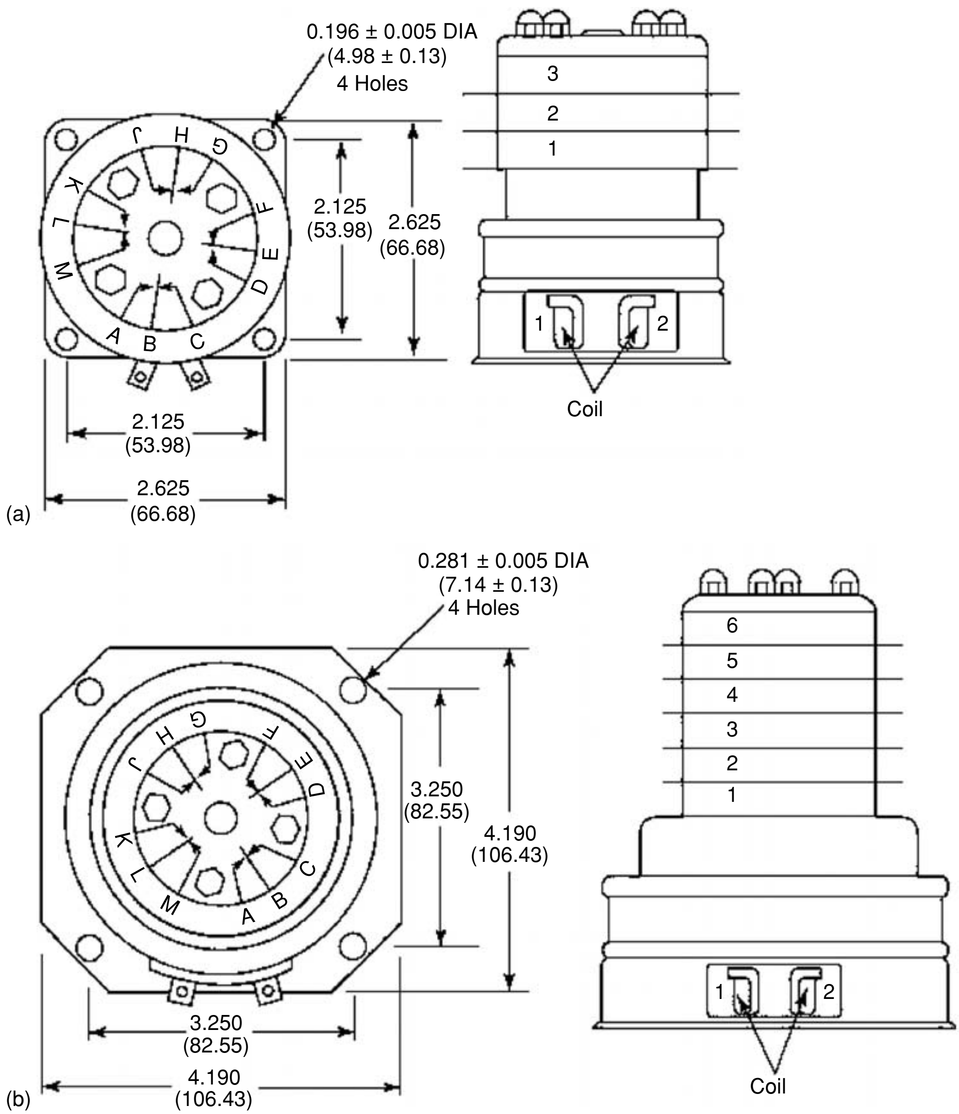


FIGURE 16.39
Overall size of relay of the MDR series with 4 to 12 changeover contacts (a) and 16 to 24 changeover contacts (b).

two-position operation. When one set of coils is energized, the rotor shaft rotates through a 30° arc, changing the state of the contacts. The other set of coils must be energized to return the relay to its original position. Relays of this type are capable of switching currents up to 10 A with voltage up to 115 or 3 A with voltage of 440 V AC (or 28 V DC).

16.5 Moving-Coil Relays

Relays of this type have a quite unusual external design, sometimes resembling a vacuum tube (Figure 16.40) or a measuring device (Figure 16.41). It is only natural that such a relay resembles a measuring device because in fact it is a highly sensitive measuring mechanism, with very sensitive contacts (Figure 16.42). The functioning of this device is based on the interaction of the magnetic field of the permanent magnet with the current in the winding. The winding is wound around a light aluminum bobbin of rectangular shape (a frame) placed in the gap between the permanent magnet and the core ring, Figure 16.43.

When current is applied to the winding, it creates its own magnetic field, interacting with the field of the permanent magnet and tending to swing the frame around its axis. If one links this frame with a pointer, one will obtain a measuring device (galvanometer). If one fixes a contact instead of a pointer, one will obtain a moving-coil relay.

The phenomenon of interaction of two conductors with current, and later of a current conductor with a permanent magnet, was investigated by many scientists in the 19th century. Instruments to measure the passage of an electric current depend on a serendipitous observation. In the course of a lecture demonstration in April 1820, the Danish natural philosopher, Hans Christian Orsted (1777–1851), passed a heavy current through a metallic wire, and noticed that a nearby compass needle was affected. In the early summer, the experiment was repeated under controlled conditions, and on July 20th he published (in Latin) the first paper on electromagnetism. His discovery of the interaction of the magnetic field produced by the current with the compass needle also provided the

FIGURE 16.40
Moving-coil relay of the E51-1 type with glass cover (BBC).

FIGURE 16.41
Moving-coil relay of the Z_T type (BBC).

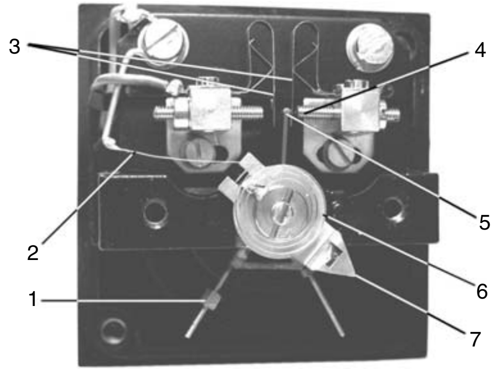


FIGURE 16.42
Contact system of the moving-coil relay. 1 — Balance beam; 2 — outlet of the movable contact; 3 — stationary contact springs; 4 — first adjustable stop; 5 — movable contact; 6 — concentric spring; 7 — indicator of pick-up current.

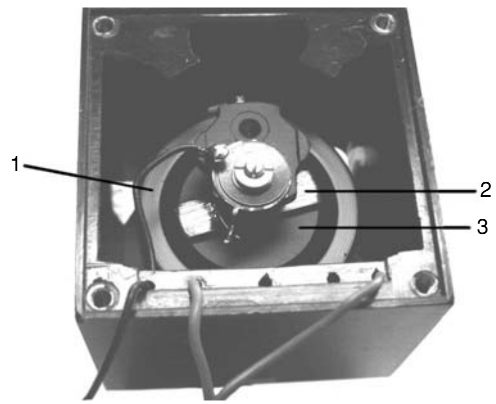


FIGURE 16.43
Magnetic system of the moving-coil relay. 1 — Core ring; 2 — aluminum frame with the winding; 3 — permanent magnet.

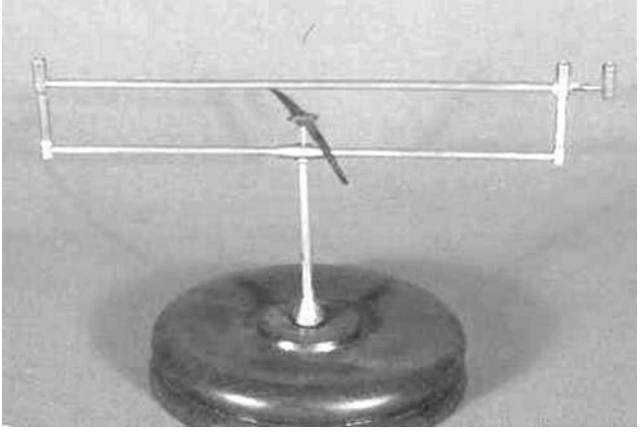


FIGURE 16.44
Sturgeon's galvanometer.

mechanism for the measurement of the electric current. Shortly after, Andre Marie Ampere (1775–1836) suggested that this effect could serve as the basis for measuring the electric current.

The basic galvanometer, devised by the British physicist William Sturgeon (1783–1850) in 1825, allowed all of the various combinations of current and magnetic needle directions to be tried out. By making suitable connections to the screw terminals, current can flow to the right or to the left, both above and below the needle. Current can be made to travel in a loop to double the effect, and, with the aid of two identical external galvanic circuits, the currents in the two wires can be made parallel and in the same direction (Figure 16.44). Note that the wires are insulated from each other where they cross.

In 1882, due to efforts of the French engineers Jaques-Arsène d'Arsonval and Marcel Deprez (Figure 16.45), the galvanometer looked like a measuring device used not as a physical curious thing or a visual aid for lectures in physics, but as a measuring device for practical needs.

(a)

(b)

FIGURE 16.45
(a) Jaques-Arsène d'Arsonval and (b) Marcel Deprez.

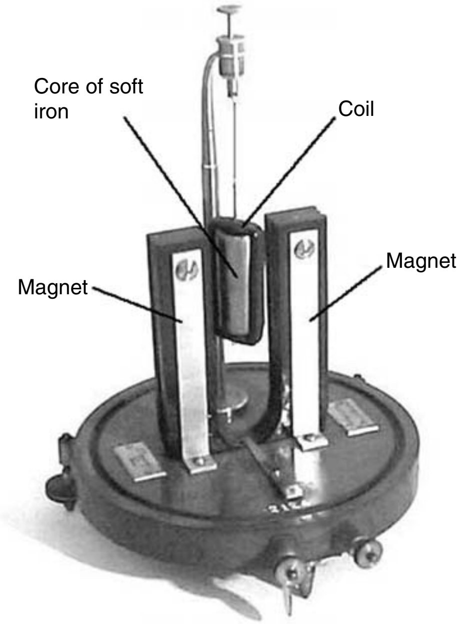


FIGURE 16.46
The D'Arsonval–Deprez galvanometer.

Jacques D'Arsonval (1851–1940) was a director of a laboratory of biological physics and a professor of experimental medicine, and one of the founders of diathermy treatments (he studied the medical application of high-frequency currents). Marcel Deprez (1843–1918) was an engineer and an early promoter of high-voltage electrical power transmission.

The galvanometer proposed by d'Arsonval in collaboration with Deprez is also defined as a mobile-bobbin (or moving-coil) galvanometer and differs from those with a mobile magnet in that it is based on the interaction between a fixed magnet and a mobile circuit, followed by a measurement of the current. Among the advantages of this type of galvanometer is higher sensitivity based on the strong magnetic field inside the bobbin. All mobile-bobbin instruments, both portable and nonportable, are derived from this galvanometer. In the D'Arsonval–Deprez design (Figure 16.46) the coil has many turns of fine wire and is suspended by a flat ribbon of wire, which serves as one lead-in wire. The connection to the lower end of the coil is provided by a light, helical spring that provides the restoring torque. The electromagnetic torque is greatest when the magnetic field lines are perpendicular to the plane of the coil. This condition is met for a wide range of coil positions by placing the cylindrical core of soft iron in the middle of the magnetic gap, and giving the magnet pole faces a concave contour. Since the electromagnetic torque is proportional to the current in the coil and the restoring toque is proportional to the angle of twist of the suspension fiber, at equilibrium the current through the coil is linearly proportional to its angular deflection. This means that the galvanometer scales can always be linear, a great boon to the user.

There are alternative constructions of the magnetic system in which the core and the permanent magnet are replaced by each other, such as putting the frame with the winding on an iron core, with the magnet placed outside (Figure 16.47), and also constructions with axial moving of the frame with the winding.

There are constructions in which instead of a magnet, the second winding is used as a source of a permanent magnetic field. In this case, the relay picks up at a certain

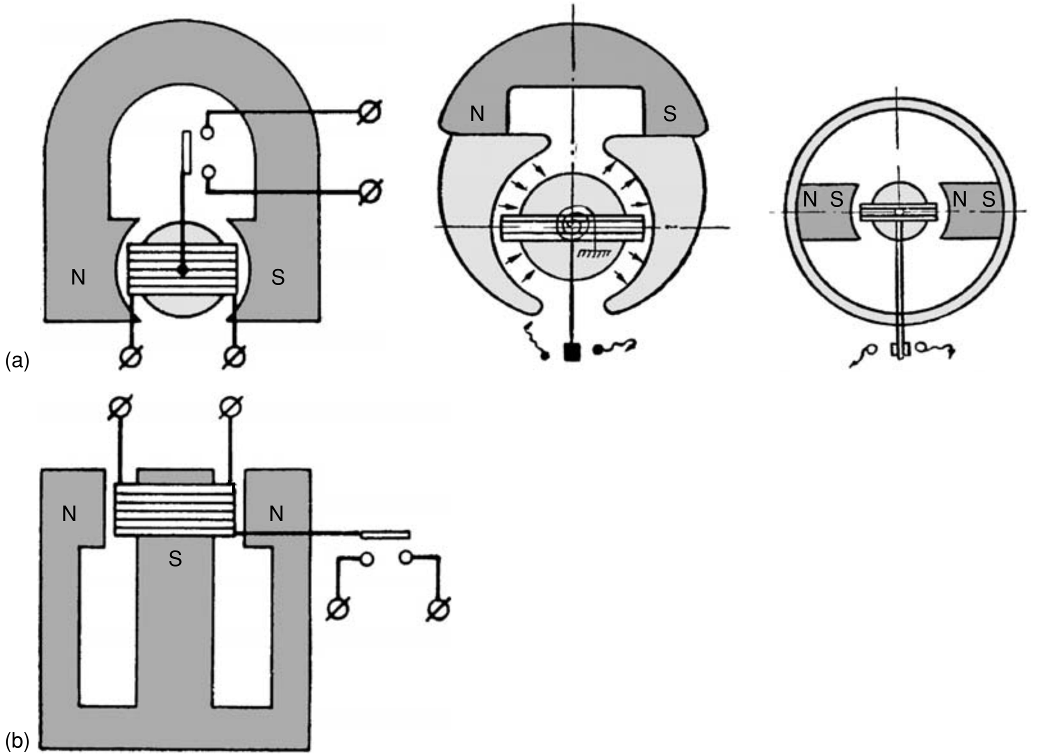


FIGURE 16.47
Alternative constructions of the D'Arsonval mechanism. (a) With external magnet; (b) with axial moving of the frame with a winding.

interaction of two currents (that is, currents flowing in two windings). Such a relay is called *electrodynamic.*

As both pointer-type devices and moving-coil relays are based on the similar D'Arsonval mechanism, it is only natural that there was an attempt to combine two types of these devices in one device. Such hybrid devices are called *control-meter relays* (Figure 16.48). These devices operate on an optical principle associated with the meter mechanism. A light source (infrared LED) and a phototransistor combination are positioned by the set point mechanism. An opaque vane is attached to the meter mechanism so that when the indicating pointer reaches the set point the vane intercepts the light from the source. This interruption changes the state of a phototransistor attached to the set pointer and switches an electronic circuit that either energizes or deenergizes the output relay. As

FIGURE 16.48
Control-meter relays (Beede Co.).

long as the indicating pointer remains above the set pointer, the electronic circuit remains switched. As the indicating pointer falls below the set pointer, the electronic circuit automatically returns to its former state.

Relays with a D'Arsonval mechanism are noted for the highest sensitivity among all types of electromechanical relays. Pick-up power of some types of such relays is only 10^{-7} to 10^{-8} W. Pick-up time is 0.05 to 0.1 sec. Contact pressure and therefore switching capacity are very low.

Lately, because of rapid development of electronics, there has been a tendency to use high-sensitive electronic amplifiers with standard electromagnetic relays at the output, instead of a moving-coil relay, which is why moving-coil relays have not been so widely produced and applied in recent years.

16.6 Amplifier-Driven Relays

Due to the development of semiconductor electronics and miniature transistors, in particular with working voltages of hundreds of volts, capable of amplifying signals by tens of thousands of times, moving-coil relays are not as popular as high-sensitive relays. Cheap miniature electronic elements for amplification of the control signal in combination with standard electromagnetic relays have superseded complex high-precision mechanics.

Most often high-sensitive relays are used as part of other complex devices. In such cases, there are no problems with several additional elements constituting a simplest amplifier working in the key mode. Very often single bipolar (Figure 16.49), or field-controlled (Figure 16.50) transistors are used as amplifiers.

Diodes switched parallel to the winding of the relay are necessary for preventing damage to transistors by over-voltage pulses occurring on the winding of the relay at the moment of blocking of the transistors (transient suppression).

Two back-to-back transistors (Figure 16.49b and Figure 16.50), are used to control a double-coiled latching relay of high sensitivity. Especially for electromagnetic relay control, a set of amplifiers on the basis of Darlington's transistor is produced in a standard case of an integrated circuit (Figure 16.51). The eight n–p–n Darlington connected transistors in

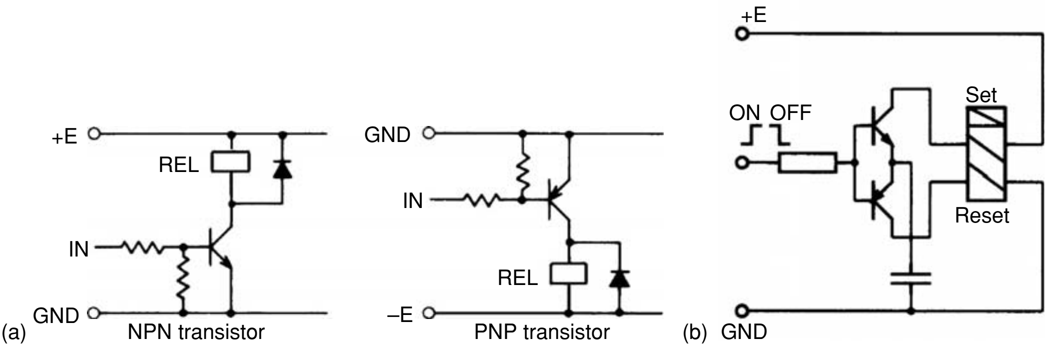


FIGURE 16.49
Amplifier-driven relays on bipolar transistors.

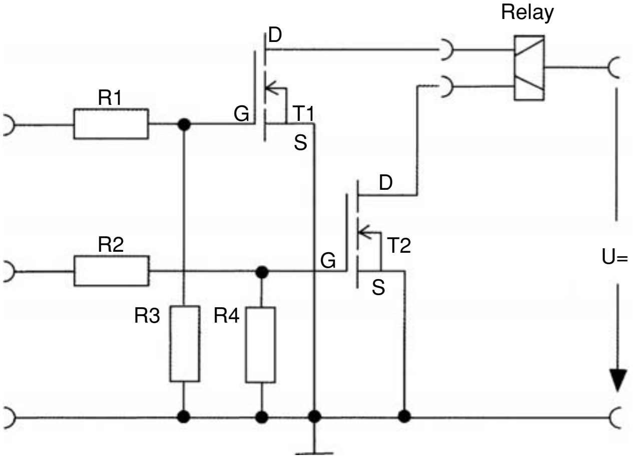


FIGURE 16.50
Amplifier-driven latching relay on FET transistors.

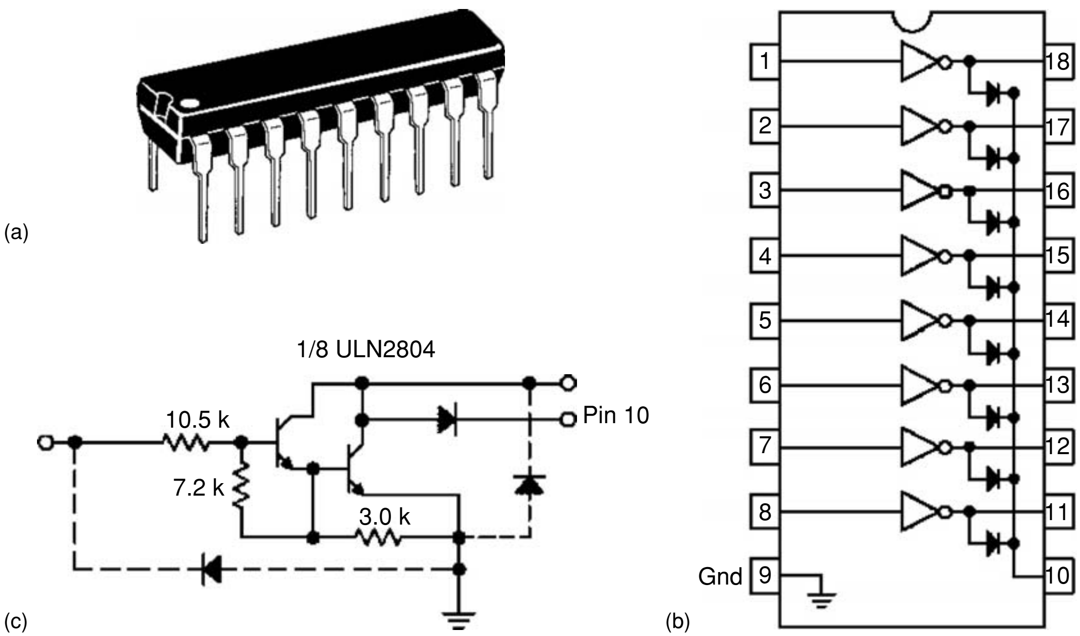


FIGURE 16.51
UNL2804 type chip (Motorola).

this family of arrays are ideally suited for interfacing between low logic level digital circuitry (such as TTL, CMOS, or PMOS/NMOS) and the higher current or voltage relays for a broad range of computer, industrial, and consumer applications. All these devices feature open-collector outputs and free wheeling clamp diodes for transient suppression. The ULN2803 is designed to be compatible with standard TTL families, while the ULN2804 is optimized for 6 to 15 V high-level CMOS or PMOS.

Amplifier-driven relays are produced by some firms in the form of independent fully-discrete devices with the electronic amplifier built-in directly to the case of the electromagnetic relay (Figure 16.52). The Type 611 relay is an amplifier-driven relay that allows an input signal as low as 12 mW to control a double pole-double throw 10 A output. This

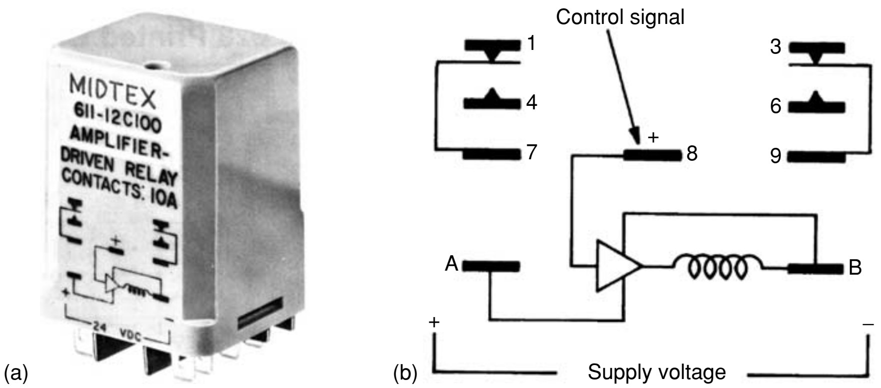


FIGURE 16.52
Amplifier-driven relay 611 type (Midtex).

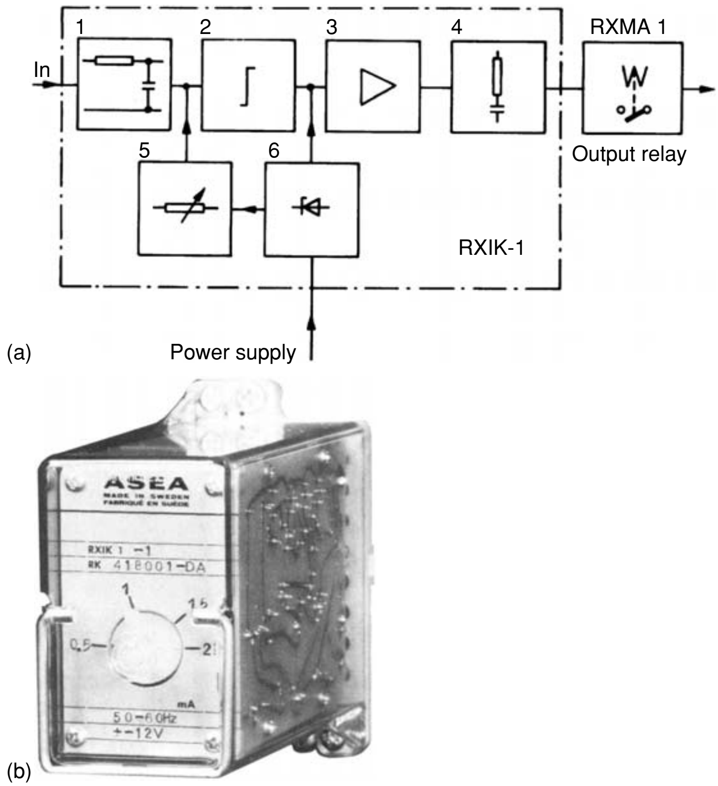


FIGURE 16.53
High-sensitive instantaneous AC and DC relay of the RXIK1 type (ASEA, ABB). 1 — RC filter; 2 — level detector; 3 — amplifier; 4 — smoothing filter; 5 — potentiometer; 6 — auxiliary voltage stabilizer (Zener diode).

low control sensitivity permits direct interfacing with most types of logic. The 611 is packaged in the popular Midtex Type 157 relay enclosure for panel mount, socket plug-in, or direct wiring.

Another example is an RXIK-1 type relay (Figure 16.53). The RXIK1 includes a level detector with an amplifier, a potentiometer, RC-circuit and Zener diode.

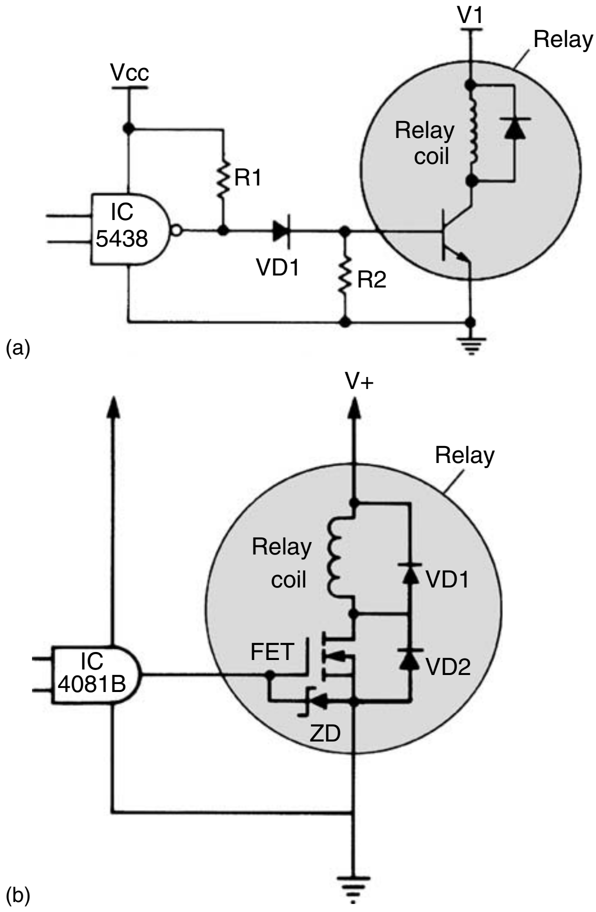


FIGURE 16.54
Amplifier-driven super miniature relays on bipolar (a) and FET (b) transistors, produced by Teledyne Relays Co. (a) Circuit diagram for relay series: 411, 412, 431, 432. (b) Circuit diagram for relay series: 116C and 136C. (Teledyne 1999 catalog.)

The operating value is set (0.5 to 2 mA) with a knob at the front. To reduce the risk of undesired operation upon high frequency signals, the input has an RC-circuit which causes the operating value of the relay to increase with the frequency. The output circuit has a smoothing filter, which ensures the function of the external output relay (RXMA-1). The measuring input is connected with the terminal for the auxiliary voltage; therefore the auxiliary voltage ought to be supplied via galvanically isolated converters. RXIK1 can be used for measuring in both voltage and current circuits.

The RXIK1 is used where high sensitivity is required (20 μW power consumption), where the RXIK1 constitutes the measuring unit. When the shunt is connected, the relay can be used to measure large DC. The shunt wires may be long and have small area, since the relay power consumption is very low. In conjunction with additional units, special versions of the RXIK1 may be used in, for example, over-current relays, neutral-point voltage relays, and differential relays, and will continue to operate even at very low frequencies.

Even the smallest electromagnetic relays in the world, for military and industrial applications, produced by Teledyne, are placed in transistor cases (TO-5 type packages, see above) and are produced with built-in amplifiers (Figure 16.54). Similar relays are produced also by some other companies (Figure 16.55).

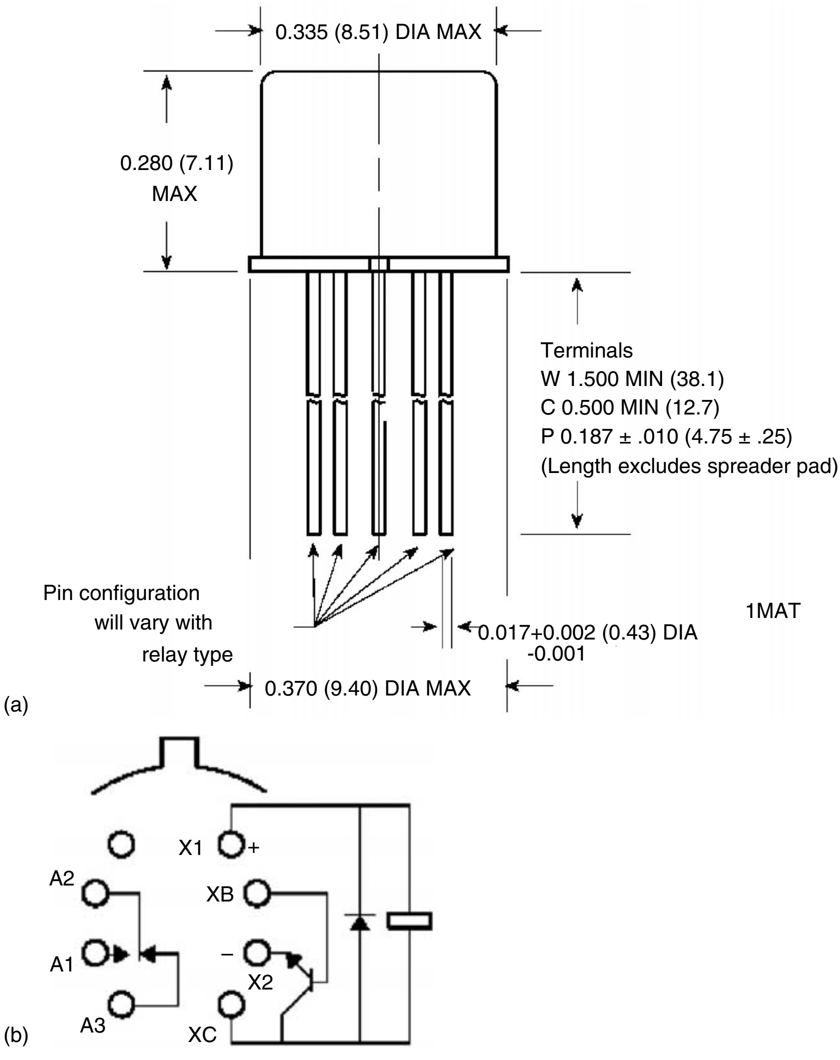


FIGURE 16.55
Amplifier-driven super miniature relay 1 MAT type in a standard transistor case, produced by Communications Instruments, Inc. (U.S.A.). Some parameters: Commutation: 1 A 28 VDC or 250 mA 115 VDC. Mechanical life: one million operations. Consumption power: 400 mW.

16.7 Magneto-Hydro-Dynamic Relays

The basic element of the magneto-hydro-dynamic (MHD) relay is an MHD pump (Figure16.56a). Usually mercury is used as conducting liquid. When electric current is applied between the electrodes (that is through the mercury) in the direction perpendicular to the direction of the magnetic field of the magnet, a magnetic field appears and interacts with the magnetic field of the permanent magnet. As a result of the interaction of the two magnetic fields an electromagnetic force (EMF) (F) and the corresponding pressure (P) tend to push out the mercury from the overlapping area of the magnetic fields. As a result, the mercury starts moving rapidly along the channel.

On DC:

$$P = BIk$$

where

B — magnetic induction in the channel
I — current through electrodes
k — the coefficient of proportionality.

On AC:

$$P = BIk \cos \gamma$$

where

γ — the angle of phase displacement between current I and the magnetic flux.

On AC, the traveling magnetic field is created by a three-phase current (the current in each phase is displaced with regard to current in the next phase by an angle of 120°). It is enough to create a traveling magnetic field near the channel with mercury, and there will be AC in the mercury, which is why there is no need to use electrodes linked by working liquid (mercury) to enable the current flow through the mercury.

Current induced in mercury creates its own magnetic field, interacting with the field causing it. As a result, the mercury is affected by some force, carrying it along the channel. The pump using induced currents is called an *induction pump* (Figure 16.56).

This device is capable of transferring electro-conductive liquid when there is an input signal (current, voltage) and can be easily used as a relay. One only has to place the contacts in the way of the mercury (Figure 16.56c). This idea was implemented by the Ukrainian inventor Dr. Barinberg from Donetsk Polytechnic University in the 1980s.

When there is no current in the control windings of these relays, the mercury level is the same in both parts of the hermetic container 4. Contacts 3 are placed below contacts 2 and plunged into the mercury. Contacts 2 do not touch the mercury. When current is applied to the control windings of the relay, the mercury moves from one part of the container 4 to the other. Contacts 3 open and contacts 2 close, and the relay picks up. When there is no current in the winding, the mercury returns to the initial state, affected by the force of gravity.

In the AC relay (Figure 16.56c) one can attach an additional transformer, matching voltages and currents of the power source of the relay and providing galvanic insulation of control circuits from contact circuits. A lot of interesting relay constructions can be implemented on the basis of the MHD pump, for example, a high-voltage relay (Figure 16.56d). When current is applied to the windings, the traveling magnetic field causes them to make the mercury move from container 5 to container 1. As a result, the gas pressure in the right tube decreases, and increases in the left tube. The mercury in 3 is squeezed from the left bend to the right one and closes the contacts.

The displacement degree of the mercury (and therefore the number of closed contacts) depends on the current value in the winding. One can obtain a relay with a time delay dependent on current by increasing the hydraulic resistance of the channels.

Unfortunately, Dr. Barinberg failed to develop his inventions to the industrial level, and as far as the author knows lives in Germany now. It seems that on the basis of

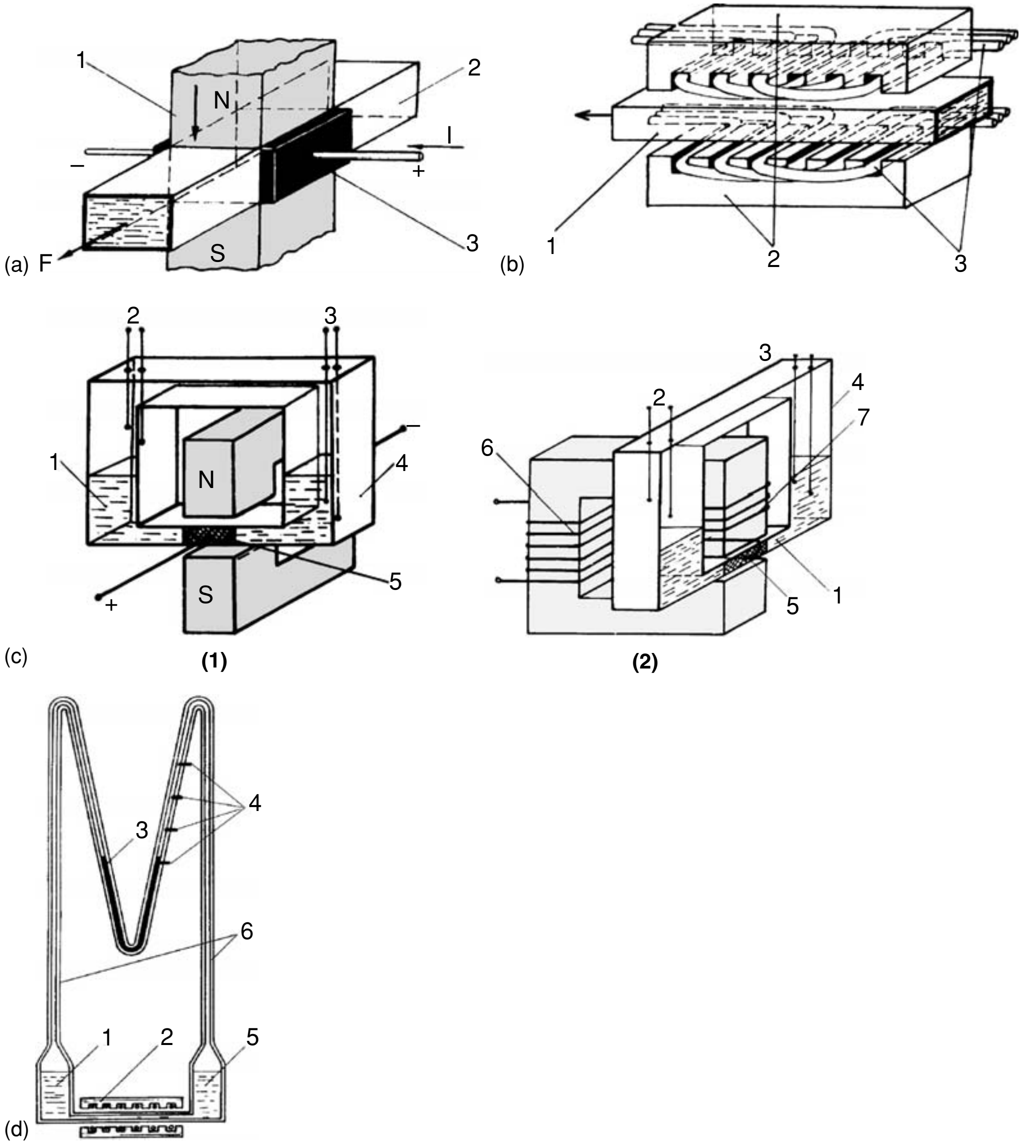


FIGURE 16.56
(a) MHD pump of conduction type. 1 — Permanent magnet; 2 — channel filled with conducting liquid; 3 — electrodes contacting with conducting liquid. (b) MHD pump of induction type. 1 — Channel with mercury; 2 — inductors; 3 — conductors forming a three-phase winding. (c) DC (left) and AC (right) MHD relay. 1 — Mercury; 2 and 3 — contact outlets; 4 — hermetic container for mercury; 5 — current-carrying electrode; 6 — primary winding of the additional matching transformer; 7 — secondary winding of the transformer switched to the electrodes 5. (d) High-voltage relay based on the MHD pump. 1 and 5 — Containers with mercury; 2 — source of the traveling magnetic field; 3 — mercury; 4 — contacts; 6 — insulation tubes filled with gas.

Dr. Barinberg's ideas one can construct quite compact and simple relays in solid metal–ceramic cases with various properties and practically unlimited service life.

16.8 Annunciator Target Relays

An *annunciator relay* (*target relay, signal relay, flag relay*) is a nonautomatically reset device that gives a number of separate visual indications of the functions of protective devices and which may also be arranged to perform a lock-out function.

In other words, target relays are used in relay protection and automation systems as an indicator of pick up of other relays. Since target relays do not have an automatic reset to the initial position, they are elements of memory storing the fact of pick up of some protective relay even if this pick up was momentary and the protective relay has returned to its initial position.

Target relays can be switched in series or parallel. In the former case, the winding of such a relay is made with low resistance (as a current one) and is switched in series with the current coil of the trip of the protective relay. In the latter case, it is a high-resistance coil switched parallel to the voltage coils of the protective relays.

The target relay has quite a simple construction containing a movable mechanical element (a shutter, flag, or disk), which is retained in the initial position with the help of a latch (Figure 16.57 and Figure 16.58).

At a short-term pick up, the armature of the target relay is attracted to the core and releases the latch. A white or colored flag drops or turns into a cut on the front board, thus becoming invisible. In passing it can close or open contacts. The flag is returned to the initial position with the help of a manual-reset mechanism. Sometimes target relays are based on standard multicontact electromagnetic relays already containing the unit, with a drop-out shutter and a reset mechanism (Figure 16.59).

The RXSF-1, for example, consists of two electromechanical relays with indicating flags. Standardly, each relay is provided with a red indicating flag (in certain cases yellow) but can be fitted with yellow or white flags if so required. The indicating flags are reset either manually with an external knob or automatically, that is, when the flag follows the movement of the armature. No-voltage relays have only automatic resetting. In cases

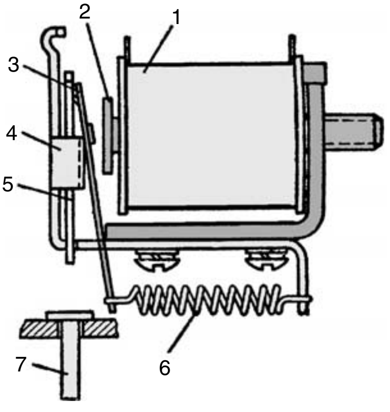


FIGURE 16.57
Construction of the target relay with a ''dropping'' flag. 1 — Coil; 2 — core; 3 — armature; 4 — inspection hole; 5 — drop flag; 6 — spring; 7 — pusher of the manual flag reset.

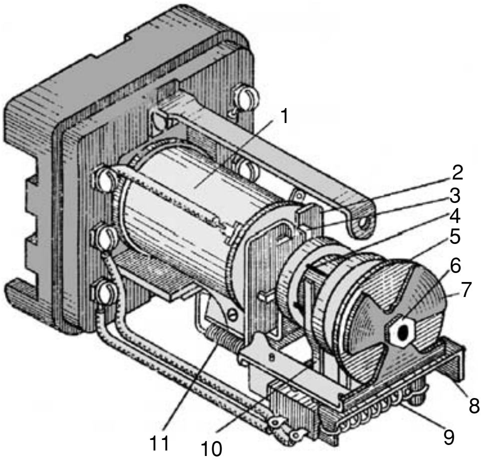


FIGURE 16.58
Construction of a target relay of the RY-21 type with a turning flag (Russia). 1 — Coil; 2 — armature; 3 — pin of the latch; 4 — contact bridge (movable contact); 5 — indicating disk with an eccentric load painted in sectors in white and black colors; 6 — axis of rotation the indicating disk; 7 — black stationary shutter with three cutout sectors; 8 — reset lever of the indicating disk; 9 — restorable spring; 10 — stationary contact spring; 11 — counter spring of the armature.

where an indication is not required a flag-locking strip can be supplied as an accessory. This may only be used on manually reset flags.

The RXSF-1 is also available as a no-voltage relay, that is, indicating when the voltage supply is interrupted. This indication can be obtained for both relays of the unit. Each relay can be supplied with 2 to 4 twin-type contacts.

Certain RXSF-1 relays can be supplied with a 4 to 5 sec time-lag on pick up (bimetallic contact) by making an external connection on the rear of the terminal base. There are constructions in which the traditional shutter is replaced with an indicating element of another type — for instance, with a colored pin (Figure 16.60), jumping put of the case of the target relay as it picks up. The relay is returned to the initial position by burying this pin in the relay case.

Target seal-in units are provided in many protective relays (Figure 16.61). These units provide a visible target to indicate that trip current has flowed. They also contain seal-in contacts, which shunt the flow of trip current away from the restraint spring in a

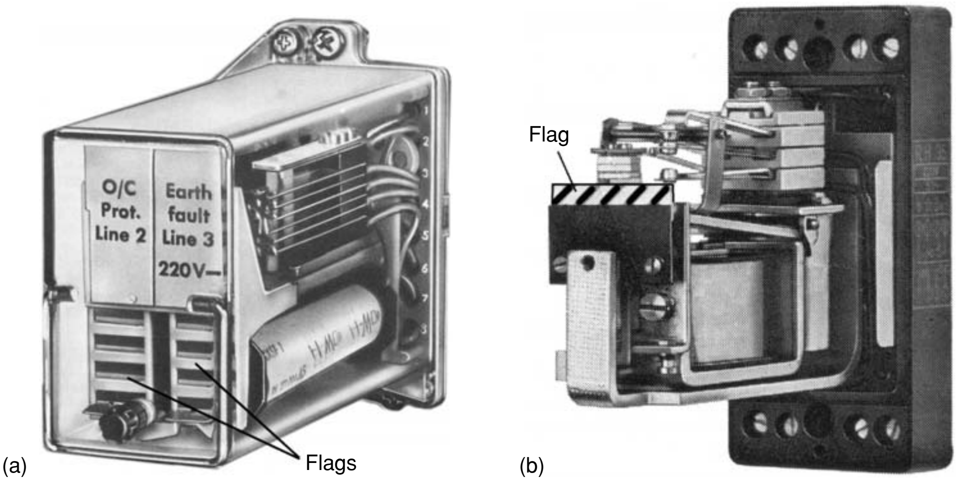


FIGURE 16.59
Target relays based on standard electromagnetic relays. (a) Dual-target relay of the RXSF-1 type (ASEA); (b) target relay RH-35 type (Siemens).

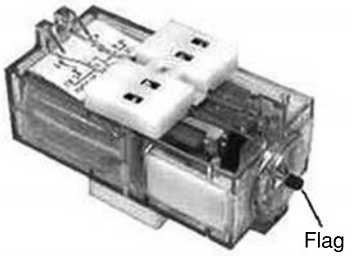


FIGURE 16.60
REY-11 target relay (Russia) with an indicating flag in the form of a colored pin.

protective relay. When the protective relay operates, its contacts close to initiate the flow of current in the trip circuit. In induction disc relays, that contact is mounted on the disc shaft and is connected to the trip circuit through the restraint coil spring. That spring has only a short time rating so the trip current must be shunted away from it to prevent overheating. When the disc contact closes and trip current begins to flow, it flows through the coil of the target seal-in unit. This causes the hinged armature unit to operate and close its seal-in contact, which then shorts out the disc contact and restraint spring. The seal-in contact remains closed until the circuit breaker trips.

The operation of the armature of this unit also sets a target flag to indicate that tripping has occurred. The flag remains set (red color showing) until manually reset from the front cover of the relay. On some units, a second electrically separate contact is also supplied. There are also target relays of the electronic type (Figure 16.62). The annunciator target relay (ATR) from Electroswitch is a compact, reliable solid state replacement or alternative for electromechanical devices currently used in many utility applications. Accepting an input signal for a variety of devices, the ATR will perform two basic functions. It will illuminate a bright LED to indicate a trip event, and also sense signals to activate up to two other devices within the system.

Once a trip signal has been detected, the ATR will latch on, keeping the LED lit until it has been manually reset. The target LED is highly visible even when viewed from extreme angles. It is designed for long life (100,000 h), available in a variety of colors, and

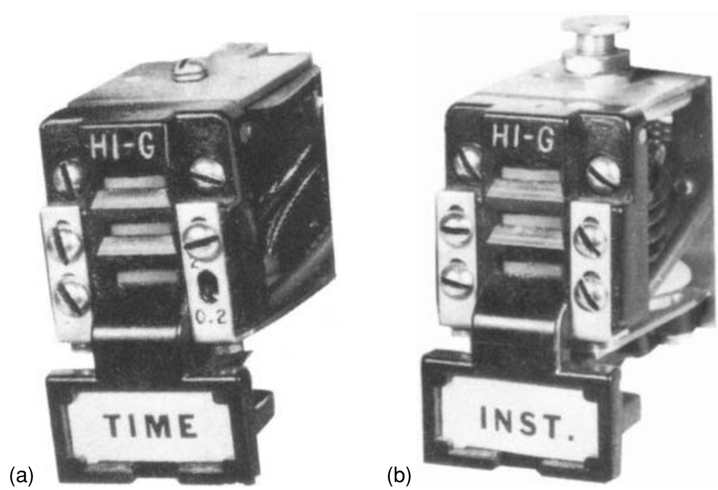


FIGURE 16.61
Target seal-in units.

FIGURE 16.62
Electronic target relay (Electroswitch, U.S.A.).

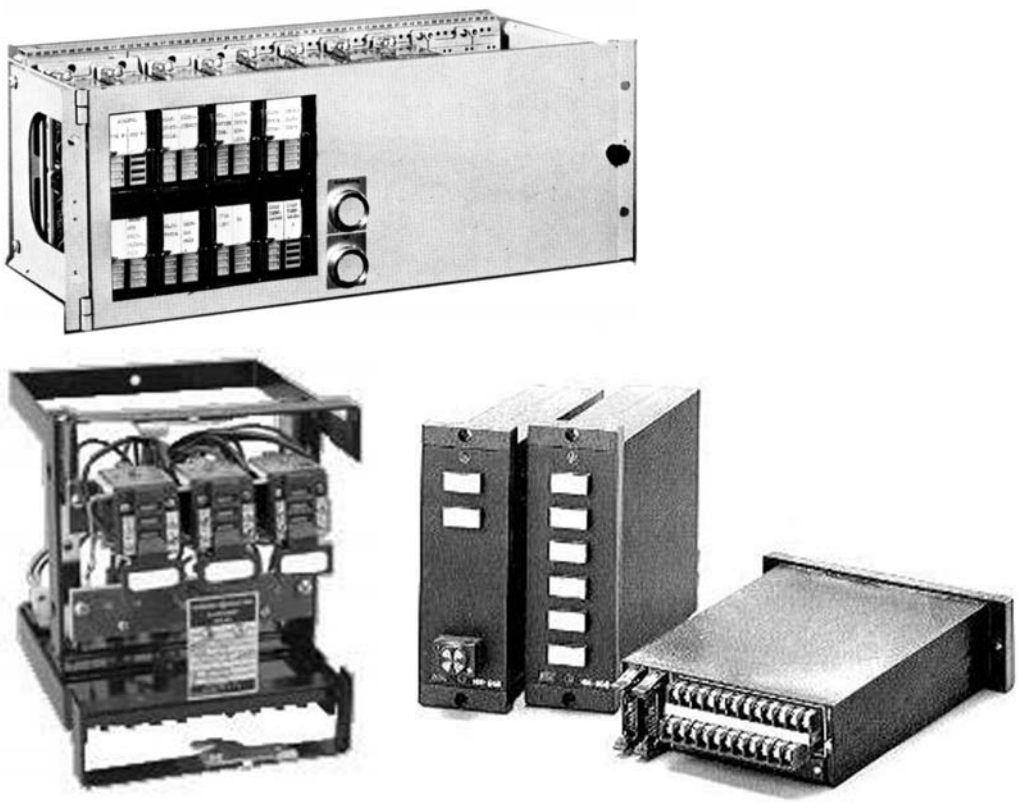


FIGURE 16.63
Units from a set of target relays.

replaceable from the front of the unit. The initial offering senses voltage and has an operating range of 37 to 140 V DC. Trip time can be specified from 0.001 to 0.100 sec by the user. Unless specified, a 0.500 sec response time is preset.

When a trip signal is received, a digital algorithm is used to validate the trip with high reliability. In its tripped state, the LED remains lit. A nonvolatile memory assures that the

ATR will retain in its state even through power outages. It will return to normal only when manually reset.

On power units (power stations, substations) a great number of protective relays are applied. In order to block and indicate the state of most of them, target relays are used. That is why such target relays are combined in units and even turned to indicator boards with legends indicating the functional peculiarity of each of them (Figure 16.63).

16.9 Flashing-Light Relays

Flashing-light relays (or *Flashers*) are used to produce the flashing light of signal lamps that, due to that flashing, attract more attention than permanently switched-on lamps. Such relays are widely used to control single signal lamps, and as a part of multivalve signal boards (Figure 16.64).

In Figure 16.65a there is a simplest relay circuit for a flashing light. Normally, when there is voltage in the circuit of the relay, current flows around KL1 and its contacts are open. When the signal is applied through signal lamps, fore example HLT, to the tie ($\sim$) *EP*, relay KL2 picks up, breaking the supply circuit of relay KL1, which links by its contacts the tie ($\sim$) *EP* with tie 0. As a result, phase voltage is applied to the lamp (HLT) and it becomes light up. Relay KL2 appears to be shorted by the contacts of KL1 and is no longer relevant. Relay KL1 picks up again, the lamp (HLT) is switched in series to KL2 and therefore it goes out. Then the process starts all over again.

The required intervals between lightings of the lamp are provided by the capacitors C1 and C2, switched parallel to the windings of the relay.

FIGURE 16.64
Signal board with lamps and flashing-light relays (ABB).

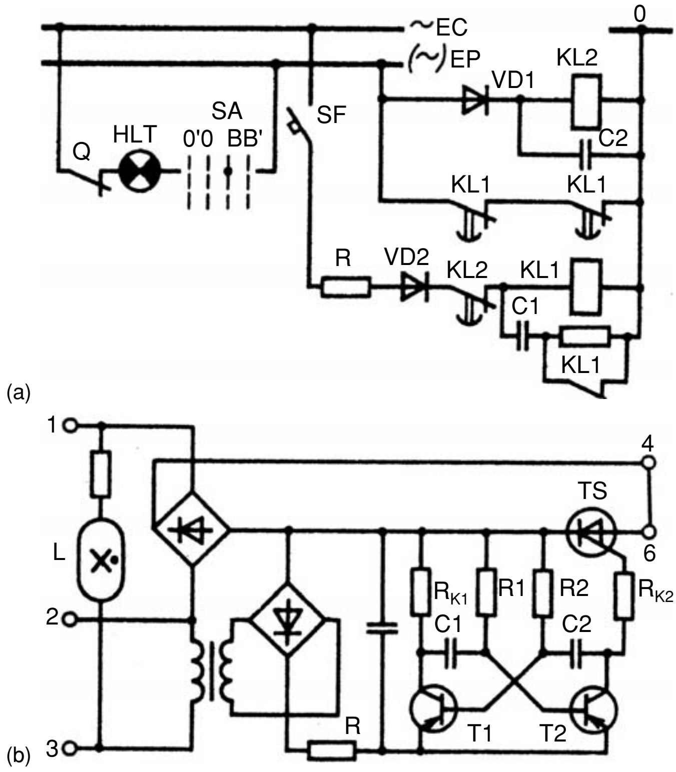


FIGURE 16.65
Simplest circuits of flashing-light relays: (a) Based on electromagnetic relays; (b) on semiconductor elements.

The thyristor (TS) in the circuit (Figure 16.65b) is enabled (ON) when a current pulse produced by an multivibrator formed by transistors T1 and T2 flows through its gate. The frequency of interruption and relative pulse duration are determined by the frequency of the multivibrator and depend on its timing circuits. The thyristor is disabled (OFF) when there is no current in the gate circuit, and when current flowing through the main junction anode–cathode equals zero.

In electronic relays of this type, different chips are applied (Figure 16.66). The TDE1767, for example, is a monolithic IC designed for high-current and high-voltage applications, specifically to drive lamps, relays, and stepping motors. These devices are essentially blow-out proof. The output is prompt and protected from short-circuits with a positive supply or drive. In addition, thermal shut down is provided to keep the IC from overheating. If internal dissipation becomes too high, the driver will shut down to prevent excessive heating. The output stays null after the overheating is off, if the reset input is low. If high, the output will alternatively switch on and off until the overload is removed. These devices operate over a wide range of voltages, from standard 15 V operational amplifier supplies to the single +6 or +48 V used for industrial electric systems. Input voltages can be higher than in the V_{CC}. An alarm output suitable for driving an LED is provided. This LED, normally on (if referred to ground), will die out or flash during an overload, depending on the state of the reset input. Output current is up to 0.5 A without an external amplifier, and up to 10 A with the addition of an output transistor (Figure 16.66c).

Flashing-light relays based on the principles described above are produced by many companies (Figure 16.66–Figure 16.68). The RXSU device (Figure 16.67) contains

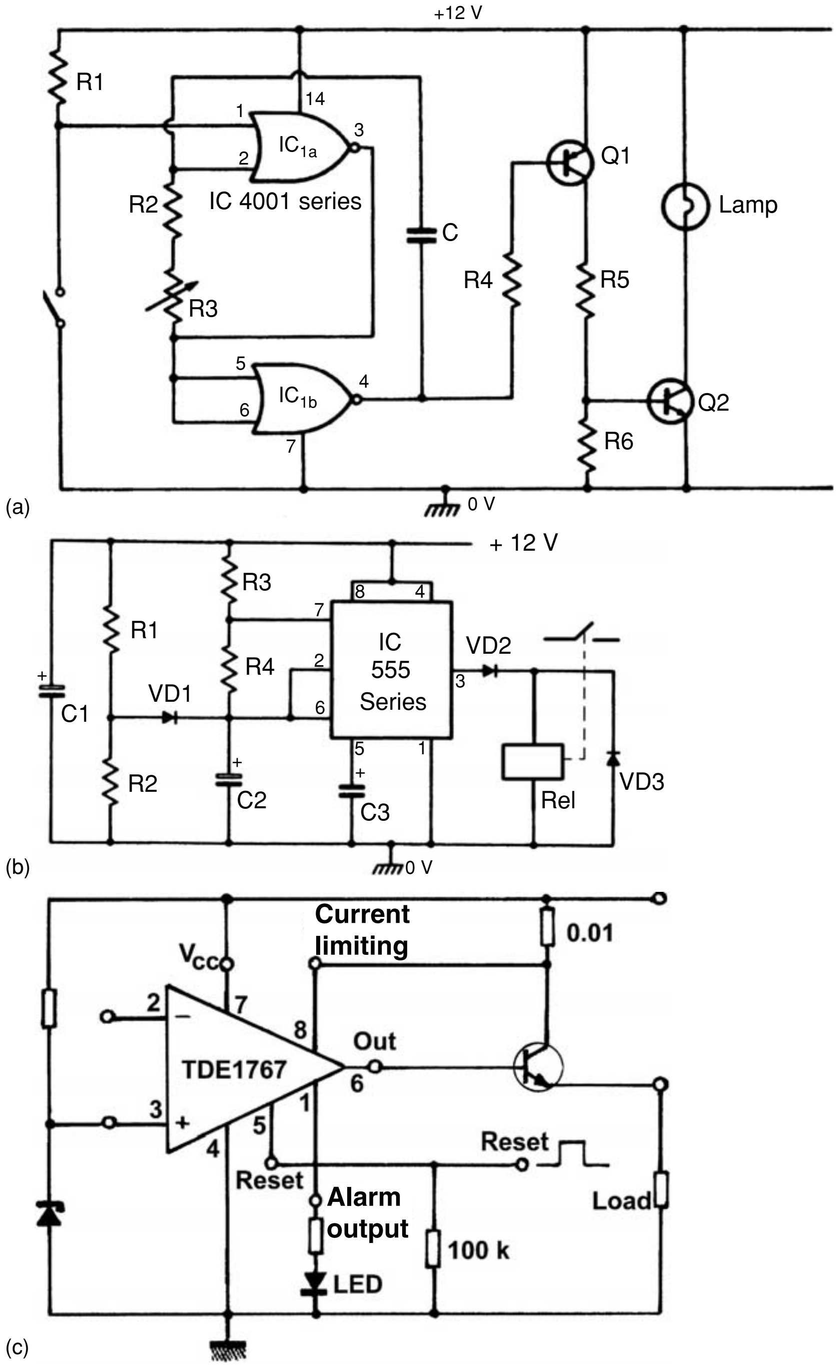


FIGURE 16.66
(a) Contactless flashing-light relay with a multivibrator, based on chip 4001, and a transistor amplifier at the output. (b) Flashing-light relay on the basis of the IC 555 series, with an electromagnetic relay at the output. (c) Electronic flashing relay with protected power output, based on the specializing TDE1767 type IC (SGS-Thomson).

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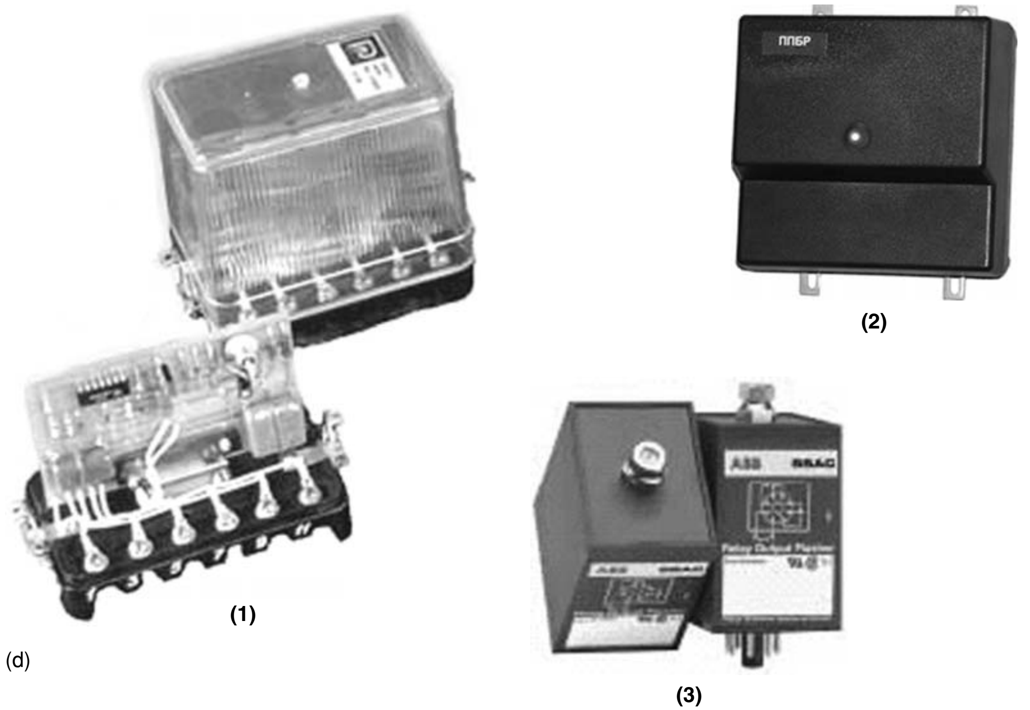


FIGURE 16.66 (*Continued*)
(d) Flashing-light relays based on IC. (1) and (2) — PPBR types (Russia, 2002); (3) — FS500 series (ABB).

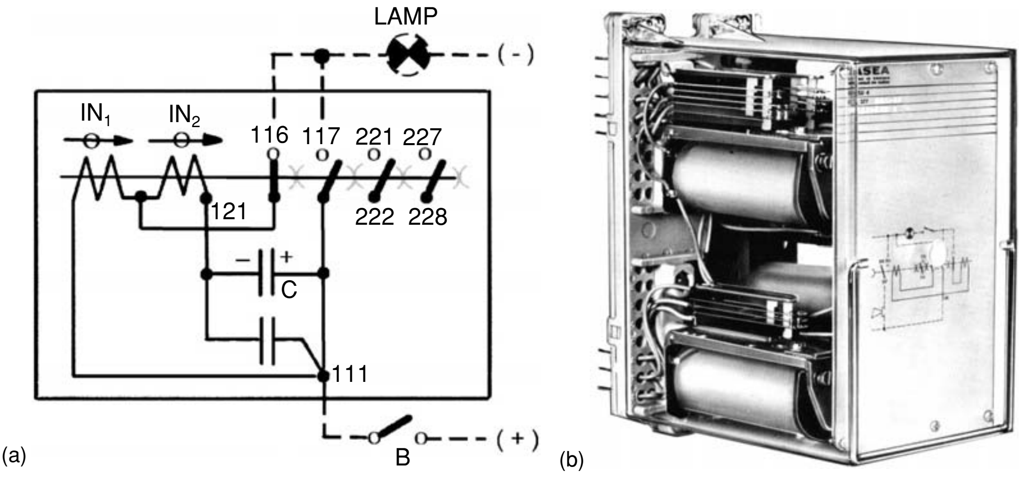


FIGURE 16.67
Flashing-light relay of the RXSU type, on electromechanical relays and capacitors. (ASEA (ABB) 1975.)

one relay with two approximately identical windings. Capacitor C is connected in series with one of the windings (see figure alongside). In addition the RXSU 4 has an auxiliary relay with a time-lag on dropout, which is picked up while the flashing-light relay is working.

When contact B closes, the relay coil is connected in series with the signal lamp. The voltage drop across the coil is so large that the signal lamp does not light up. To begin

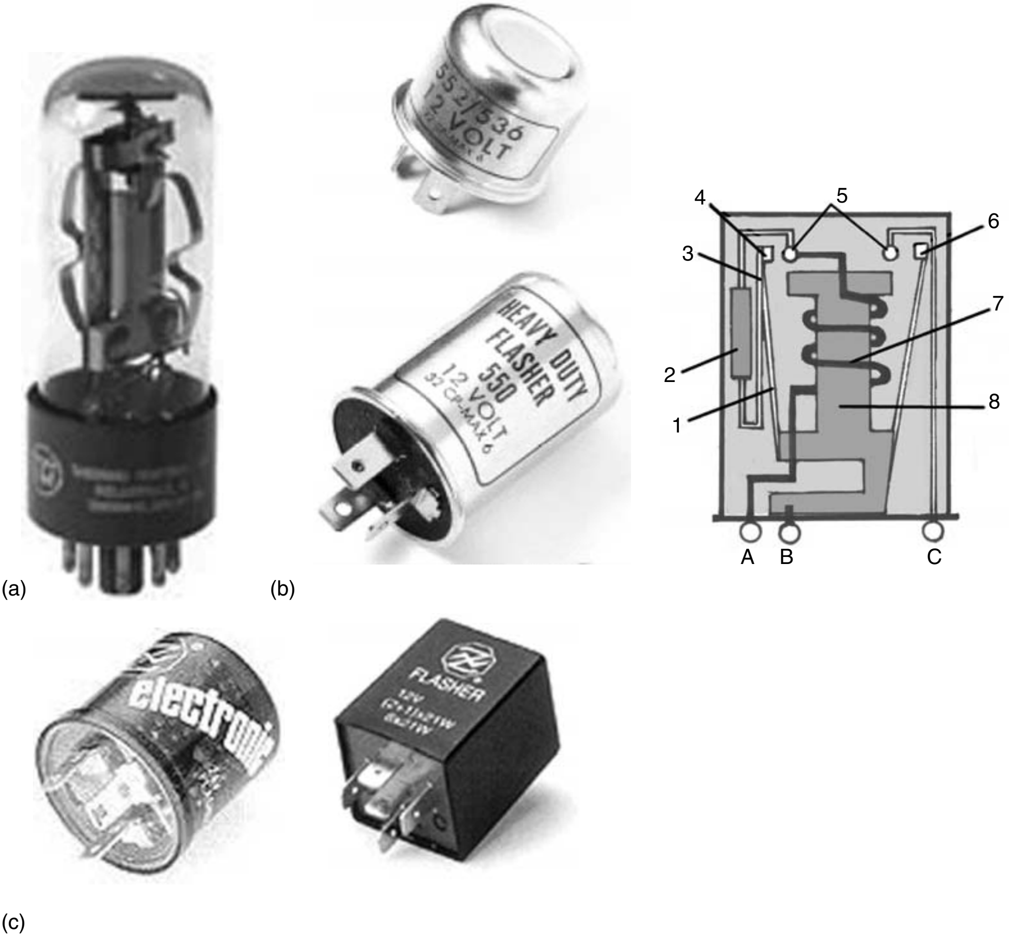


FIGURE 16.68
(a) Early thermal flashes relay of the 26F60T type, on basis of vacuum electron tube. (b) Thermo-magnetic automotive flashers in aluminum covers and it's design. 1 — Nihrom thread (20% Cr, 80% Ni); 2 — resistor (5 to 10 Ω); 3 — attracted armature; 4 — main moving contact; 5 — stationary contacts; 6 — auxiliary moving contact; 7 — coil; 8 — ferromagnetic core. (c) Electronic automotive flashers (Zung Sung Enterprise, Taiwan).

with, the ampere turns IN_1 and IN_2 are approximately equal but oppose each other, and the relay does not pick up. IN_1 is constant whereas IN_2 decreases as the current through the capacitor decreases. When the difference between IN_1 and IN_2 has become sufficiently large, the relay picks up and the lamp lights via contact 111–117. Contact 116 breaks at the same time and the capacitor discharges through both windings in series, causing IN_2 to change direction and ensuring that excitation suddenly becomes intense, so that the relay picks up distinctly. When the capacitor is discharged, the relay drops out and contact 116 makes again. Since IN_2 changes direction once more, the relay also drops out rapidly and cleanly. The sequence is repeated as long as contact B is closed. The signal lamp lights up and goes out via contact 111–117, and continues to flash as long as the relay is working. The relay is designed to give even flashing, that is, the light and dark intervals are equal in length. The flashing frequency is approximately 600 or 100, or approximately 40 flashes per min (rapid flashing and slow flashing, respectively). A flashing-light relay for AC supply has a built-in rectifier.

Automotive flashers take a separate place in this group of relays. Along with electronic devices (the principle of operation of which was described above), in automotive flashers the thermal principle is widely used. Very many companies are engaged in production of these relays.

Early thermal flashes relays were designed in bodies of vacuum electron tubes and outwardly were very similar to them (Figure 16.68a). Later on, many companies began making such relays in simple aluminum (and even plastic) covers (Figure 16.68b). Thermal (Bi-Metal) flashers are mechanical relays that operate through the heating and cooling of a bi-metal strip, opening and closing the contacts, causing the lamps to ''flash.''

The thermo-magnetic flasher works as follows: At actuation of the flasher, the current is applied on terminal B, from it to core 8, across nihrom thread 1 into armature 3, resistor 2 into the coil 7 to terminal A, then into the switch and further, in lamps of the parking lights and rear canopy.

In connection with that, resistor 2 is also for the purpose of burning of lamp filaments by partial light. At a passing of current through nihrom thread 1, it is heated and lengthened. The current, passing through coil 7, creates in core 8 magnetic fields. The aim of these fields is to attract armature 3 to core 8. As soon as thread 1 is lengthened to a definite value, contact 4 of an armature connecting with stationary contact 5 and resistor 2 is shunted (switched OFF) from the series circuit. The filaments of lamps thus ignite with full heat. The lamps will shine brightly as long as the thread 1 does not cool down and armature 3 is not removed from the core. The contacts thus will be disconnected, and resistance will also join in a circuit of lamps. Further all will repeat. One cycle lasts 0.6 to 0.8 sec (70 to 100 flashings in minute).

Simultaneously with armature 3, the addition armature with contact 6 is attracted to another side of core 8. This contact 6 actuates an indicating light in automotive control panel. At burnout of one of main lamps, the indicating light does not ignite. This is a very old principle that for tens of years has been widely applied in automotive flashers. During the last 10 years, such thermo-magnetic devices are being displaced with electronic ones.

Not only are totally electronic devices on IC relevant to electronic automotive flashers, but also simple devices, founded on charge–discharge of capacitors (similar, figured in Figure 16.67). Such a flasher is comprised of an electromechanical relay with an opposing A and B coil. A capacitor prevents one coil from pulling in relay contacts until it is fully charged. The charging and discharging of the capacitor, along with a resistor, determine the flash rate and set the duty cycle (ON/OFF time).

Specializing companies produce a wide range of automotive flashers of all types, for example Amperite, Littelfuse, Zung Sung Enterprise, and others. As can be seen from the examples considered above, flashing-light relays are quite simple and compact devices that are not noted for great originality. But it turns out that among these relays, there are also some very imaginative and mind-boggling constructions (Figure 16.69).

The principle of operation of this relay lies in periodic oscillations of the mercury filling the lower part of a U-shaped glass tube, when mercury is periodically squeezed from the right bend to the left, closing contacts A and C and returning, opening these contacts. The mercury is displaced by gas filling the free space in the section II, above the right mercury pile. The heater W, heating the gas, is also placed there. When part of the mercury is squeezed out from the right part of the U-shaped tube, contact B, through which the contact is supplied, opens, the gas cools down, and the mercury gradually returns to its initial state.

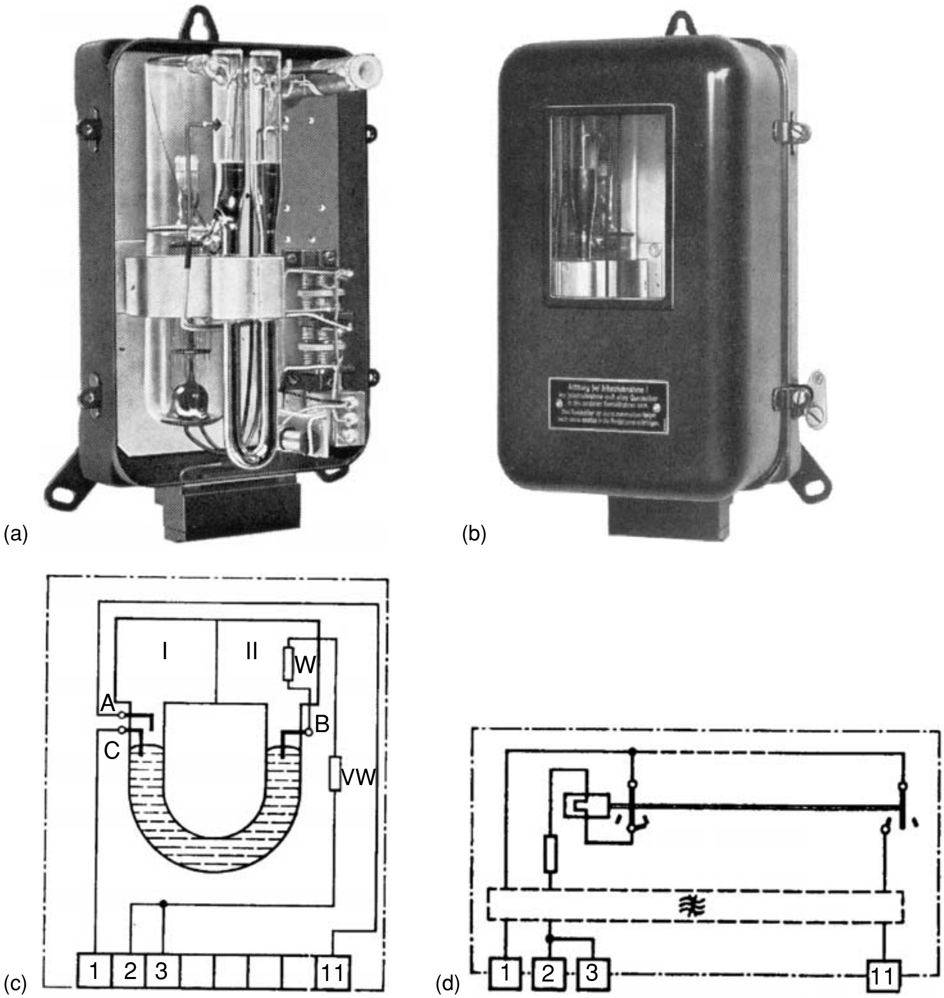


FIGURE 16.69
Mercury flashing-light relay produced by Siemens. External design and circuit diagram. (Siemens 1989 catalog.)

In what century do you think such relays were produced? You are most likely to be mistaken! Siemens produced such relays in 1972 (!), at the very same time when there were so many of the simplest constructions, of small size and weight, on the market. Perhaps this relay was a breakthrough in engineering in the 19th century. It is a very strange to see such device in middle 1970s of the 20th century.

16.10 Buchholz Relays

Protection relays of the Buchholz principle have been known for over 60 years. This *Gas Detector Buchholz Relay (Gas Relay, Buchholz Relay)* is used to protect equipment immersed in liquids by monitoring the abnormal flow or its absence, or an abnormal formation of gas by the equipment (most faults in an oil-filled power transformer are accompanied by a generation of gas). These relays are normally used in transformers with expansion tanks. They collect gas that is gradually released due to small internal problems such as bad connections, small arcs, etc. until the volume of gas operates a switch, which then gives an alarm signal. The gas can then be collected and analyzed to determine the nature of the problem.

The Gas Detector Relay also responds to larger internal faults, where larger amounts of gas are released. It will detect a larger flow of gas and operate a switch to give a trip signal, which can be used to trip the primary device and deenergize the transformer until the severity of the fault can be determined. The Gas Detector Buchholz Relay is normally installed between the main tank of the transformer and the oil expansion tank. (Figure 16.70) The Gas Relay has one (Figure 16.72) or, generally two independent contacts (Figure 16.71) (a twin-float relay) coupled to the float and the deflector or float, respectively. One of the contacts operates according to the gas accumulation and the other with sudden variations of the insulating liquid flow. It has two opposing viewing glasses with graduated scales, indicating the accumulated gas volume.

When the item of equipment being monitored is operating normally, the Buchholz relay is completely filled with oil and the up thrust on the floats keeps them at their top limit or ''rest'' position. If a fault causes gas to be generated slowly, the gas bubbles eventually accumulate in the Buchholz relay. The resulting fall in the oil level brings the float down and the permanent magnet incorporated in the float operates a contact until the response position is reached, which usually causes an alarm signal to be initiated.

The amount of gas that accumulates is approximately 200 cm^3. The bottom float is unaffected by the gas. Any excess gas generated escapes to the conservator and this prevents tripping of the transformer by the bottom contact system, which is intended only to detect serious internal faults. When an alarm is given, the gas in the equipment must be examined without delay in order to prevent the fault from possibly becoming more serious. In the event of a leak in the transformer, the fall in oil level causes the top float to move downwards and the top contact system responds in the same way.

If the loss of oil continues, the conservator, pipe work, and the Buchholz relay itself, drain through the Buchholz relay, which causes the bottom float to fall and operate the contact to trip the transformer. Any sudden pressure surge in the transformer produces a surge flow of oil in the pipe to the Buchholz relay. The baffle plate, which is suspended in the oil flow, responds to a velocity of 100 cm/sec and works through two actuating levers to move the bottom float to a position where it triggers the contact system. The bottom float latches in the response position and this holds the contact system in the trip position. The float can be unlatched and returned to its original position by quickly rotating the test button to the stop.

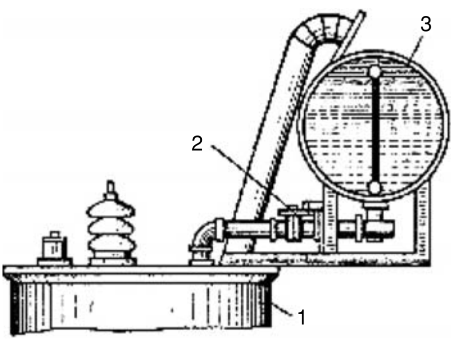


FIGURE 16.70
Mounting of a Buchholz relay on a power oil-filled transformer. 1 — Transformer tank; 2 — Buchholz relay; 3 — oil expansion tank (conservator).

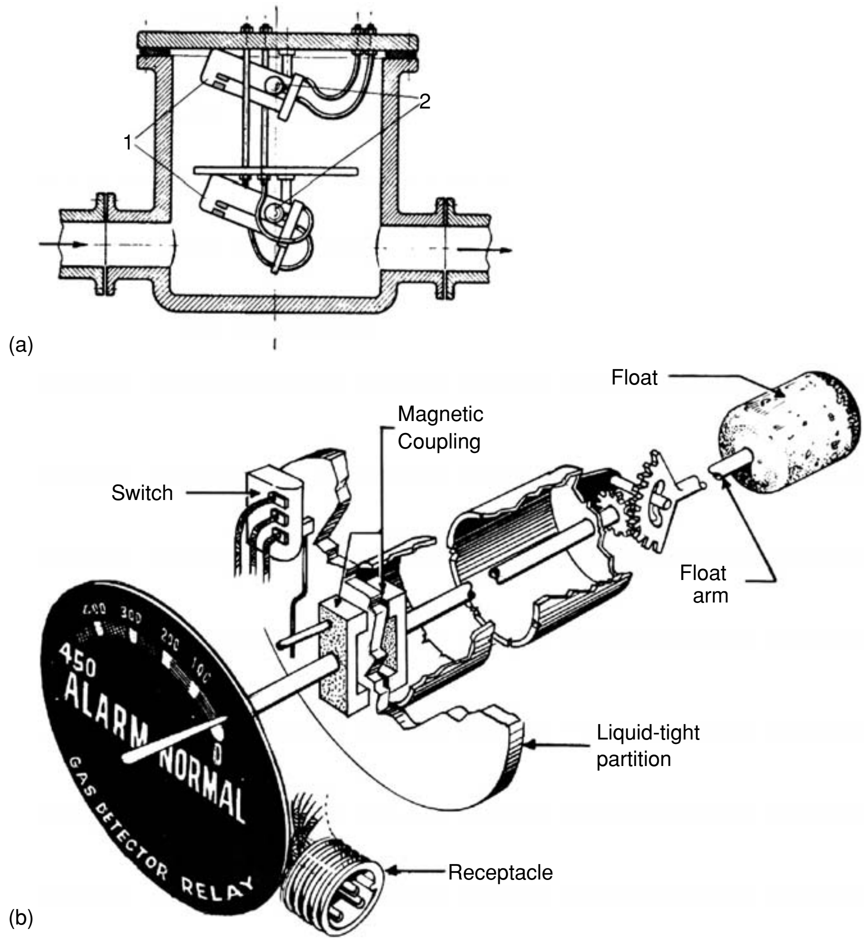


FIGURE 16.71
Earlier constructions of gas detector relays: (a) With overlapping iron balls (2), placed inside a hollow float with contacts (1); (b) with a float and a train linking the float with the contacts and also with a pointer indicator. (General Electric gas detector relay.)

Relays with hollow floats turned out to be not very reliable, because of a great number of cases of depressurization and filling of the float with oil, causing the ''float'' to stop being a float and the relay to stop functioning.

The construction of the Buchholz relay with cup-shaped elements, eliminating problems of this kind, was considered quite reliable. Relays of this type were produced by the Zaporozhye Transformer Plant (in the former U.S.S.R.) in 1970–80's. In these relays in a normal mode (when the entire relay volume is filled with oil), cups 2 and 3, also filled with oil, are retained in the initial position (shown in Figure 16.73), that is, they set against the stops with the help of the springs 8.

The oil pressure affecting the cups from all sides is balanced, and only the dead weight of the light aluminum cups is compensated by springs. When the upper part of the case is filled with gas, the level of oil decreases and the cup filled with oil, affected by the force of gravity of the oil, turns, closing the contacts. Serious damages in the transformer entail

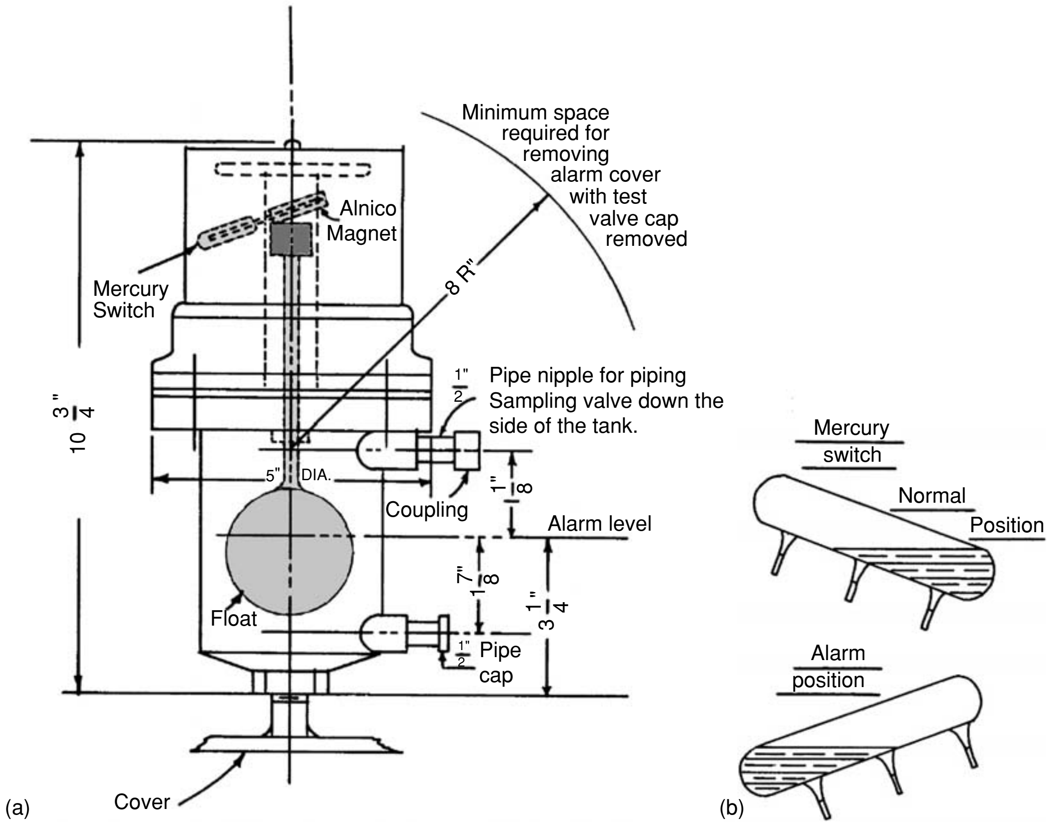


FIGURE 16.72
Later construction of gas detector relays based on mercury switches. (General Electric gas detector relay.)

violent gassing. In such cases the oil stream, directed into the conservator through the Buchholz relay installed on its way, affects blade 4 (Figure 16.73), causing rotation of the cup and the closing of the contacts.

When dry-reed switches controlled by a permanent magnet appeared, practically all producers of Buchholz relays started to apply these elements (Figure 16.74), and molded floats from foam plastic.

Various modern constructions have negligible construction differences (Figure 16.75), for example, translation coaxial displacement of floats (Figure 16.76) instead of an angular one.

Two essential parameters of the Buchholz relay are sensitivity and noise-immunity. These two parameters are equally important (malfunctioning of the relay or its false operation, and disabling of the power transformer are equally adverse) but their functions are not. It is impossible to considerably increase the sensitivity of the Buchholz relay without deterioration of its noise-immunity, which is why adjustment of such a relay is always a compromise between its sensitivity and noise-immunity.

False pick ups of the relays cause some specific problems during short circuits in the high-voltage line (that is outside of the transformer), which is why no additional gassing occurs inside the transformer and the Buchholz relay must not pick up. If such relay does pick up, the maintenance staff is faced with a dilemma: either to ignore such pick up of the Buchholz relay and switch the transformer under voltage, or to disable the trans-

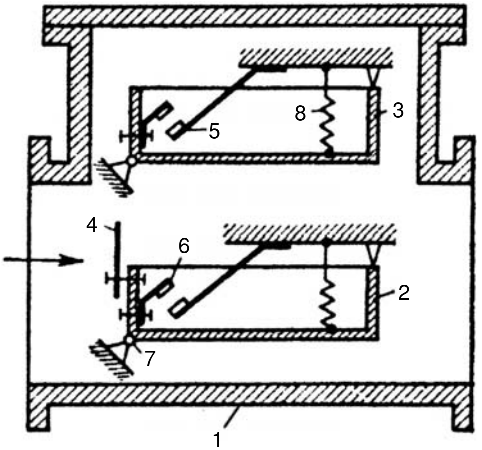


FIGURE 16.73
Construction of a Buchholz relay with cup-shaped elements. 1 — Case; 2 and 3 — open flat-bottomed aluminum cups; 4 — paddle; 5 — stationary contact; 6 — movable contact; 7 — axis of rotation of the cup; 8 — spring.

former and examine its insulation. In either case, this is quite a crucial decision because one runs a risk of very great potential damage.

Examination of a situation like that which the author happened to witness has shown that the prime certification center KEMA, conducting tests and certification of power transformers for the power industry, does not check and fix the state of the Buchholz relay when transformers are tested for resistance to short-circuit currents. Thus it remains unclear how this or that type of the Buchholz relay will operate during exploitation in

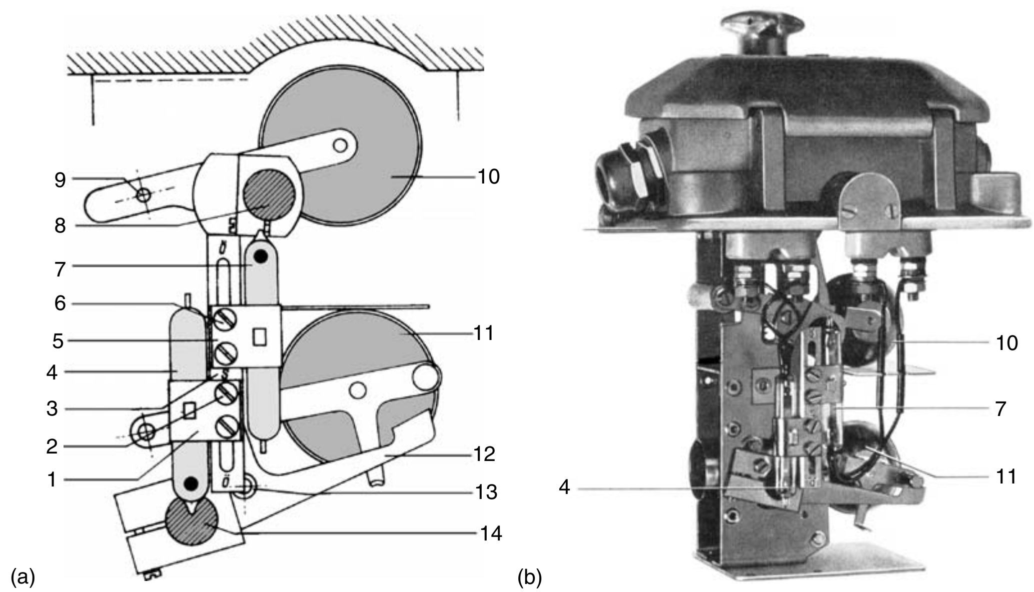
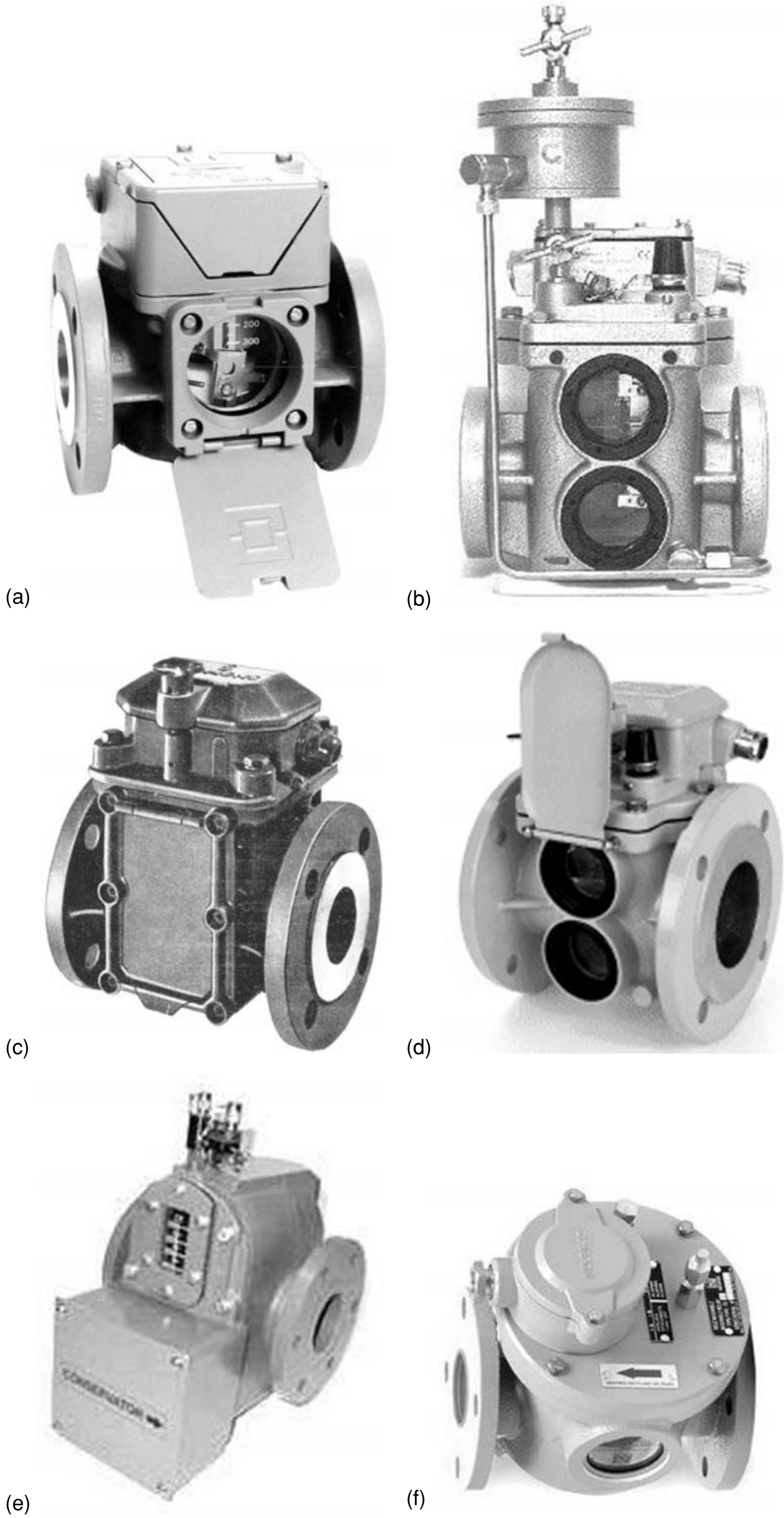


FIGURE 16.74
Buchholz relay of the RT 823 type, with dry-reed switches, operated by a moving permanent magnet (Siemens). 1 and 5 — Brackets for rearrangement of contact (reed switch) tubes; 2 and 6 — screws; 3 — slide rail for contact tube rearrangement; 4 and 7 — dry-reed switch tubes; 8 and 14 — permanent magnets; 9 — fulcrum of float; 10 — alarm float; 11 — trip float; 12 — tripping lever; 13 — bearing.



(a) (b) (c) (d) (e) (f)

FIGURE 16.75
Modern types of Buchholz relays, produced by different companies.

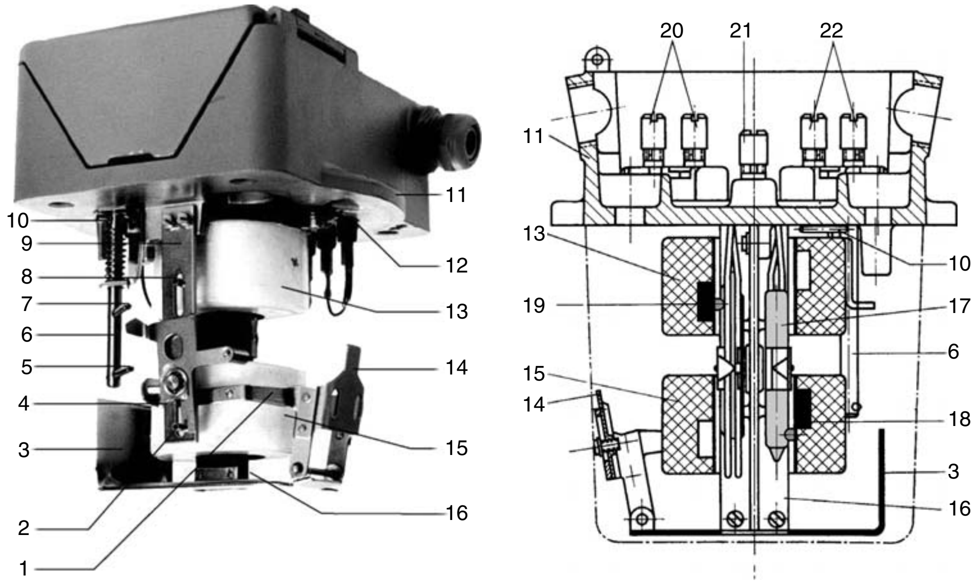


FIGURE 16.76
Modern Buchholz relay of the DR-50 type, with translating floats and permanent magnets molded into solid floats (Siemens). 1 — Actuating lever; 2 — location pin; 3 — flow guide plate; 4 — latch for bottom contact system; 5 — bottom test pin; 6 — test rod; 7 — release pin; 8 — location pin; 9 — guide rail; 10 — top test pin; 11 — housing cover; 12 — triple bushing; 13 — top float (alarm); 14 — baffle plate; 15 — bottom float (trip); 16 — strut (T-section); 17 — dry-reed switch for bottom float (trip); 18 — permanent magnet in bottom float; 19 — permanent magnet in top float; 20 — alarm terminals; 21 — earthing terminal; 22 — trip terminal. (Siemens. Twin Float Buchholtz relays.)

real circumstances, when short-circuit currents cause a sudden displacement and change of size of the windings of the transformer, leading to hydraulic shock in the oil and a shock wave in the Buchholz relay. Unfortunately, even modern constructions are prone to such false pick ups and the maintenance staff can only attempt to surmise the real reasons for picks up of the relay. One more problem is not adequate reaction of the relay at earthquake when displacement of internal parts of the transformer leads to occurrence of a wave in oil and to moving floats of the relay (and actuating contacts, of course).

16.11 Safety Relays

The technical requirements applicable to the design of control systems are stipulated in European Norm (EN) Standard EN 954-1, ''Safety-related components of control systems.'' This standard is applied following the assessment of the overall risk to EN 1050, ''Risk Assessment.'' European standard EN 954-1 stipulates that machines can be classified into five categories, whereby the safety circuits must be designed in accordance with the requirements of the relevant category. Moreover, standards VDE 0113, part 1, EN 60204, Part 1, and ICE 204 1.10 apply to control systems required to perform safety-related tasks. All safety relays can be used on the basis of their classification into the risk categories in EN 954-1, are approved by the employers' liability insurance associations and/or the German Technical Inspection Authority (TÜV), and comply with the requirements of EN 60204, Part 1. EN 954-1, in order to achieve as high a level of personal safety and machine protection as possible. This classification is preceded by a risk assessment to EN 1050, which allows for various criteria such as the ambient conditions in which the machine is operated.

Control reliability information can also be found in documents published by the American National Standards Institute (ANSI) and Occupational Safety and Health Administration (OSHA). ANSI is an institute that provides industry guidance through their published machinery standards. OSHA is a U.S. government agency responsible for labor regulations. These organizations have provided the following definitions for control reliability. ''Control Reliability'' means that, ''the device, system or interface shall be designed, constructed and installed such that a single component failure within the device, interface, or system shall not prevent normal stopping action from taking place but shall prevent a successive machine cycle.'' (ANSI B11.19-2003 ''Performance Criteria for Safeguarding''; ANSI B11.20-1991 ''Machine Tools — Manufacturing Systems/Cells — Safety Requirements for Construction, Care, and Use.'') In addition, OSHA 29 CFR 1910.217 states that, ''the control system shall be constructed so that a failure within the system does not prevent the normal stopping action from being applied to the press when required, but does prevent initiation of a successive stroke until the failure is corrected. The failure shall be detectable by a simple test, or indicated by the control system.''

Unfortunately, there is more than a little confusion in the world of safety terms and codes, but the discussion of these problems is beyond the framework of our book The risks and dangers, and the possible technical measures to reduce these risks and dangers, are stipulated in the subsequent assessment of the overall risk.

Electric relays contain many parts, which are subject to dynamic, electrical, or thermal wear. There are many applications where safety is very critical and it is important to use electrical equipment, ensuring that dangerous machine movement cannot occur when a fault is detected with the moving relay contacts during the cycle in which the fault is indicated.

In order to assure safe function, especially in the event of a failure, appropriate controls are built into the circuits of safety devices. Relays with forced guidance contacts play a decisive role in preventing accidents in machines and systems. Safety control circuits enable switching into a failsafe state. Forcibly guided contacts monitor the function of the safety control circuits. For this safety function, all assumed faults that can occur must already have been taken into consideration and their effects examined. Standard EN 50205, ''Relays with forcibly guided contacts,'' contains current internationally defined design requirements. Relays with forcibly guided contacts that comply with EN 50205 are also referred to as ''safety relays.''

Safety relays (Figure 16.77) are used in all control circuits for safeguarding devices such as interlocks, emergency stops, light screens, safety mats, and two-hand controls, to comply with the control reliability requirement. Safety relays have *Positive-Guided* (*Force-Guided* or *Captive,* IEC 60947-1-1) contacts, which are very different from conventional relays. The actuator (mechanical linkage) for the positive-guided relay is placed much closer to the contacts than on conventional relays. This placement of the actuator, and the lack of gap tolerance on the positive-guided relay, insures a consistent relationship between the NO contacts and the NC contacts: contacts in a contact set must be mechanically linked together so that it is impossible for the NO Make contacts and the NC Break contacts to be closed at the same time. The relays can provide positive safety for the NO and NC contacts, which assure that the *NO contacts will not close before any NC contact opens.* Therefore, if one of the contacts welds due to abnormal conditions in the control circuit, the other contacts will also remain in the same position as when the welding occurred. The positive-guided relay is guaranteed to maintain a minimum 0.5 mm distance between its

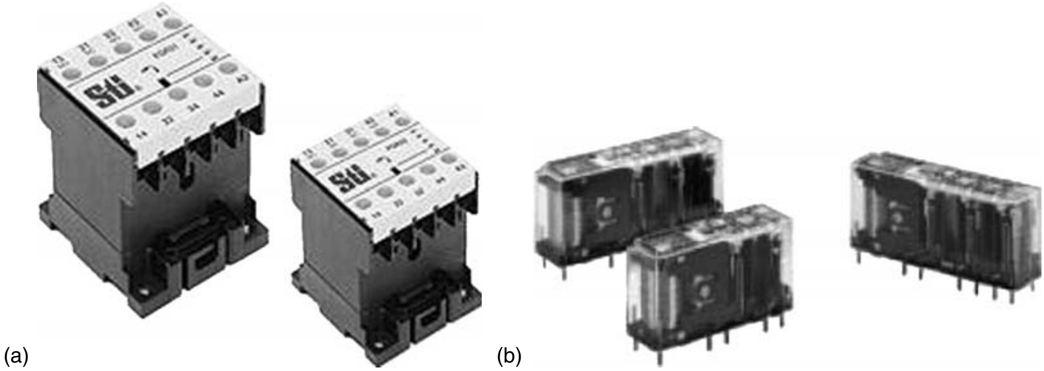


FIGURE 16.77
Positive-guided relays with mechanically-linked contacts conforming to IEC 60947-1-1 as required for safety-related control systems: (a) FGR type (STI Scientific Technologies GmbH) (b) G7SA type (Omron).

NC contacts when the NO contact is held closed. This characteristic makes the positive-guided relay a preferred relay when designing safety circuits for generating a safe output.

Safety relays are specifically designed to monitor safety-related control systems, such as emergency-stop circuits, safety mats and bumpers, security doors, standstill, over-travel monitors; two-hand controls, etc. Special expansion units are available if a large number of safety circuits are required.

In accordance with EN954-1, ''Safety-related components of emergency stop and monitoring of guard doors control systems,'' the classification is made on the basis of one of five possible risk categories. These categories: B, 1, 2, 3, and 4 (the highest), then indicate the requirements applicable to the design of the safety equipment, whereby B as the basic category describes the lowest risk and stipulates the minimum requirements. Thus, for instance, category 2 requires compliance with the requirements of B and the use of time proven safety principles. Moreover, the safety function must be checked at appropriate intervals by machine control.

The choice of emergency stop of the machine is determined by its risk assessment. In EN 60204-1 the Stop Function is divided into three categories. Emergency stops must conform to category 0, category 1, or category 2.

Category 0 — STOP:

Shut-down by immediate switching off of the power supply to the machine drives (uncontrolled shut-down)

Category 1 — STOP:

A controlled shut-down, whereby the power supply to the machine drives is maintained in order to achieve the shut-down, and the power supply is only interrupted when the shut-down has been achieved.

Category 2 — STOP:

A controlled shut-down, whereby the power supply to the machines is maintained.

Stop functions of category 1 or 2 or both must be provided when this is necessary for the safety and functional requirements of the machine. Category 0 and category 1 stops must be able to function independently of the mode, and a category 0 stop must have priority. Stop functions must take place by deenergizing the corresponding circuit and have priority over the associated start functions.

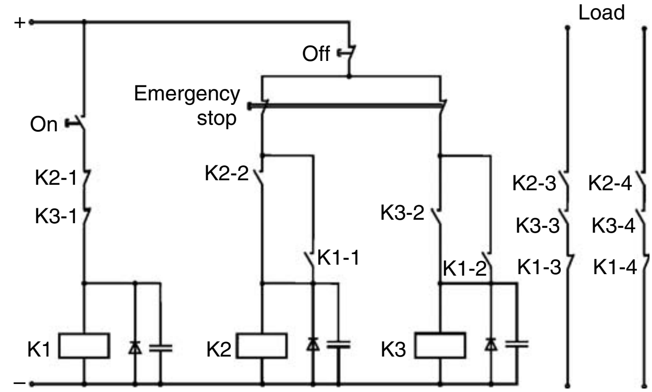


FIGURE 16.78
Basic connection diagram for safety emergency-stop relays.

In a redundant circuit (e.g., EMERGENCY STOP), it is possible for cross-circuiting to go unnoticed. If an additional fault then occurs, the safety device ceases to be effective. This is exactly what must not happen in a category 4 circuit. In other words, a cross-circuit does not cause the EMERGENCY STOP switch to be bridged. Other possible faults are what cause this. For this event, the safety relays are equipped with cross-circuiting detection.

Due to such switching (Figure 16.78), no damages of any of the relays can lead to lack of emergency switching of the load. Many companies around the world produce safety relays of different types. The Allen-Bradley Company produces the greatest number of variants of relays of this kind. Some variants of safety relays produced by Allen-Bradley under the trade brand ''Minotaur'' are briefly considered below.

The MSR5T relay (Figure 16.79.) has one NC single channel input for use with gate interlocks, and emergency-stop buttons, in lower risk applications. The MSR5T has output monitoring that can accommodate an automatic or manual-reset function. Automatic or manual-reset can use a jumper or can be used to check operation of the contacts. The MSR5T has three NO safety outputs and one NC auxiliary output. The safety outputs have independent and redundant internal contacts to help ensure the safety function. The

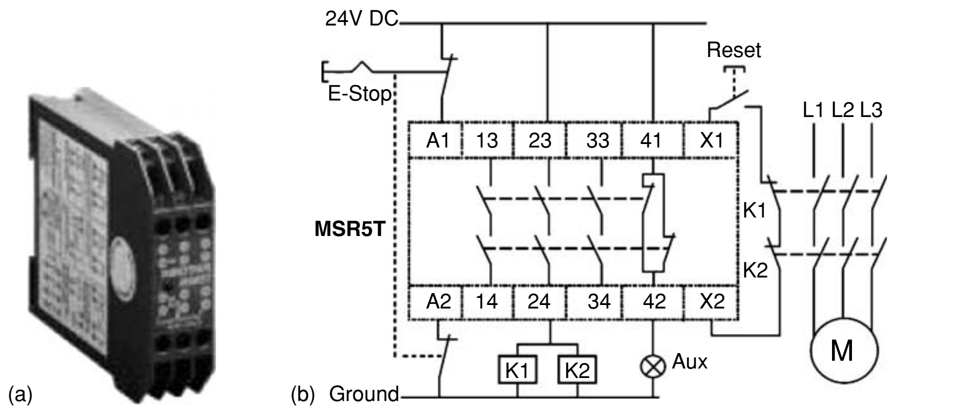


FIGURE 16.79
A dual-channel E-stop relay, MSR5T, with manual reset and monitored output. (Allen Bradley [Rockwell Automation 2004].)

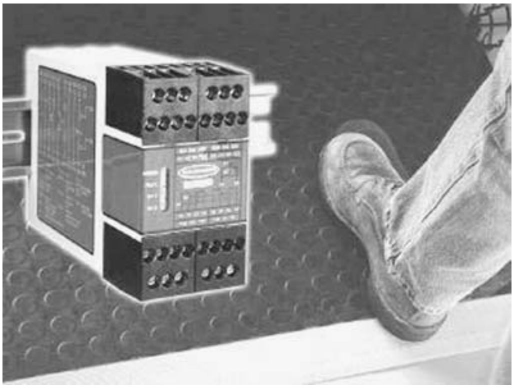


FIGURE 16.80
Safety-mat relay of the SM-GA-5A type (Banner Engineering Co.)

auxiliary contact is a nonsafety output, intended to provide an external signal regarding the status of the safety outputs.

The *Safety-mat relay (Monitor* — Figure 16.80) feature provides a uniform activation threshold (on/off signal) throughout the entire mat surface area. Modern design of uniform activation also provides a guarding system that contains no dead zones. This provides the user with a much safer guarding system, as well as compliance with domestic international standards.

The relay's sensor circuit monitors the contact plates of the safety mat and consists of bipolar (diverse) redundant channels that issue the stop command (i.e., open the safety outputs) when the two channels are shorted together, as individual steps onto the safety mat. The relay provides the redundant safety outputs required to create a control-reliable safety circuit. Contacts include four redundant, forced-guided (positive-guided) outputs rated at 6 A. One NC output monitors status, and two auxiliary solid-state outputs indicate the state of the internal relays and power supply. The safety mat relay offers two primary functions. It monitors the contacts and wiring of one or more safety mats, preventing machine restarts in the event of a mat or module failure. It also provides a reset routine after an operator steps off a mat (per ANSI B11 and National Fire Protection Association (NFPA) 79 machine safety standards, via selectable Auto-Reset or Monitored Manual Reset modes).

The MSR23M (Figure 16.81) control relay is designed to monitor four wire safety mats that are connected together to form a safeguarded zone. The size of the safeguarded zone is limited by the total input impedance (100 Ω maximum), created by the wiring and connections.

The controller is designed to interface with the control circuit of the machine and includes two safety relays to ensure control redundancy. The controller detects a presence on the mat, a short circuit, or an open circuit. Under each of these conditions, the safety output relays turn off. When interfaced properly, the machine or hazardous motion receives a stop signal, and an auxiliary output turns ON.

Special safety relays are available for *two-hand controls* (Figure 16.82). Two-hand circuits (Switch-1 and Switch-2) require simultaneous operation by both hands to initiate and maintain the operating status of a machine. As a result the operator is protected, because he cannot reach the danger zone during hazardous procedures. The electronic safety relay monitors whether or not both buttons are operated within 0.5 sec of one another.

The MSR22LM safety-monitoring relay (Figure 16.83) is designed to monitor light curtains with the added features of muting and *presence sensing device initiation* (PSDI). It provides an output to a machine control system when the light curtain is clear. When

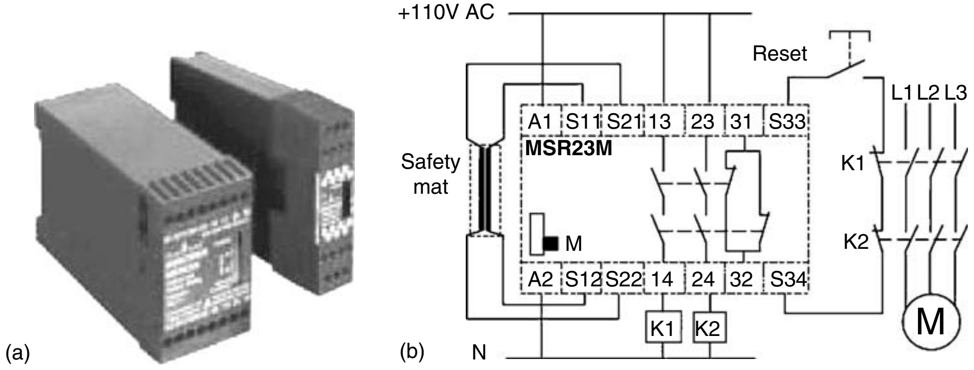


FIGURE 16.81
Safety-mat relay of the MSR23M type, with dual-channel monitored output and manual reset. (Allen Bradley [Rockwell Automation 2004].)

the inputs to the MSR22LM are closed (conducting), the output relays are closed if the monitoring circuit is satisfied. The MSR22LM has three sets of dual channel inputs. This allows it to operate in four different configurations:

1. Monitors up to three light curtains in guard only mode.
2. Monitors up to two light curtains with two muting sensors (only one curtain muted).
3. Monitor one light curtain with four muting sensors.
4. Monitors up to three light curtains with PSDI (only one curtain initiated).

The MSR21LM uses microprocessor-based technology to offer a wide variety of advanced safety solutions in a small 45 mm DIN rail mounted housing. Internal selector switches provide for easy selection of up to ten different applications. Four LEDs give

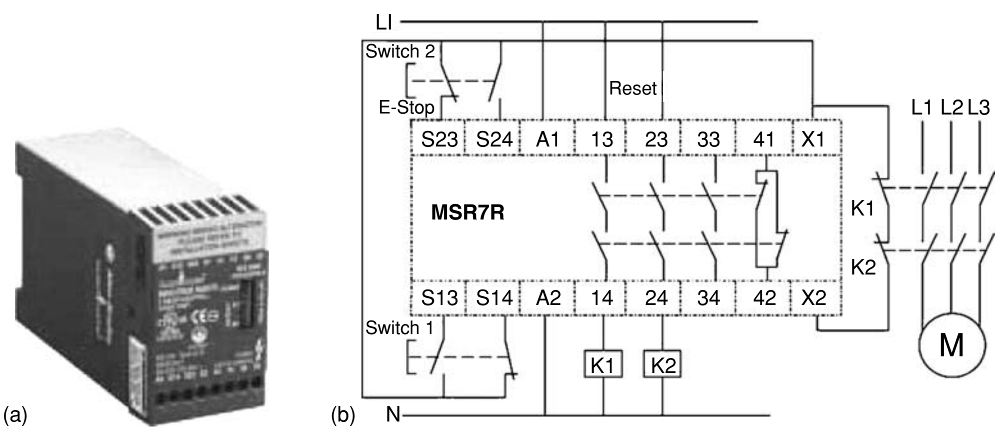


FIGURE 16.82
Two-hand safety relay of the MSR7R type, with dual-channel monitored output and automatic reset. (Allen Bradley [Rockwell Automation 2004].)

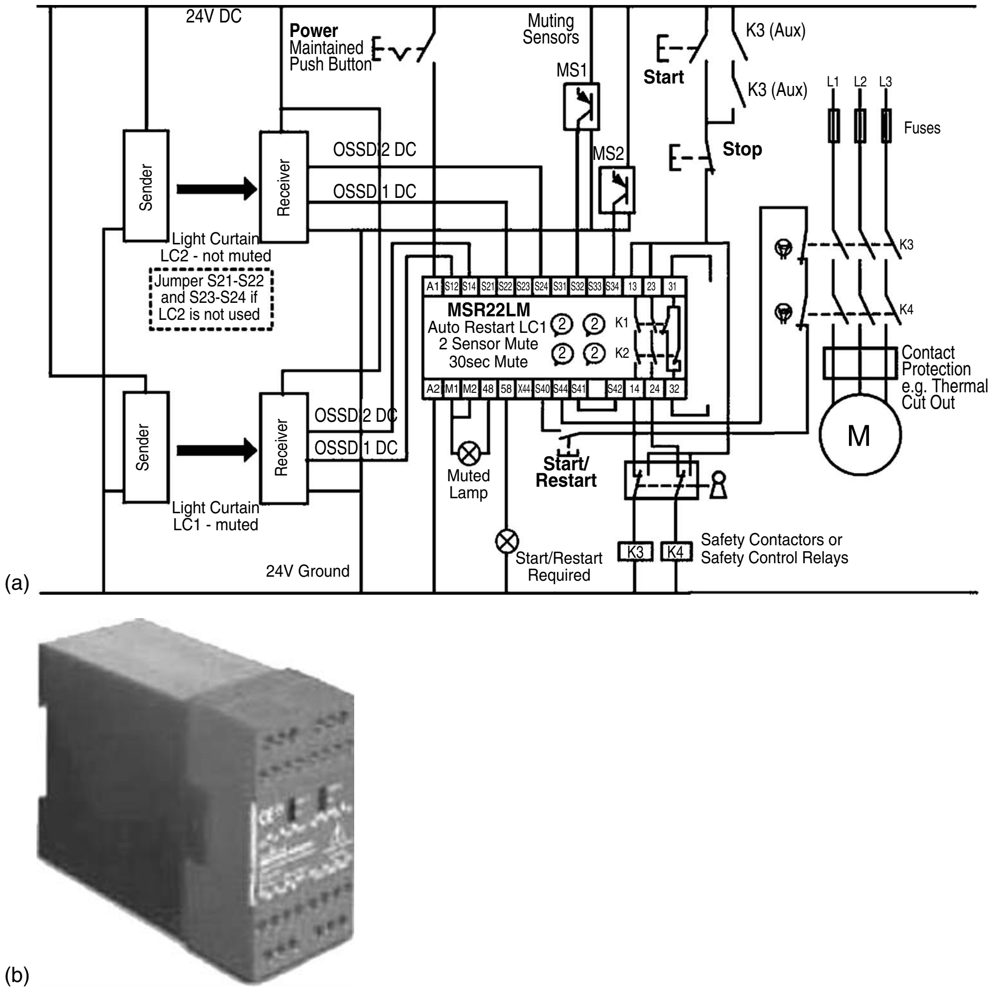


FIGURE 16.83
The MSR22LM safety monitoring relay. (Allen Bradley [Rockwell Automation 2004].)

operational status as well as diagnostic information. Removable terminals reduce wiring and installation costs when replacement is necessary.

If the stopping time of the machinery is unpredictable, use a *Standstill Relay* (Figure 16.84). This relay measures the back EMF of the connected motor from the terminals of one stator winding. When the EMF has decreased to almost zero, this device detects that the motor has stopped and energizes its output relays.

In addition, the FF-SR05936 monitors the connections to the motor for broken wires on terminals Z1 and Z2. If an open (line break) is detected, the output relay contacts the latch in the deenergized position, as if the motor was running. After the break has been repaired, the relay is reset by momentarily removing power to the module.

We have considered only a few main types of safety relays produced by several companies. There are several other types of such relays and the production of them has turned into quite a large industry, in which tens of major and many smaller companies work.

FIGURE 16.84
Standstill relay of the FF-SR05936 type (Honeywell).

16.12 Ground Fault Relays

A *Ground Fault Relay* is a device that is intended to trip out an electricity supply in the event of a current flow to earth. As such, it can provide protection from harmful electric shocks in situations where a person comes into contact with a live electrical circuit and provides a path to earth. These devices KILL THE CURRENT before the current KILLS YOU! Typical examples of this occurring are with the use of faulty electrical leads and faulty appliances.

Fuses or overcurrent circuit breakers do not offer the same level of personal protection against faults involving current flow to earth. Circuit breakers and fuses provide equipment and installation protection and operate only in response to an electrical overload or short circuit. Short-circuit current flow to earth via an installation's earthing system causes the circuit breaker to trip, or a fuse to blow, disconnecting the electricity from the faulty circuit, however, if the electrical resistance in the earth fault current path is too high to allow the circuit breaker to trip (or a fuse to blow), electricity can continue to flow to earth for an extended time. Ground fault relays detect a very much lower level of electricity flowing to earth and immediately switch the electricity OFF.

In various countries they have different names for ground fault relays: In *Germany* and in *Austria*: ''Fehlerstrom-Schutzschalter'' or ''Fehlerstrom-Schutzeinrichtung'' (Schutzschalter — protective switch, Schutzeinrichtung — protective device), and they also use the abbreviation FI (F — Fehler — fault, error, escape, I — indication of current in electrical engineering); in *France*: ''Disjoncteur Differentiel'' (differentia switch) or — DD in the abbreviated form; in *Great Britain*: ''Earth Leakage Circuit Breaker,'' ELCB or ELB in abbreviated form; in the *U.S.A. and Canada*: ''Ground Fault Circuit Interrupter,'' GFCI or GFI in abbreviated form; in *Israel*: ''Mimsar Phat'' (''Mimsar — relay, ''Phat'' — remainder, remaining).

At present, the International Electrotechnical Commission applies a joint name for all types of devices of this kind: *Residual Current Devices (RCD).* There are also some derivatives of this mane:

- Residual current circuit breaker (RCCB) — mechanical switch with an RCD function added to it. Its sole function is to provide protection against earth fault currents.

- Residual current Breaker with overcurrent protection (RCBO) — an overcurrent circuit breaker (such as an MCB) with an RCD function added to it. It has two functions: to provide protection against earth fault currents and to provide protection against overload currents.

An RCD should be fitted to socket outlets installed in wet environments and outside, and must be provided on sockets in premises of public entertainment such as clubs, village halls, and pubs:

- SRCD — socket outlet incorporating an RCD
- PRCD — portable RCD, usually an RCD incorporated into a plug
- SRCBO — a socket outlet incorporating an RCBO

The basis for protective switching OFF as an electro-protective means is the principle of limitation (due to rapid switching OFF) of duration of current flowing through the human body when one unintentionally touches elements of charged electrical installation. Of all known electro-protective means, the RCD is the only one that protect a human being from electric current upon direct touch of a current-carrying unit.

Another important property of the RCD is its capability to provide protection from ignition and fires taking place in units because of various insulation damages, electric wiring and electrical equipment failure. Short circuits occur, as a rule, due to insulation defects, earth connections, and earth current leakages. In addition, the energy released at the point of insulation fault at leakage current flowing may be enough for ignition. Released power of just 50 to 100 W can ignite a fire, depending on the material and service life of the insulation. This means that timely pick up of a fire-preventive RCD with a pick-up threshold of 300 to 500 mA will prevent a power release, and therefore the ignition itself (RCDs for such pick-up currents cannot protect people from electrical shock).

The first construction of an RCD was patented by the German firm RWE (Rheinisch — Westfalisches Elektrizitatswerk AG) in 1928 (DR Patent No. 552678, 08.04.28). It suggested using the well-known principle of current differential protection of generators, power lines, and transformers for protection of people from electrical shocks. In 1937 Schutzapparategesellschaft Paris & Co. produced the first functioning device of this type, based on a differential transformer and a polarized relay with a sensitivity of 0.01 A and speed of operation of 0.1 sec. In the same year a volunteer conducted a testing of the RCD. The experiment was successful, the device picked up in time and the volunteer experienced only a slight electrical shock (though he refused to take part in further tests). During the next few years, with the exception of the war years and the postwar period, much research was done concerning the impact of electric current on human beings and development of electro-protective means; including first and foremost, the development and implementation of the RCD. In the 1950s it was stated that the human heart is most prone to electric current impact. Fibrillation (irregular twitching of the muscular wall of the heart) may occur even at small current values. Assumptions that asphyxia, muscle paralysis, and cerebral affection were primary reasons for the lethal outcome of electric current impact, ceased to have significance. It was also determined that the impact of electric current on the human organism depends not only on the current value but also on its duration, its route through the human body, and to a lesser degree on current frequency, form of the curve, pulsation factor, and some other factors. Results of research of the impact of electric current on humans are given in numerous publications, and serve as a basis for today's existing standards. One should pay special attention to fundamental

TABLE 16.1

Affection of Electric Current on the Human Organism.

Current (mA)	Effect	Result
0.5	Is not felt. Slight sensation by the tongue, finger-tips or through the wound	Safe
3	Sensation similar to that of ant bite	Safe
15	No chance to drop the conductor if one happens to touch it	Unpleasant, but not dangerous
40	Convulsions of the body and the diaphragm	Risk of asthma for a few minutes
80	Vibration of the ventricle of heart	Very dangerous immediate lethal outcome

research carried out in the 1940–50's at the University of California (Berkeley) by the American scientist Charles F. Dalziel. He conducted a set of experiments with a large group of volunteers to determine electrical parameters of the human body and the physiological impact of electric current on human beings. Results of his investigations are considered to be classical and are still significant at present. The electric current is considered to effect the human organism in the following way (see Table 16.1 and Table 16.2).

In the 1960–70's the RCD began to be actively implemented in practice all over the world, first place in countries of Western Europe, Japan and the U.S. At present, according to official statistics, hundreds of millions of RCDs successfully protect life and property of citizens of the U.S., France, Germany, Austria, Australia, and some others from electrical shocks and ignitions. The RCD has become a usual and compulsory element of any industrial or social electrical installation, of any switchboard panel, in all mobile dwellings (caravans in camping areas, commercial vans, junk food vans, small temporal electrical installations of external units fixed during festivals), hangars, and garages. RCDs are also integrated to switch sockets and units through which electrical tools or household devices are exploited in dangerous humid, dusty, etc., places with conductive floors. Insurance companies take into account insurance of RCDs installed on the unit and their state. Statistically, at present every resident of the countries mentioned above has at least two RCDs.

TABLE 16.2

Another Classification of Threshold Levels for 60 Hz Contact Currents.

Current (mA)	Threshold Reaction or Sensation
	Perception
0.24	Touch perception for 50% of women
0.36	Touch perception for 50% of men
	Cannot let-go
4.5	Estimated let-go for 0.5% of children
6.0	Let-go for 0.5% of women
9.0	Let-go for 0.5% of men
	Heart fibrillation
35	Estimated for 0.5% of 45 lb children
100	Estimated for 0.5% of 150 lb adults

Nevertheless, tens of major firms such as Siemens, ABB, GE Power, ABL Sursum, Baco, Legrand, Moeller, Merlin-Gerin, Cutler-Hammer, Circutor (In Russia: Gomel Plant ''Electrical Equipment,'' Kursk Public Corporation ''Electrical Device,'' Moscow Electrical-Type Instruments Plant, Cheboksar Electrical Equipment Plant) continue to produce such devices in different modifications, constantly improving their engineering factors.

Functionally the RCD can be defined as a high-speed protective relay, responding to differential current in conductors conducting electric power to a protected electrical installation. A differential measuring current transformer is its essential component.

Regardless of the function of the RCD it is switched ON in such a way that all working load currents, both phase current(s) and midpoint wire current, must pass through its most sensitive element, the differential current transformer. When it is switched ON accordingly, and when there are no faults, the magnetic fields created by all of these currents are mutually compensated (the algebraic sum of all currents passing through the transformer equals zero), and there is no voltage on the output (secondary) winding of the transformer. When the insulation is damaged (Figure 16.85) or one touches one of the phase conductors (Figure 16.86), additional leakage current through this damaged insulation or through the human body occurs. This current upsets the general balance of currents flowing through the transformer. Since it flows in only one direction, between the phase and the ground, it is not compensated by the reverse current of the neutral wire. This additional current is the ''*residual current*,'' inducing EMF in the second winding of the transformer. At that point the induced voltage is applied to the executive relay, which picks up at a certain level of input voltage (proportional to the residual current) and defuses the circuit. Technically, construction of executive relays can be divided into electromechanical and electronic ones.

Electromechanical relays do not depend functionally on the voltage of the power supply (so-called: ''*Voltage Independent*'' or *VI* — type). The source of energy necessary for protective functions (that is disabling operations) is the differential current to which it responds. Such relays are based on sensitive direct-action polarized latching relays (Figure 16.87 and figure 16.88).

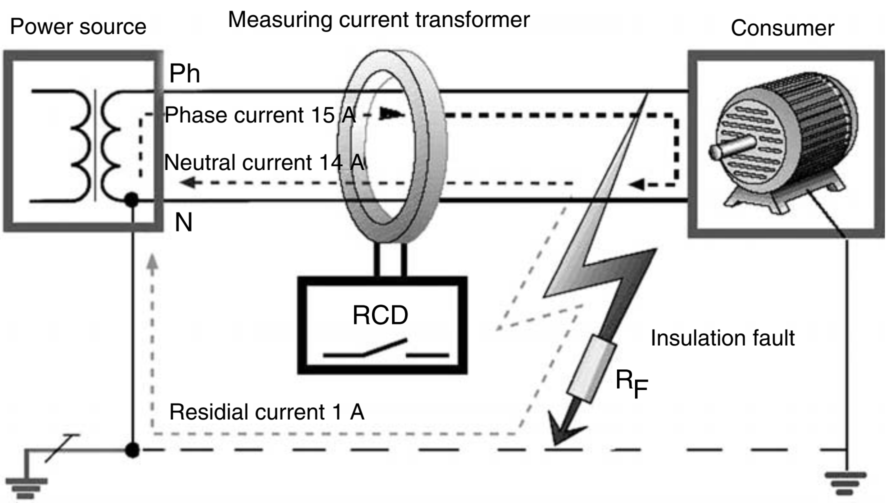


FIGURE 16.85
Principle of operation of a fire-preventive single-phase RCD device for pick-up current of 300, 500, and 1000 mA.

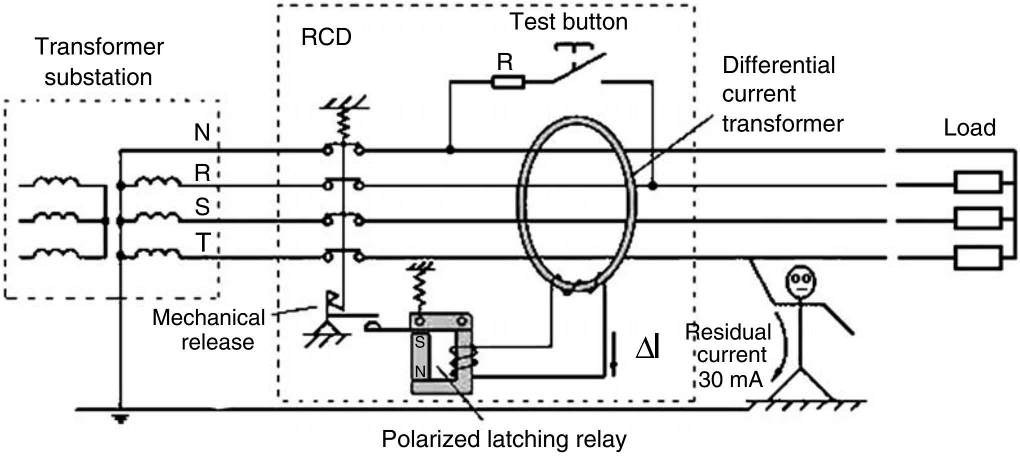


FIGURE 16.86
Principle of operation of a three-phase RCD device protecting from electrical shocks, with pick-up settings of 10, 30, and 100 mA.

Electronic executive relays depend functionally on the voltage supply (being *''Voltage Dependent''* or of the *VD* — type) and their switching-OFF mechanism requires electrical energy, which they obtain from the controlled circuit. The executive relay affects the disabling mechanism, which contains a contact group and a drive.

The principle of operation of the RCD can lead to the following conclusion: An RCD will significantly reduce the risk of electric shock, however, an RCD will not protect against all

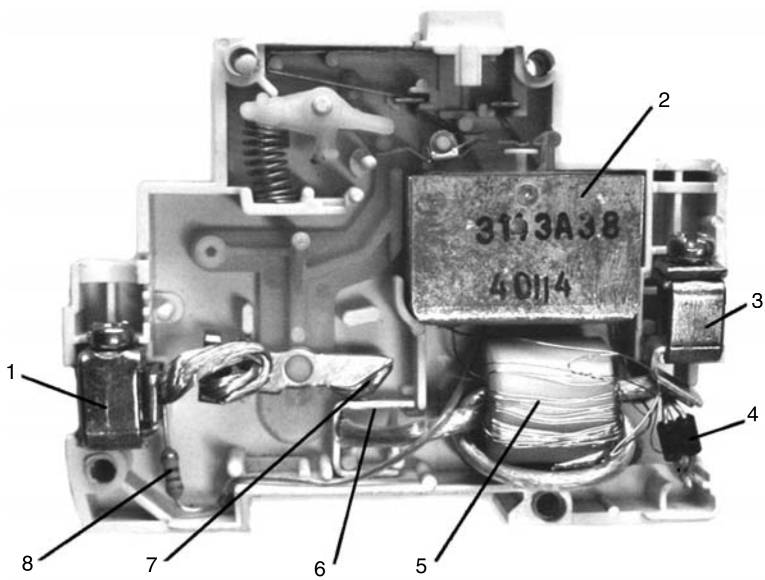


FIGURE 16.87
Construction of a single-phase electromechanical RCD made in the form of an additional section of a protective relay (automatic circuit breaker) of combined action. 1 and 3 — Terminals for connecting to the external circuit; 2 — executive relay; 4 — rectifying diodes for supply of the executive relay; 5 — differential current transformer; 6 and 7 — contact system; 8 — resistor of the tested circuit.

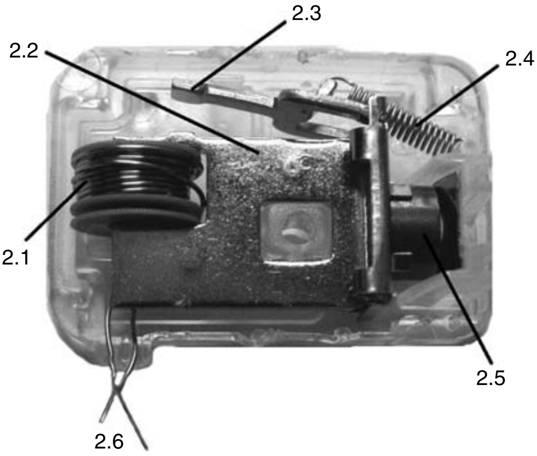


FIGURE 16.88
Construction of an electromechanical executive relay (enlarged). 2.1 — Coil; 2.2. — magnetized core keeping the armature of the relay on attracted position; 2.3. — armature-pusher; 2.4. — spring; 2.5 — spring tension (pick-up threshold) regulator; 2.6. — outlets of the coil.

instances of electric shock. If a person comes into contact with both the Active and Neutral conductors while handling faulty plugs or appliances causing electric current to flow through the person's body, this contact will not be detected by the RCD unless there is also a current flow to earth. On a circuit protected by an RCD, if a fault causes electricity to flow from the Active conductor to earth through a person's body, the RCD will automatically disconnect the electricity supply, avoiding the risk of a potentially fatal shock.

To check the serviceability of the RCD it is supplied with a test button creating a nonbalanced current (flowing through the differential transformer only in one direction) limited by the resistor R to the level of nominal pick-up current. This current affects the device in the same way as leakage current between phase and ground.

Electronic RCDs are constructed from standard elements (Figure 16.89) and special integrated circuits (Figure 16.90). Electromechanical RCDs are considered to be more reliable than electronic ones. In European countries — Germany, Austria, France — electrical specifications permit only applications of the first type of RCD — voltage-independent ones. RCDs of the second type can be applied in circuits protected by electromechanical RCDs only as additional protection for ultimate consumers, for example for electric tools, nonstationary electric transmitters, etc. The most essential drawbacks of electronic RCDs are considered to be malfunctioning during frequent and most dangerous, in terms of possibility of electric shocks, fault of the electrical installation — during breaks of the zero (neutral) conductors in the circuit up to the RCD in the direction to the power supply. In this case the ''electronic'' RCD will not function without a supply and potential dangerous for a human is applied to the electrical installation through the phase conductor.

That is why in constructions of many ''electronic'' RCDs, there is a function of switching OFF from the circuit of the protected electrical installation when there is no voltage of the supply. Constructively, such function is implemented with the help of an electromagnetic relay operating in the mode of self-holding. The power contacts of the relay are in the ''ON'' position only when current flows through its winding. When there is no voltage on the input outlets of the device, the armature of the relay falls OFF, the power contacts open and the protected electrical installation is defused. Similar construction of the RCD provides secure protection of human-beings from electrical shocks in electrical installations if a break of the zero conductor takes place. It is also notable that electronic RCDs are prone to impact of moisture and dust, which can delay the pick-up time of the device. Unstable voltage in circuits and voltage drops have a negative impact on electronic RCDs and can lead to their malfunctioning.

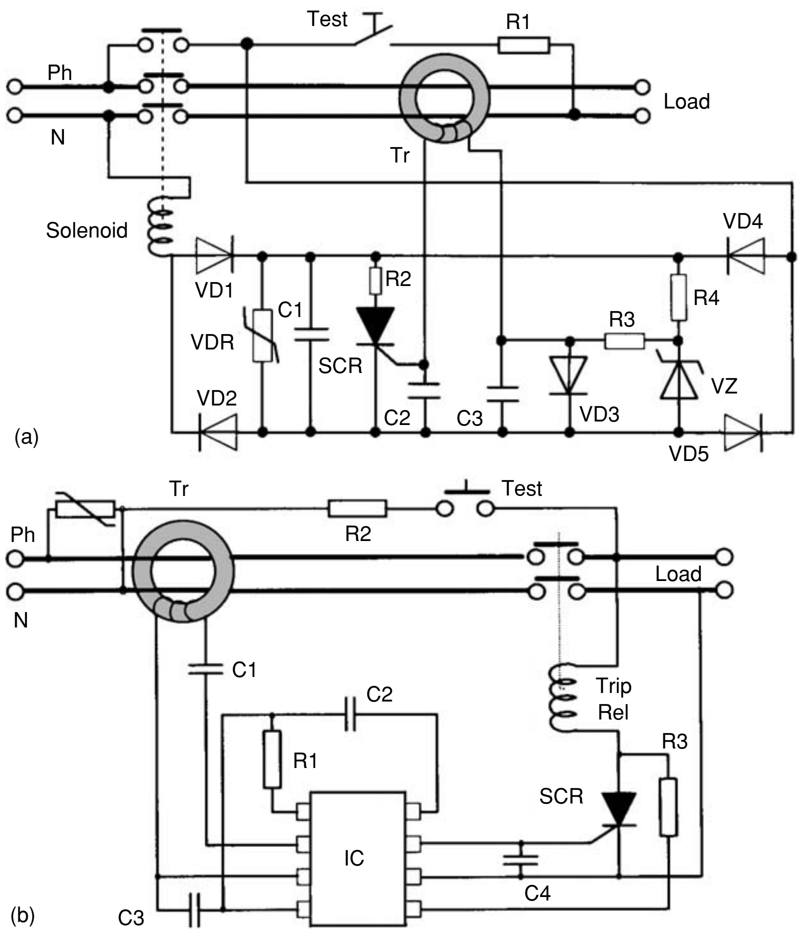


FIGURE 16.89
Electronic RCD based on standard elements.

As already mentioned above, RCDs differ from each other by sensitivity (pick-up current value). In accordance with the IEC Standard 1008/1009 of 30 mA, sensitivity for domestic and personal protection is a tolerance of 30 mA plus zero and minus 50%, that is a range from 15 to 30 mA. RCD units are manufactured to operate in a tolerance band of 19 to 26 mA. For personal protection 30 mA offers a high degree of protection and will operate by cutting off the earth fault current well within the time specified in IEC Publication 1008/1009.

Lower sensitivities (above 30 mA current trip) are sometimes used for individual circuits where there is less chance of direct contact such as in hot water tanks on a roof or under-floor heating. These earth leakage units from 100 to 375 mA provide reasonable protection from the risk of electrical fires, but it should be noted that under certain circumstances a current of less than 500 mA flowing in a high resistance path is sufficient to bring metallic parts to incandescence and can start a fire.

In addition to the pick-up current value, RCDs also differ by pick-up time. Standard pick-up time of an RCD must be 30 to 40 msec, but there are devices with pick-up time delays (the "G" and "S" type) that are designed for selective work in a group of several protective devices. RCDs also differ according to the type of current to which they

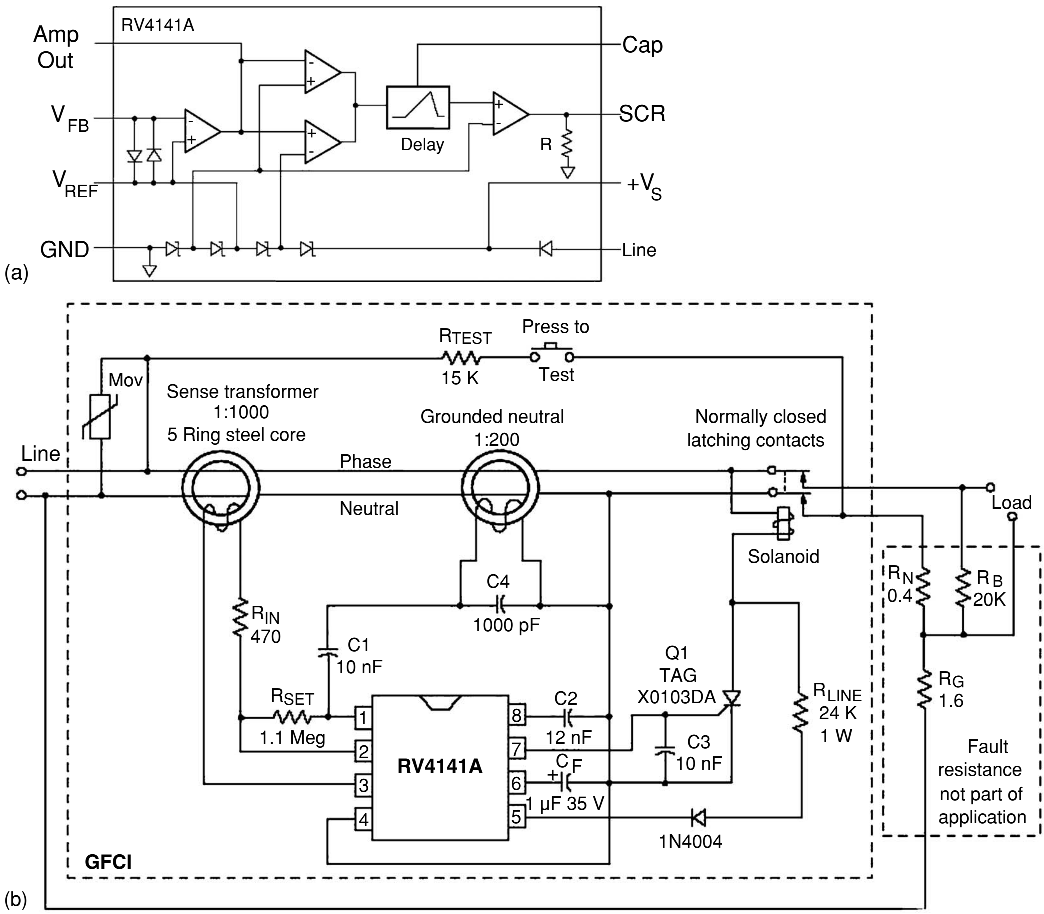


FIGURE 16.90
Electronic RCD based on a special integrated circuit (the U.S.A. patent 3,878,435).

respond. Class "AC" devices are used where the residual current is sinusoidal. This is the normal type, which is most widely in use. Class "A" types are used where the residual current is sinusoidal and/or includes pulsating DCs. This type is applied in special situations where electronic equipment is used. Class "B" is for specialist operations on pure DC, or on impulse direct or AC.

RCDs are constructed in cases very similar to those of the thermal and electromagnetic protective relays (automatic switches) considered above (Figure 16.91). RCDs are frequently combined with these switches in the same case, in such a way that the mechanism opening the power contacts runs when affected by any of three elements — a coil with a core of current cutoff responding to the short-circuit current, a bi-metal plate responding to the overload currents, and a polarized electromagnetic trip responding to differential current.

The RCD type numbers indicate over-current trip, residual current trip, and the number of poles. RCDs produced by the Cutler–Hammer company have quite an unusual external design (Figure 16.92). In such devices, the equipment wires connected to the terminals must pass through the window of the external CT.

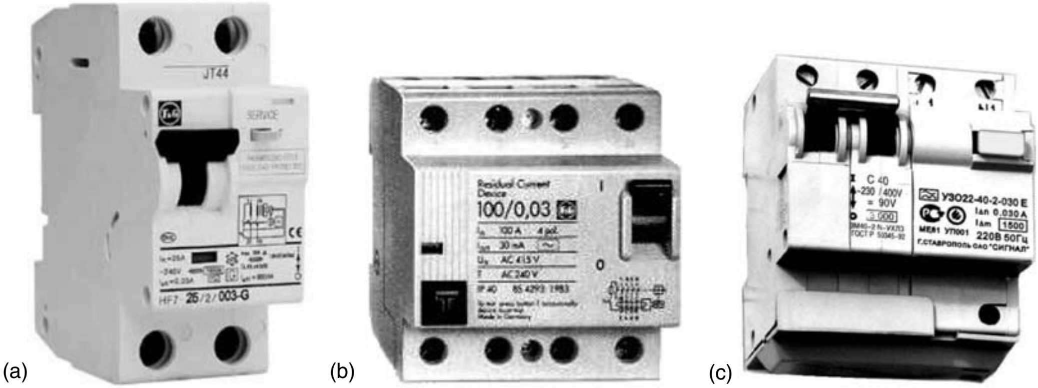


FIGURE 16.91
RCD devices of different types: 1 — HF7-25/2/003 type (Moeller); 2 — NFIN-100/0.03/4 type (Commeng Enterprise Corp.); 3 — Y3O22-40-2-030 type (''Signal'' plant, Russia).

During exploitation of RCDs, there are sometimes problems connected with false pick ups, which can give a lot of trouble (see Ward P., Demystifying RCD's, *Irish Electrical Review*, December 1997). Usually, false pick ups are caused by transient processes, over-voltages, dissymmetry, spikes, inrush current, etc. These are typical problems of electromagnetic compliance (EMC) common for many types of electrical equipment. Sometimes problems occur because of the wrong choice of an RCD. IEC recommends choosing a RCD in such a way that its nominal residual current trip is three times as high than the actual leakage current through the insulation at the place of installation of the RCD. But even the correct choice of an RCD does not guarantee normal operation. As the RCD is incapable of distinguishing between constantly flowing leakage current through the insulation to the ground and from an emergency current of closing through the human body, and responds to the sum of both currents, a situation may occur when, after a lapse of time (from the time the RCD was installed) the state of the insulation deteriorates (increased temperature, moisture, aging) and gradually the current passing through it increases. As an RCD with a nominal current of 30 mA can pick up within a

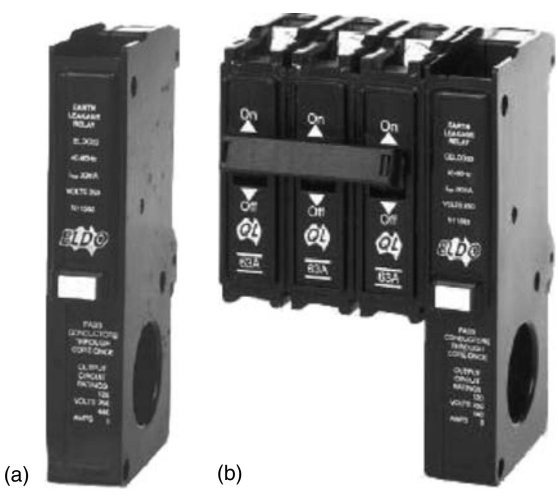
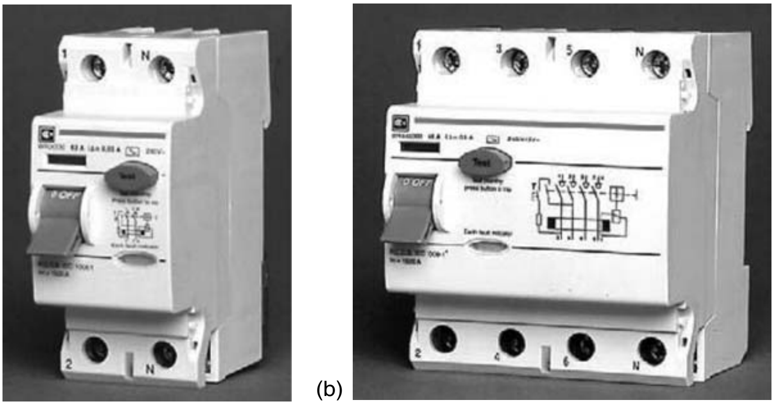


FIGURE 16.92
ELDO type (left) and combined QELDO (right) RCD devices with external differential current transformers. (Cutler-Hammer 2004 online catalog.)



(a) (b)

FIGURE 16.93
Two-and four-pole RCD devices of the WR type, independent of line voltage, 23 to 63, 30 mA. (Cutler–Hammer 2004 online catalog.)

range of 15 to 30 mA (see above), even a slight increase of leakage current — for instance, by 5 mA (from 10 to 15 mA), may cause false pick ups of even a well-functioning RCD chosen in accordance with all requirements.

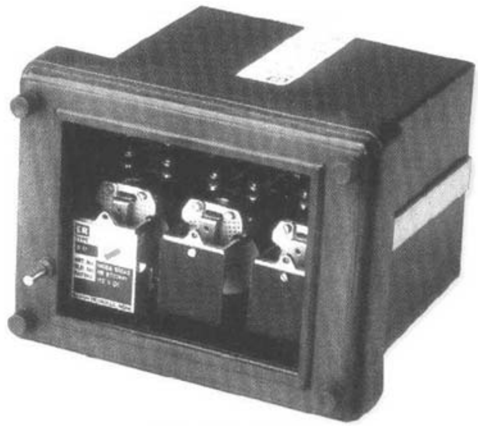
The problem is aggravated because of the wide use of filters in electrical equipment, which are designed to eliminate radio interference. Such filters create increased leakage currents between the phase wire and the ground.

Short-term increases of potential of the grounded circuits when short-circuit currents or stray currents pass through them, can cause false pick ups of the RCD. In other words there are a lot of reasons for false pick ups of well-functioning RCDs. Some of them can be compensated by using RCDs with increased noise-immunity, for example, of the WR type produced by the Cutler-Hammer Company (Figure 16.93). In these RCDs, a filter device is incorporated as standard to protect against nuisance tripping due to transient voltages (lightning, etc.) and transient currents (from high capacitive currents).

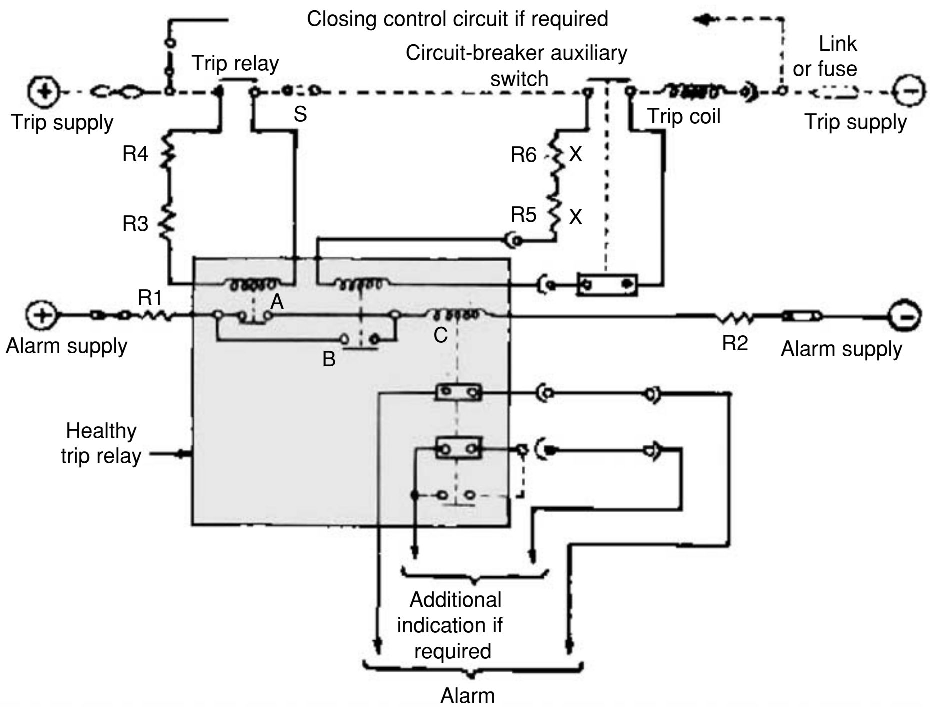
Of course such devices are more expensive than those produced in China, but in some cases this can be the only solution allowing us to avoid much trouble.

16.13 Supervision Relays

What is the relay-supervisor? For whom or what reason does it supervise? Main purpose of such relays is a continuous monitoring of serviceability of important units (or important electric parameters of power applied to such units). The trip coils and the power supply of high-voltage circuit breakers in electrical networks; power supply circuits for sensors of fire-alarm systems; phase sequence and phase losses in power supply for electric motors; insulation level of electric equipment, etc., concern for such units and parameters. Supervision relays also detect interruptions, too high resistances caused by galvanically bad connections, increased transfer resistance in the contacts, welding of the control contact, disappearing control voltage, and voltage failures in the relay itself.



(a)



(b)

FIGURE 16.94
(a) Simplest circuit breaker supervision relay, based on electromechanical relays (Easun Reyrolle, India). (b) Circuit diagram and external connection of a B51 supervision relay (called: ''Healthy trip relay'' in manufacturer documentation).

For example, a relay with a high coil resistance and suitable pick-up voltage, connected in series with the trip coil of a high-voltage circuit breaker, should be considered for red light indication and auxiliary contact to allow remote supervision of the trip coil (Figure 16.94). The B51 (Figure 16.94b) is the simplest circuit breaker supervision relay, comprising three attracted armature relays, continuously excited during normal operation by the external DC power supply voltage and slugged at the coil base to provide a delay on drop-off. The alarm contacts will not close in less than 400 msec after failure of the trip circuit.

The contacts are self-reset. The flag, fitted only to the output relays, may be hand reset or self-reset and indicates that the relay is deenergized. To prevent the supervision relay from providing spurious alarm signals, for instance, at circuit-breaker operation, the measuring current of the control circuit is supplied with external resistors (R3–R6), which are current limiters. The resistance of the components in the circuit across the trip–relay contacts is such, that accidental short-circuiting of any one will not result in trip-coil operation. With both trip–circuit supervision relay coils and limiting resistors connected in series, the current through the trip-coil will not exceed 10 mA. With only one trip-circuit supervision relay coil and a limiting resistor connected in series, the trip-coil current will not exceed 20 mA.

If the breaker-tripping coil does not tolerate this, the electromechanical auxiliary relay can be replaced by an optocoupler (Figure 16.95) in order to further reduce the current in the tripping circuit. The modern SPER series supervision relays, produced by ABB (Figure 16.96), are used for monitoring important control circuits such as circuit breaker and disconnector control circuits, signaling circuits, etc., in power installations.

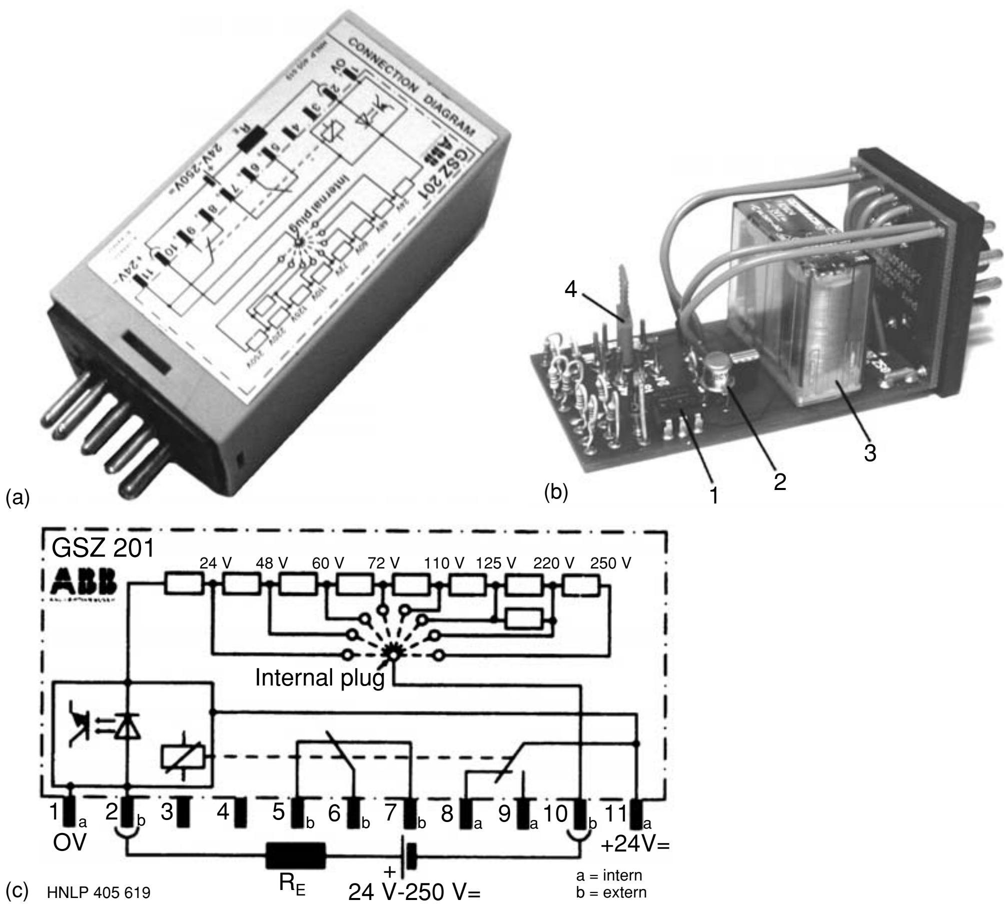


FIGURE 16.95
Circuit-breaker supervision relay GSZ201 type with optocoupler for reduce input current (ABB). 1 — Optocupler, 2 — amplifying transistor, 3 — output relay, 4 — internal plug for manual switching of voltage in supervision circuit (R_E — supervision circuit). (ABB ASEA Relays buyers guide 1985–1986.)

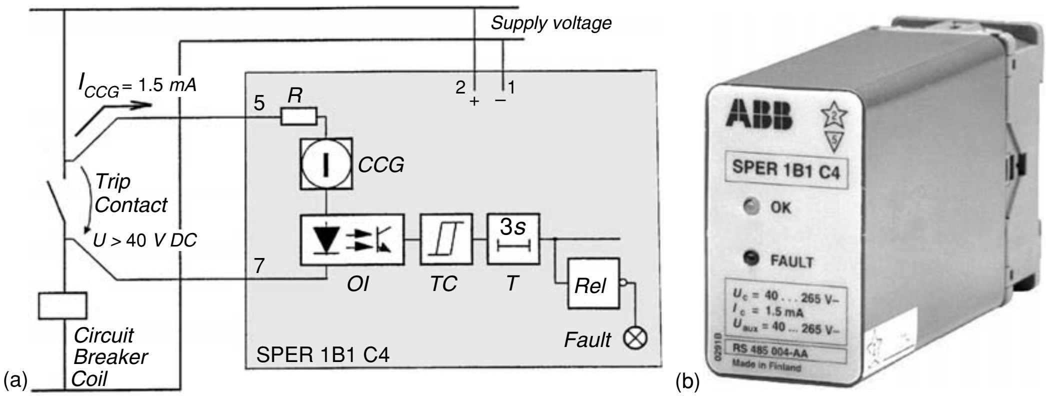


FIGURE 16.96
Modern supervision relay of the SPER type, produced by ABB. CCG — Constant current generator; OI — opto-isolator (optocoupler); TC — triggering circuit; T — time circuit; Rel — output relay; Fault — LED indicator.

One contact circuit is monitored by one relay. If several branches of a circuit are to be monitored, the required number of relays can be connected to the same control circuit.

The constant current generator (CCG) of the driver circuit feeds a small I_{CCG} current of some 1.5 mA, depending of the relay type used, through the circuit to be monitored. The contact inputs 5 to 7 are connected over the NO trip contact, so the measuring current flows between the poles of the control voltage.

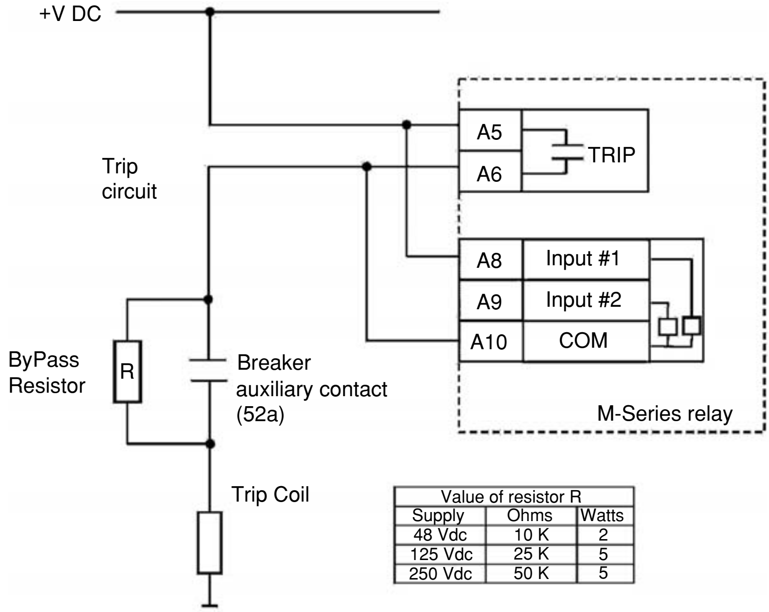
The driver circuit of the relay operates independently of the measuring circuit and the output circuit, so different voltage levels are permitted. Should the auxiliary voltage supply be interrupted, the indicator LEDs of the supervision relay go out and the changeover contacts of the operated output relay operate without a time delay in the measuring circuit. The contact operation of the relay is the same as for a fault in the circuit monitored.

To avoid spurious CB tripping, for instance in the event of a short circuit in the control circuit, the CCG circuit of the SPER relay contains an internal current limiting series resistor (*R*).

Similar supervision relays are producing by many companies; see Figure 16.97, for example. For continuous monitoring of a trip circuit (that is, while the breaker is open as well as closed), a bypass resistor must be added in parallel to the 52a contact as shown below. This technique maintains current flow through the circuit when the breaker is open.

The EN 60204 standard ''Safety of Machinery'' (and also some medical applications with similar requirements), stipulates that auxiliary circuits must be protected with an earth-leakage supervisor in order to increase operating safety. The *insulation supervising relay* of type RXNA4 (Figure 16.98), is used for insulation supervision and as an earth-fault relay in single and three-phase networks with an isolated neutral, such as on board ships.

In comparison with an earth-fault relay consisting of a voltage-measuring unit connected between the neutral and earth of the system, the RXNA4 has the following advantages:



Value of resistor R		
Supply	Ohms	Watts
48 Vdc	10 K	2
125 Vdc	25 K	5
250 Vdc	50 K	5

FIGURE 16.97
Trip circuit supervision for M-Family Relays (General Electric Co.).

- The operating value is not influenced by the capacitance to earth
- Operates even during a symmetrical drop of the insulation resistance
- Higher internal impedance

This implies that the RXNA4 can be used to supervise the insulation to the ground without any dangerous earth currents arising on the occurrence of a single-phase earth fault. A milliampermeter, which continuously indicates the value of the insulation resistance, can be connected to the relay.

For voltage supply purposes the RXNA4 has a fully isolated input transformer that is connected either to the supervised network or to a separate source of voltage. After transformation, the connected supply is rectified and stabilized into two voltages of 24 V each.

One voltage is used partly as an auxiliary supply to the static circuits, and partly for supplying the output relay. The other voltage is connected between the supervised AC network and the earth. On the occurrence of an earth fault, a DC current flows from the relay through the point of the fault to earth, and back again to the relay. This current is measured by a level detector the operating value of which is sleeplessly adjustable with a knob located on the front of the relay. When the insulation resistance drops below the set value, the output relay picks up after approximately 2 sec. Simultaneously, a light emitting diode lights up on the front of the relay.

A low-pass filter is incorporated in the input of the relay to prevent the operation of the relay from being influenced by the AC voltage of the network. A pushbutton is incorporated in the front of the relay, to facilitate the testing of the relay's operation. When the pushbutton is depressed the measuring input is short-circuited and the relay picks up.

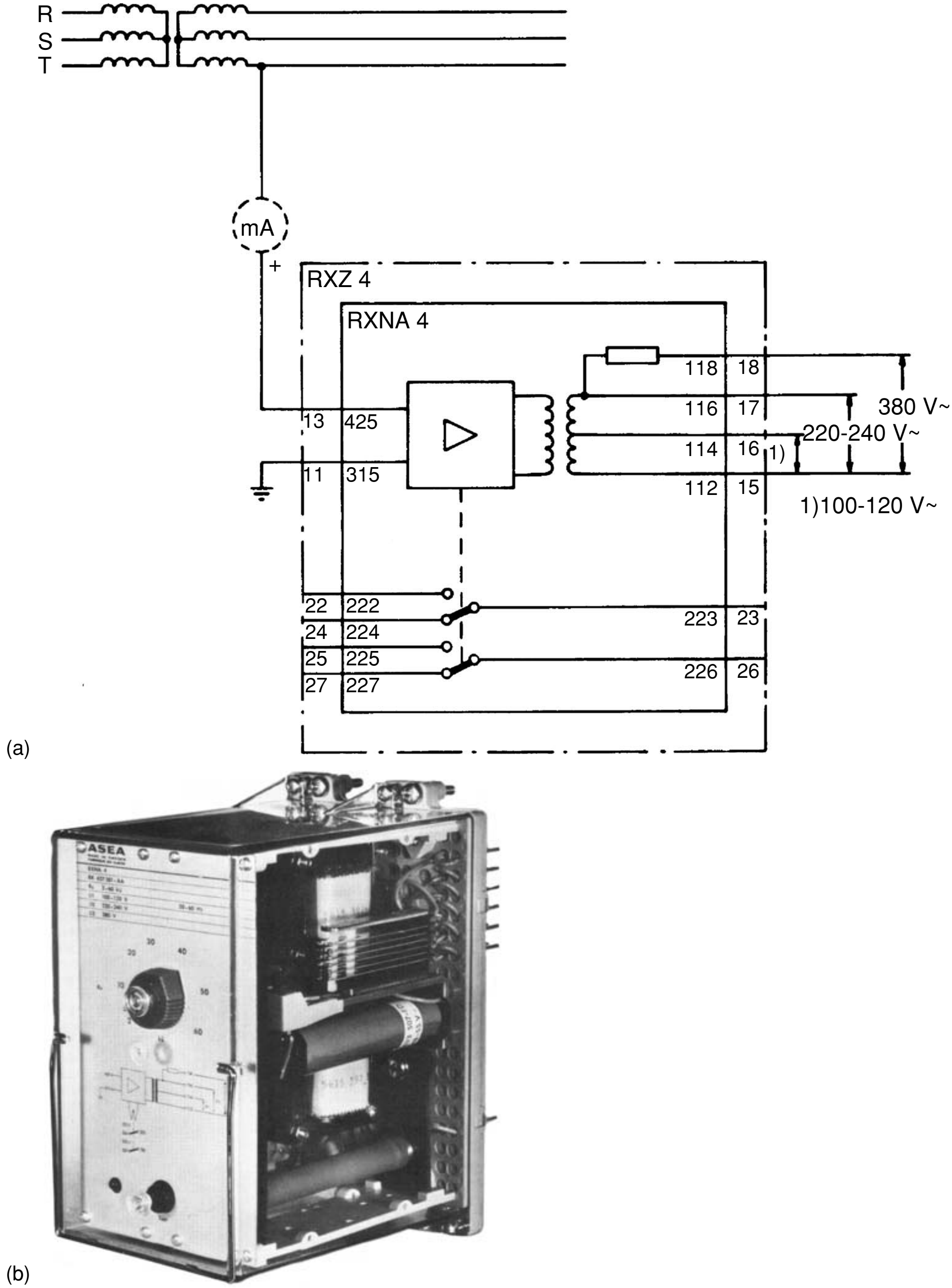


FIGURE 16.98
Insulation supervising relay, type RXNA4. (ABB ASEA Relays buyers guide 1985–1986.)

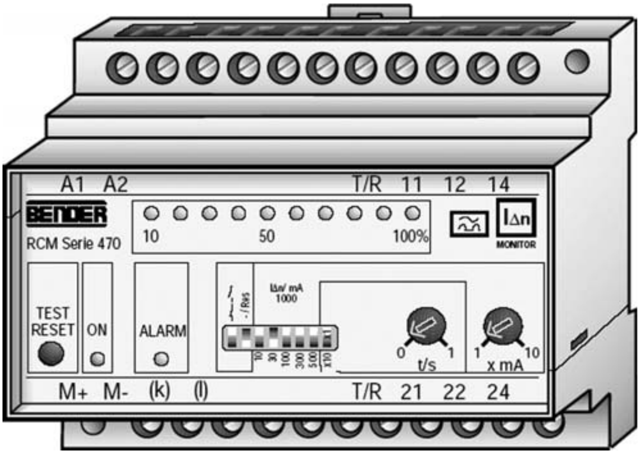


FIGURE 16.99
RCM series ground fault supervision relay, manufactured by the BENDER company.

Many companies specialize in manufacturing insulation supervision relays, for example BENDER. The BENDER RCM series (Figure 16.99) is specially designed to provide advanced warning of developing faults without the problems usually associated with high-sensitivity nuisance tripping. The RCM470LY and RCM475LY are IEC755 Type A Ground Fault Relays that can detect sinusoidal AC ground fault currents and pulsating DC ground fault currents. The response value ΔI is sleeplessly adjustable between 6 mA to 600 A or 10 mA to 10 A, and the delay time can be adjusted between 0 and 10 sec. The relay is equipped with an LED bar graph indicator. An external analog meter can be connected, and by using an optional external transducer a 4 and 20 mA signal is available. Meter indication is from 10 to 100%, where 100% is equal to the alarm set-point value.

The RXNAE 4 supervision relay (Figure 16.100) is primarily used for *monitoring arcs* on the commutators of DC machines. Substantial arcs can result in flashovers, which can damage the commutator.

Light-sensitive detectors placed in the machine activate the RXNAE 4, which instantaneously trips. The light detector contains a phototransistor which reacts to the infra-red radiation from an arc, and provides current to the supervision relay. The current is measured in the relay by a tripping detector and a signal detector. The tripping detector

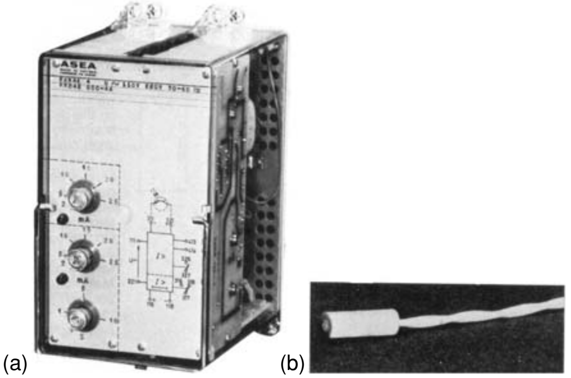


FIGURE 16.100
The RXNAE 4 type supervision relay with an infrared sensor for monitoring arcs. (ABB ASEA Relays buyers guide 1985–1986.)

is set for instantaneous tripping for severe arcs. It has two outputs, one a static high-load output and the other a dry-reed relay output. The static output triac is used for tripping of the main circuit breaker (AC or DC), while the relay output is used for signaling.

If the power supply to a four-wire (separately powered) smoke detector fails, or if the wires are cut, the detector will not work. To prevent a tragedy, we need to know immediately when there is a failure in the power system.

The EOL-1224RLY (Figure 16.101) is an end of line power supervision Relay used for the supervision of four-wire smoke detector voltage. If the power is interrupted, the EOL-1224RLY will cause your alarm panel to indicate a ''trouble'' condition. This is a requirement of the NFPA.

This supervision relay is called ''End of Line'' because it is installed at the end of the detector power circuit. A break in the detector power circuit or a loss of power deenergizes the power supervision relay, opening the contacts and causing a trouble annunciation at the fire alarm control unit.

A *Phase sequence supervision relay* (Figure 16.102), is used for monitoring the clockwise rotation of movable motors for which the phase sequence is important, such as with pumps, saws, and drilling machines. The phase sequence supervision relay detects the timed sequence of individual phases in a three-phase supply. In a clockwise phase sequence, contacts 11 to 12 and 21 to 22 are open, and contacts 11 to 14 and 21 to 24 are closed. In an anticlockwise phase sequence, contacts 11 to 12 and 21 to 24 are open, and contacts 11 to 14 and 21 to 22 are closed.

The EMR4-A *unbalance supervision relay*, (Figure 16.103) with its 22.5 mm module width, is the ideal protective device for supervision of phase loss. The detection of phase loss on the basis of phase shift means that reliable phase loss detection is ensured and overloads even when large amounts of energy are regenerated to the motor. The EMR4-A relay can be used for protecting motors with a rated voltage of $U_N = 380$ to 415 V at 50 Hz, and provides:

- Phase loss detection even with 95% phase regeneration
- Phase sequence detection
- ON-delay of 0.5 sec
- LED status indication.

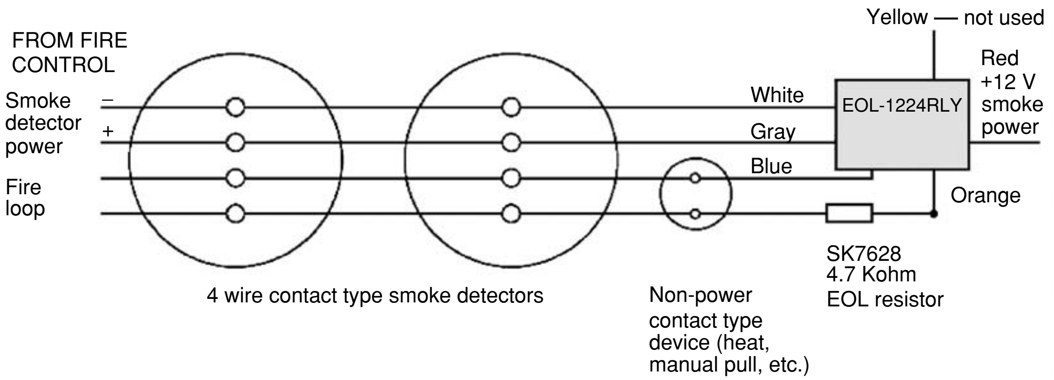


FIGURE 16.101
Typical installation of end-of-line relay of the EOL-1224RLY type, for supervision of a four-wire smoke detector voltage (Silent Knight, U.S.A.).

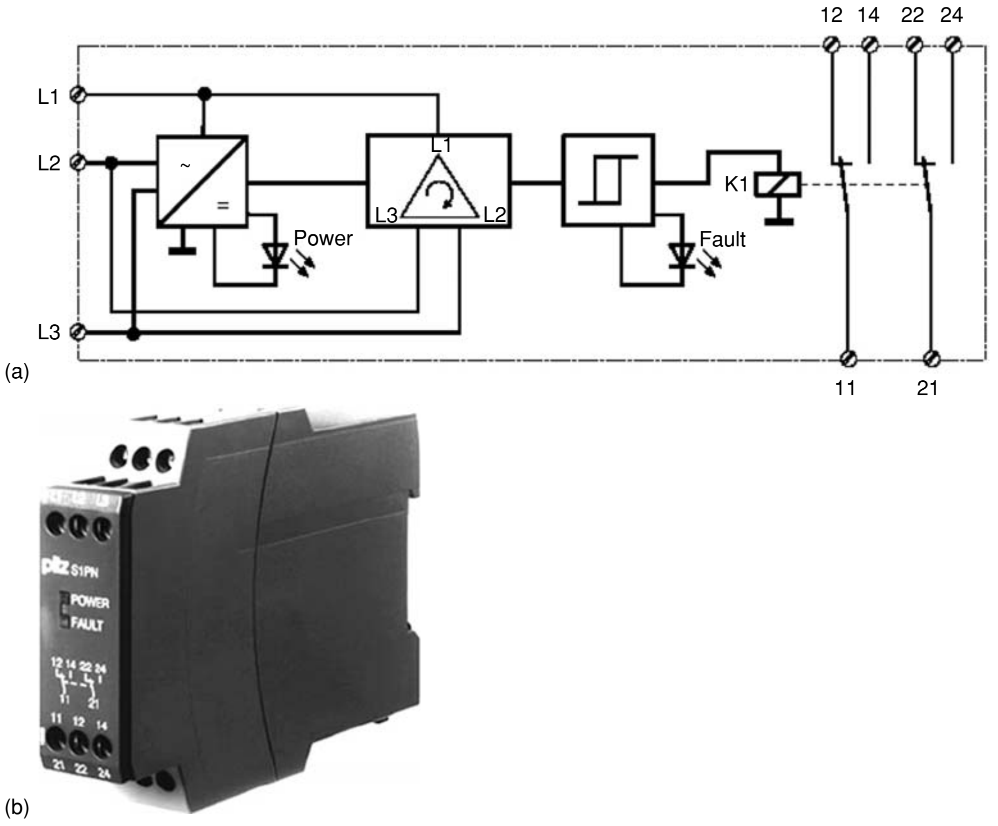
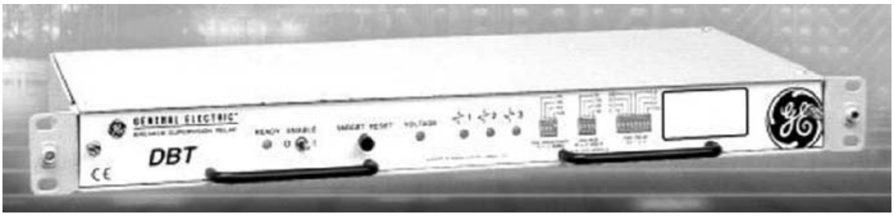


FIGURE 16.102
A phase sequence supervision relay of the S1PN type (Pilz GmbH & Co.)

FIGURE 16.103
Unbalance Supervision Relay of the EMR4-A type. (Klokner–Moeller 2004 online catalog.)

The relay has its own power supply, that is, an additional supply voltage is not required. As it is possible to see from the above descriptions of supervision relays, they are very simple devices and are intended for fulfillment of very simple functions. Nevertheless, even in this area, the attempts of usage of microprocessors are undertaken.

Naturally, such relays deserve a serious view (Figure 16.104 — compare this to the relay in Figure 16.95). For whom is it necessary? Perhaps the readers themselves know the answer to this question (if no, see chapter 16).



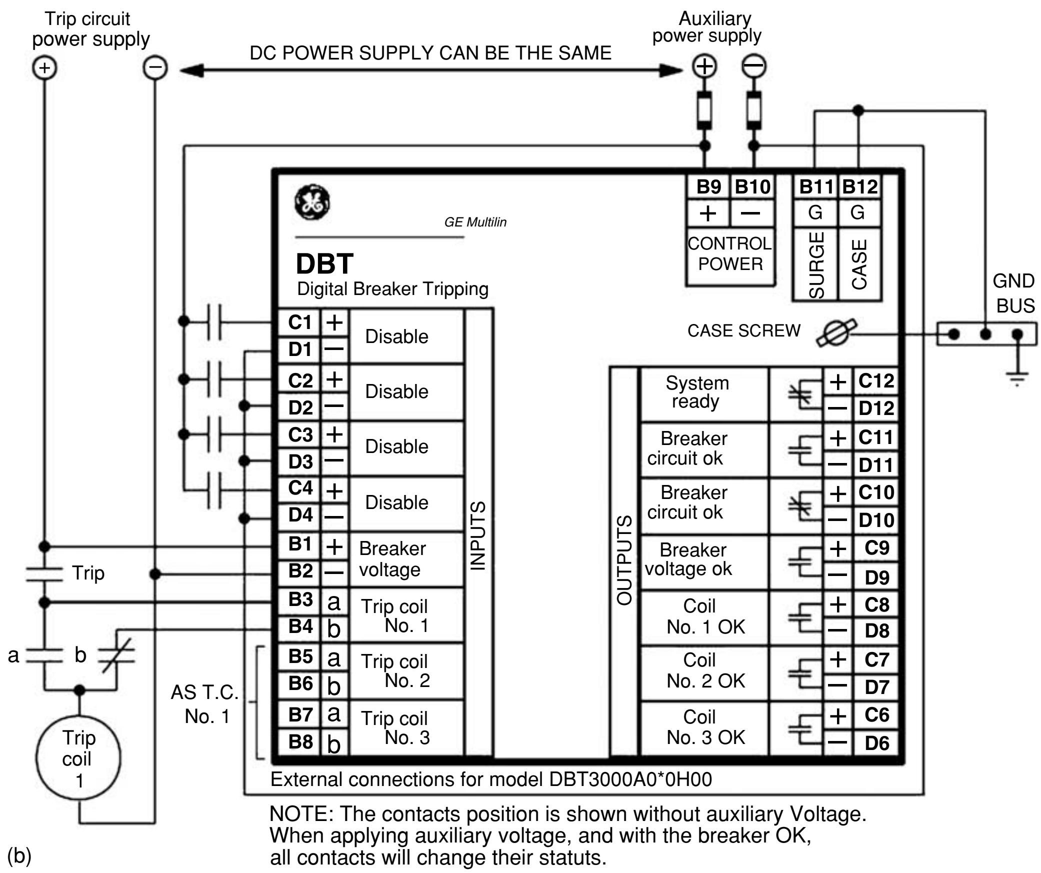


FIGURE 16.104
(a) The DBT type digital circuit breaker supervision relay (General Electric Co.). (b) Connection diagram of the DBT type supervision relay. (General Electric online catalog.)

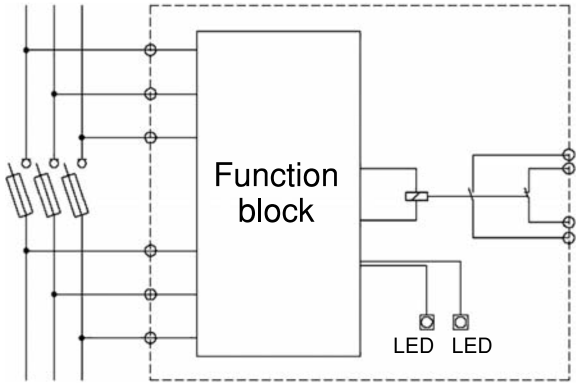


FIGURE 16.105
Principal of fuse supervision.

Fuse supervision relays are for detecting one or more blown fuses in important electrical equipment (Figure 16.105). In a normal condition of fuses, the voltage drop on them makes parts of volt even at high currents. When a fuse blows, on the input of the relay there is a voltage, causing actuation. Certainly the input circuit of such supervision relay should have high resistance and not influence load.

Many fuse supervision relays have similar principles of operation, for example, the static RXBA4 type three-phase relay (Figure 16.106). Often the fuse supervision relay is just enough to supervise only the voltage after the fuses (on part of the load), with actuation of the relay occurring at a loss of voltage in one of phases. Some companies build supervision relays on this principle (Figure 16.107).

The sort of strange solution, utilized in supervision relays manufactured by Siemens (in the Sirius-3R type), Rittal (United Kingdom), and some other companies (Figure 16.108), is based on the principle of automatic circuit breakers.

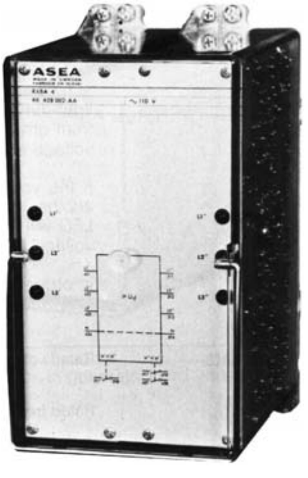


FIGURE 16.106
Fuse supervision relay of the RXBA4 type (ASEA).

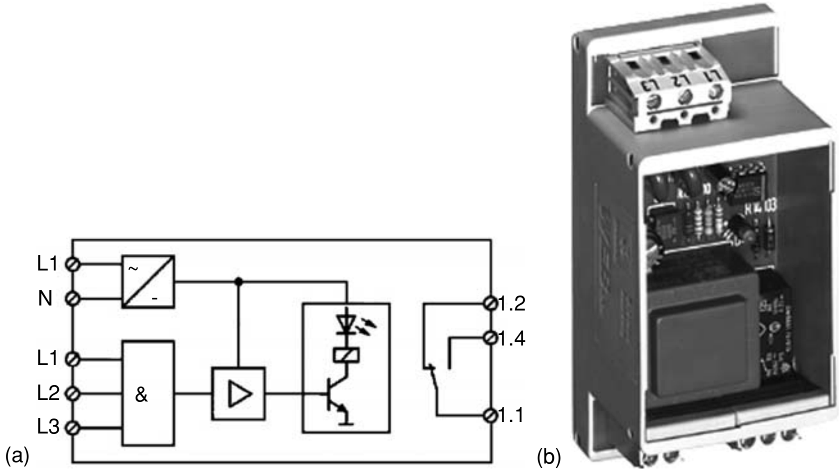


FIGURE 16.107
Fuse supervision relay produced by Weiland, Inc.

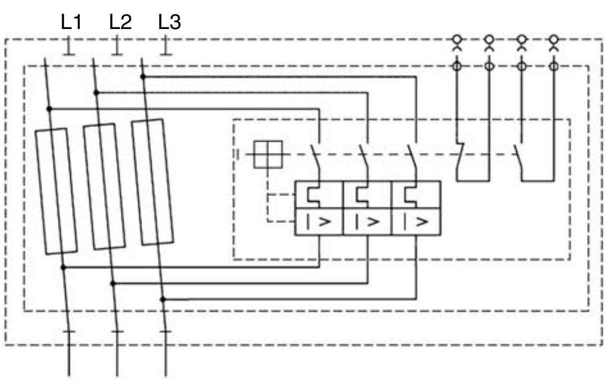


FIGURE 16.108
Fuse supervision relay based on the principle of the automatic circuit breaker.

It is designed so that at blowing of a fuse, all current will pass through these automatic circuit breakers, causing actuation and disconnecting the load. The auxiliary contacts of the automatic circuit breakers may also be used for the signaling (supervision) system.

16.14 Hydraulic-Magnetic Circuit Breakers

Hydraulic-magnetic circuit breakers (HMCB) is a relatively new type of a circuit breakers now produced by many companies for wide range of currents.

A HMCB consists (Fig. 16.109) of a magnetic frame comprising a series-connected solenoid coil wound around a hermetically sealed tube containing an iron core, a spring, and hydraulic fluid. Mounted onto this magnetic frame is an armature, which when activated unlatches the trip latch of the circuit breaker. As the electrical current passing

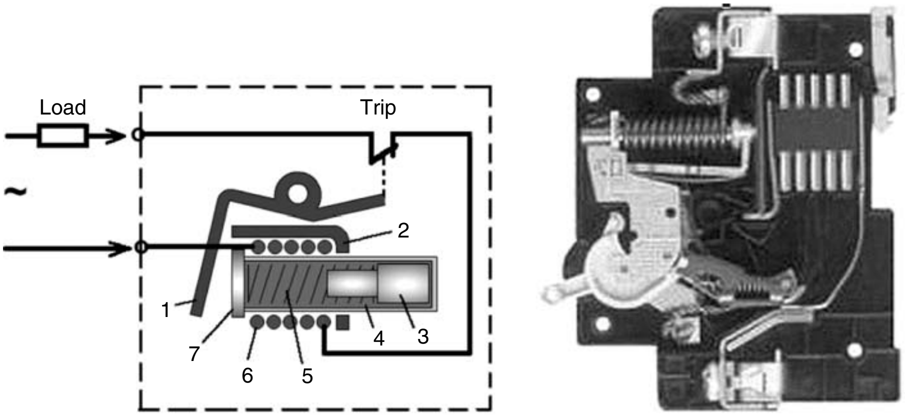


FIGURE 16.109
Construction of hydraulic-magnetic circuit breaker. 1 — Armature; 2 — frame; 3 — moving ferromagnetic core; 4 — temperature stable fluid with a special viscosity; 5 — spring; 6 — coil; 7 — pole piece.

through the coil increases, the strength of the magnetic field around the magnetic frame also increases. As the current approaches the circuit breaker's rating, the magnetic flux in the coil produces sufficient pull on the core to overcome the spring tension and start it moving towards the pole piece. During this movement, the hydraulic fluid regulates the core's speed of travel, thereby creating a controlled time delay, which is inversely proportional to the magnitude of the current.

As the normal operating or ''rated'' current flows through the sensing coil, a magnetic field is created around that coil. When the current flow increases, the strength of the magnetic field increases, drawing the spring-biased, movable magnetic core toward the pole piece. As the core moves inward, the efficiency of the magnetic circuit is increased, creating an even greater electromagnetic force, Fig. 16.110. When the core is fully ''in,'' maximum electromagnetic force is attained. The armature is attracted to the pole piece, unlatching a trip mechanism thereby opening the contacts.

Under short-circuit conditions (Fig. 16.111) the resultant increase in electromagnetic energy is so rapid, that the armature is attracted without core movement, allowing the breaker to trip without induced delay. This is called ''instantaneous trip.'' It is a safety feature that results in a very fast trip response when needed most.

The trip time delay is the length of time it takes for the moving metal core inside the current sensing coil to move to the fully ''in'' position, thereby tripping the circuit breaker. The time delay should be long enough to avoid nuisance tripping caused by harmless transients, yet fast enough to open the circuit when a hazard exists.

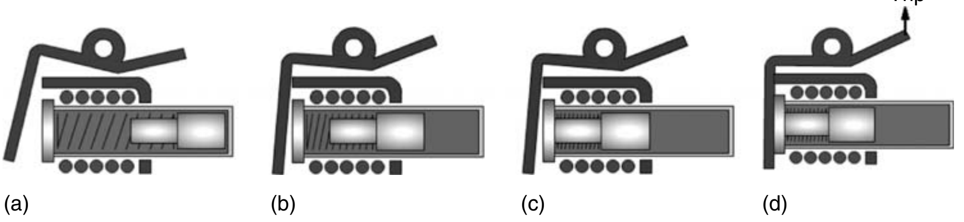


FIGURE 16.110
Phases of pick-up process under overload condition (trip time delay).

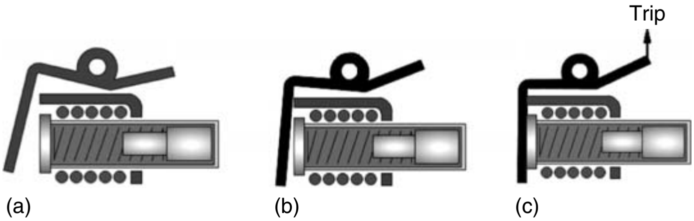


FIGURE 16.111
Phases of pick-up process under short-circuit condition (instantaneous trip).

Many hydraulic-magnetic breakers are available with a selection of delay curves to fit particular applications.

If the delay tube is filled with air, the core will move rather quickly, and the breaker will trip quickly. This is characteristic of the *ultrashort* trip time delay. Solid-state devices, which cannot tolerate even short periods of current overload, should use the *instantaneous* trip time delay, which have no intentional time delay.

When the delay tube is filled with a light viscosity, temperature stable fluid, the core's travel to the full ''in'' position will be intentionally delayed. This results in the slightly longer *medium* trip time delays that are used from general purpose applications.

When a heavy viscosity fluid is used, the result will be a very *Long* trip time delay. These delays are commonly used in motor applications to minimize the potential for nuisance tripping during lengthy motor start-ups.

Unlike the thermal-magnetic circuit breakers, the HMCB not affected by ambient temperature, and also it has no warm up period to slow down its response to overload and no cool down (thermal memory) period after overload event. After tripping, the HMCB may be reclosed immediately since there is no cooling down time necessary.

Fixed rating thermal-magnetic breakers are often limited in availability to ampere ratings not lower than about 15 amperes. The reason for this limitation is that the very light bi-metals that are necessary for the lower ampere ratings are often incapable of withstanding the stresses of the high let through or short-circuit currents for which they are normally designed. One way of solving this problem is through the use of HMCB's.

Hydraulic-magnetic technology also scores on their flexibility in regards to technical issues such as the required trip point, time delay curves, and inrush current handling capacity, and also on their ability to be tailored to suit a customer's particular application requirements. Such flexibility makes HMCB products a very responsive solution to any design problems or harsh environmental criteria.

HMCB tend to be sensitive to rotational position. These breakers should be mounted in a vertical position to prevent gravity from influencing the movement of the solenoid.

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Basic Relay Terms and Definitions — Glossary

There are several sources for definitions: the C37 subcommittee on protective relays, C83 committee on Components for Electronic Equipment, and IEEE Standards Coordinating Committee on Definitions (SCC10) which as published ANSI/IEEE Std 100–1984 Dictionary of Electrical and Electronics Terms. IEC has Technical Committee 41 on all types of relays and publication 50 (446) is a chapter of definitions on electrical relays.

Addition sources: British Standard (BS) 142 Electrical Protective Relays; BS 4727 Relay and Measurement Terminology; C37–90 American National Standard for Relays and Relay System; IEC 255 International Electrotechnical Commission Standards for Electrical Relays; IEC 50 International Electrotechnical Vocabulary: Electrical Relays; IEEE Standard 37.2 Electrical Power System Device Function Numbers and other sources of terms, used in technical literature.

1. Relay Classes

Relay

An electric device that is designed to interpret input conditions in a prescribed manner and after specified conditions are met to respond to cause contact operation or similar abrupt change in an associated electric control circuit. Inputs are usually electric, but may be mechanical, thermal, or other quantities. A relay may consist of several units, when responsive to specified inputs, the combination providing the desired performance characteristic. The relays can be electrical, thermal, pneumatic, hydraulic, and other.

Electrical Relay

A device designed to produce sudden, predetermined changes in one or more electrical output circuits, when certain conditions are fulfilled in the electrical input circuits controlling the device.

Electromechanical Relay

An electrical relay in which the designed response is developed by the relative movement of mechanical elements under the action of a current in the input circuits.

Electromagnetic Relay

A relay whose operation depends upon the electromagnetic effects of current flowing in an energizing winding. There are two basic types of electromagnetic relays: attraction relay and induction relay.

Electromagnetic ***attraction relay*** operates by virtue of a plunger being drawn into a solenoid, or an armature being attracted to the poles of an electromagnet. Such relays may be actuated by DC or by AC quantities (current, voltage, power).

Electromagnetic ***induction relay*** uses the principle of the induction motor whereby torque is developed by induction in a rotor; this operating principle applies only to relays actuated by alternating current, and in dealing with those relays we shall call them simply ''induction-type'' relays. Induction relays are basically induction motors. The moving element, or rotor, is usually a metal disk, although it sometimes may be a metal cylinder or cup. The stator is one or more electromagnets with current or potential coils that induce currents in the disk, causing it to rotate. The disk motion is restrained by a spring until the rotational forces are sufficient to turn the disk and bring its moving contact against the stationary contact, thus closing the circuit the relay is controlling. The greater the fault being sensed, the greater the current in the coils, and the faster the disk rotates.

Electronic Relay

Electrical relays whose functions are achieved by means of electronic components (vacuum or gas filled valves, semiconductor elements) without mechanical motion.

Hybrid Relay

A relay in which electromechanical and electronic devices are combined to perform a switching function.

Static Relay

An electrical relay in which the designed response is developed by electronic, magnetic, optical, or other components without mechanical motion.

It should be noted though that few static relays have a fully static output stage, to trip directly from thyristors, for example. By far the majority of static relays have attracted armature output elements to provide metal-to-metal contacts, which remain the preferred output medium in general.

Semiconductor Relay

Electronic relay based on semiconductor elements (transistors, thyristors, SCR, opto-couplers).

Solid-State Relay

Electronic relay, designed as single epoxy molded solid-state module (usually, opto-coupled).

2. Relay Types

AC Directional Relay

Are used most extensively to recognize the difference between current being supplied in one direction or the other in an AC circuit, and the term ''directional'' is derived from this usage. Basically, an AC directional relay can recognize certain differences in phase angle between two quantities, just as a DC directional relay recognizes differences in polarity. This recognition, as reflected in the contact action, is limited to differences in phase angle exceeding 90° from the phase angle at which maximum torque is developed.

AC Time Overcurrent Relay

A relay that operates when its AC input current exceeds a predetermined value, and in which the input current and operating time are inversely related through a substantial portion of the performance range.

Annunciator Relay

(target relay, signal relay, flag relay)
A non-automatically reset device that gives a number of separate visual indications upon the functioning of protective relays, indicates the present or former state of a circuit or circuits and which may also be arranged to perform a lockout function.

Auxiliary Relay

A relay that operates to assist another relay or device in the performance of a function.

Bar Relay

A relay so designed that a bar actuates several contact simultaneously.

Bimetal Relay

A form of thermal relay using a bimetallic element to activate contacts when heated electrically.

Bistable Relay

An electrical relay which, having responded to an input energizing quantity (or characteristic quantity) and having changed its condition remains in that condition after the quantity has been removed. Another appropriate further energization is required to make it change over.

Crystal Can Relay

A term used to identify a relay housed in a hermetically sealed enclosure that was originally used to enclose a frequency-control type of quartz crystal.

Current-Balance Relay

A relay that operates when the magnitude of one current exceeds the magnitude of another current by a predetermined degree.

Current-Sensing Relay

A relay that functions as a predetermined value of current; an overcurrent or an undercurrent relay, or a combination of both.

Dashpot Relay

A relay employing the dashpot principle to effect a time delay.

Dependent-Time Measuring Relay

A specified-time measuring relay for which times depend, in a specified manner, on the value of the characteristic quantity.

Differential Relay

A relay with multiple inputs that actuating when the voltage, current, or power difference between the inputs reaches a predetermined value.

Distance Relay

A relay that functions when the circuit admittance, impedance, or reactance increases or decreases beyond predetermined limits.

Dry Reed Relay

Relay with hermetically sealed, magnetically actuated reed contact. No mercury or other wetting material is used. Typical atmosphere inside the enclosure is nitrogen or a specially dried air.

Enclosed Relay

Hermetically sealed — a relay contained within an enclosure that is sealed by fusion or other comparable means to ensure a low rate of gas leakage (generally metal-to-metal or metal-to-glass sealing is employed)
Encapsulated — a relay embedded in a suitable potting compound
Sealed — a relay contained in a sealed housing
Covered — a relay contained in an unsealed housing
Dustproof — a relay with a case to protect against dust penetration

Ferreed Relay

Combined name for a special form of dry reed switch having a return magnetic paths (reeds) of high remanence material (ferrite) that provides a bistable contact.

Flasher Relay

(***flashing-light relays***)
A self-interrupting relay, usually by thermo-magnetic or electronic type.

Field Relay

A relay that functions on a given or abnormally low value or failure of a machine field current, or on excessive value of the reactive component of armature current in an AC machine indicating abnormally low field excitation.

Frequency Relay

A relay that functions on a predetermined value of frequency (either under or over or on normal system frequency) or rate of change of frequency.

Hermetically Sealed Relay

Relay with the highest degree of sealing (particularly relays with metal cases and glass insulators).

Impulse Relay

A relay that follows and repeats pulses, as from a telephone dial; or a relay that operates on the stored energy of a short pulses after the pulse ends; or a relay that discriminates between length and strength of pulses, operating on long or strong pulses and not operating on short or weak ones; or a relay that alternately assumes one of two positions as pulsed.

Independent-Time Measuring Relay

A specified-time measuring relay the specified time for which can be considered as being independent, within specified limits, of the value of the characteristic quantity

Integrating Relay — rare usage

A relay that operates on the energy stored from a long pulse or a series of pulses of the same or varying magnitude, for example, a thermal relay.

Instantaneous Overcurrent Relay (Rate-of-Rise Relay)

A relay that functions instantaneously on an excessive value of current or on an excessive rate of current rise, thus indicating a fault in the apparatus or circuit being protected.

Instruments Relay (Meter Relay) — rare usage

A sensitive relay in which the principle of operation is similar to that of instruments such as the electrodynamometer, iron vane, galvanometer, and moving magnet.

Interlock Relay

A relay with two or more armatures having a mechanical linkage or an electrical interconnection, or both, whereby the position of one armature permits, prevents, or causes motion of another.

Inverse-Time Relay

A relay in which the input quantity and operating time are inversely related throughout at least a substantial portion of the performance range. Types of inverse-time relays are frequently identified by such modifying adjectives as *definite minimum time, moderately, very,* and *extremely* to identify relative degree *of* inverseness of the operating characteristics.

Latching Relay (Lockup Relay)

A relay that maintains its contacts in the last position assumed without the need of maintaining coil energization.

Magnetic latching

A relay that remains operated, held either by remanent magnetism in the structure or by the influence of a permanent magnet, until reset.

Mechanical latching

A relay in which the armature or contacts may be latched mechanically in the operated or unoperated position until reset manually or electrically.

Lockout Relay

A variety of latching relay with manual resetting. Lockout relays are applicable where several tripping functions need to be performed by the same relay. Typical applications for these relays include: line breaker tripping and lockout, lockout of all the line breakers in the same busbar, etc. One of the most important applications of lockout relays is the combination with differential relays, where the lockout relay needs to be reset manually for avoiding accidental reclosings, when an internal fault has activated the differential relay.

Measuring Relay (Protective Relay)

1. A device used to detect defective or dangerous conditions and initiate suitable switching or give warning when its characteristic quantity, under specified conditions and with a specified accuracy, attains its operating value (current relay, voltage relay, power relay, etc.)
2. A relay designed to initiate disconnection of a part of an electrical installation or to operate a warning signal, in the case of a fault or other abnormal condition in the installation. A protective relay may include more than one unit electrical relay and accessories.

The IEEE Standard 37.2 Electrical Power System Device Function Numbers assign device numbers (1 to 100) to various types of protective relays:

Some Often Used *Device Function Numbers*

2	Time Delay Starting Relay	52	AC Circuit Breaker
3	Checking or Interlocking Relay	53	Exciter Relay
21	Distance Relay	55	Power Factor Relay
23	Temperature Control Device	56	Field Applications Relay
25	Synchronizing Device	57	Short-Circuiting or Grounding Device
26	Apparatus Thermal Device	59	Overvoltage Relay
27	Undervoltage Relay	60	Voltage or Current Balance Relay
29	Isolating Contactor	63	Liquid or Gas Pressure Relay
30	Annunciator Relay	64	Ground Protective Relay
32	Directional Power Relay	68	Blocking Relay
36	Polarity Voltage Device	74	Alarm Relay
37	Undercurrent and Underpower Relay	76	DC Overcurrent Relay
38	Bearing Protective Device	78	Phase-Angle Measuring Relay
40	Field Relay	81	Frequency Relay
44	Unit Sequence Starting Relay	82	DC Reclosing Relay
46	Reverse Phase or Phase Balance Current Relay	85	Carrier or Pilot-Wire Receiver Relay
47	Phase-Sequence Relay	86	Lockout Relay
48	Incomplete Sequence Relay	87	Differential Relay
49	Machine or Transformer Thermal Relay	91	Voltage Directional Relay
50	Instantaneous Overcurrent or Rate-of-Rise Relay	92	Voltage and Power Directional Relay
51	AC Time Overcurrent Relay	94	Trip-Free Relay

Monostable Relay

An electrical relay, which, having responded to an input energizing quantity (or characteristic quantity) and having changed its conditions, returns to its previous.

Motor-Driven Relay

A relay whose contacts are actuated by the rotation of a motor shaft.

Neutral Relay

A relay whose operation is independent of the direction of the coil current, in contrast to a polarized relay.

Open Relay

An unenclosed relay.

Over Current Relay

Protection relay that is specifically designed to operate when its coil current reaches or exceeds a predetermined value.

Over Voltage Relay

Protection relay that is specifically designed to operate when its coil voltage reaches or exceeds a predetermined value.

Phase-Sequence Voltage Relay

A relay that functions upon a predetermined value of polyphase voltage in the desired phase sequence.

Plunger Relay

A relay operated by a movable core or plunger through solenoid action.

Polarized Relay

A relay whose operation is dependent upon the polarity of the energizing current.
Monostable (***Biased***) — a two-position relay that requires current of a predetermined polarity for operation and returns to the off position when the operating winding is deenergized or is energized with reversed polarity.
Bistable (***Double-Biased***) — a two-position relay that will remain in its last operated position keeping the operated contacts closed after the operating winding is deenergized.
Center-Stable (***Un-Biased***) — a polarized relay that is operated in one of two energized positions, depending on the polarity of the energizing current, and that returns to a third, off position, when the operating winding is deenergized.

Power Direction Relay

A protective relay used in protective circuits as a unit determining by the direction of power passing through the protected power line where the damage occurred: on the protected line or on some other outgoing lines adjoined to this substation.

Power Factor Relay

A relay that operates when the power factor in an AC circuit rises above or falls below a predetermined value.

Power Relay

1. A relay with heavy-duty contacts (output circuits), usually rated 10 to 25 A or higher. Sometimes called a contactor.
2. The protective relay are commonly used (as overpower relays) for protection against excess electric power flow in a predetermined direction.

Reed Relay

A relay using hermetic enclosed magnetic reeds as the contact members and coil or permanent magnet as source of operated magnetic field.

Remanent Relay (Remanence Relay)

A remanent, bistable relay adopts a particular switching position at an energizing direct current in any direction and is held in this position by the remanence in the magnetic circuit, that is, through the magnetization of parts of the magnetic circuit. The contacts shift to the other switching position on a small energizing current of limited amplitude in the opposite direction. This demagnetizes the magnetic circuit again.

RF Relay

A relay designed to switch electrical AC energy with frequencies higher than audio range (radio frequency).
Antenna Switching Relay — A special RF relay used to switch antenna circuits.
Coaxial Relay — A special RF relay that opens or closes a coaxial cable or line. It is generally a low impedance device.

Sealed Relay

Relays which are sealed against the penetration of specified PCB cleaners or lacquers.

Immersion Cleanable

Relays that can be cleaned, lacquered or cast-in together with the printed circuit board after soldering without anything penetrating the relay. The washing requires a suitable solvent. In ultrasonic washing processes, the limiting values for temperature, duration, and frequency must be observed.

Note: Relays sealed against washing can also be used for environments with aggressive atmospheres.

Starting Relay

A unit relay which responds to abnormal conditions and initiates the operation of other elements of the protective system.

Stepping Relay (Ratchet, Multiposition, Rotary)

A relay having many rotary positions, ratchet actuated, moving from one step to the next in successive operations, and usually operating its contacts by means of cams.

Telephone-Type Relay

A term sometimes applied to relay with an end on armature, an L-shaped heel piece, and contact springs mounted parallel to the long axis of the relay coil which are originally used in old telephone systems.

Thermal Relay

A relay that is actuated by the heating effects of an electrical current.

Time Delay Relay

A relay in which the actuation of the output circuit (operation or release) is delayed internally (coil slugs or sleeves), mechanically (clockwork, bellows, dashpot, etc.), or by an accompanying electronic timing circuit.

Tripping Relay (Trip-Free Relay)

A relay that functions to trip a circuit breaker, contactor or equipment, or to permit immediate tripping by other devices; or to prevent immediate reclosure of a circuit interrupter if it should open automatically even though its closing circuit is maintained closed.

Under Current Relay

A relay specifically designed to function when its energizing current falls below a predetermined value.

Under Voltage Relay

A relay specifically designed to function when its energizing voltage falls below a predetermined value.

Zero-Voltage-Turn-On (Off) Relay

A relay with isolated input and output in which added control circuitry delays the output turn-on (turn-off) until a zero voltage transition of the AC sine wave is detected. Construction may be all solid-state or hybrid with a solid-state output.

3. Parameters of Relay

Ampere-Turn

A unit of magnetizing force. The product of current flowing, measured in amperes, multiplied by the number of turns in a coil or winding.

Breakdown Voltage

Threshold value at which breakdown does not occur when AC voltage is applied between pins, similar to insulation resistance. Usually, the breakdown voltage is tested for 1 min and the current value that defines breakdown is 1 mA. The minimum value is specified.

Coil Resistance

DC resistance of the coil. Usually measured at 25°C. A tolerance of $\pm 10\%$ usually applies.

Coil Temperature Rise

Rise of the coil temperature at a given input (power or voltage).

Degree of Protection

Ratings, for example, defined in IEC 60 529, indicating how completely a cover, seal, etc., protect against water, humidity, dust, direct contact, etc.

Dielectric Strength

The maximum allowable AC rms voltage (50 or 60 Hz) which may be applied between two test points, such as the coil and case or current carrying and noncurrent carrying points, without a leakage current in excess of 1 mA.

Duty Cycle

The ratio between the switch *on* time and total cycle time during periodical switching. Fifty per cent duty cycle means the switch on time equals the switch off time.

Eddy Current (Foucault Current)

Circulating currents in magnetic field conductive materials caused by alternating magnetic fields. They represent power losses in relay core.

Electrical Life

Switching life of the contacts expressed as the number of operations measured when the rated voltage is applied to the relay and the relay is operated at the rated operating frequency with the rated load applied to the contacts.

Electromotive Force (EMF)

The force which causes current to flow in a conductor; in other words, the voltage or potential.

Flux

Magnetic lines of force.

Flux Density

Magnetic lines of force per unit of area.

Fritting

Electrical breakdown which can occur under special conditions (voltage, current) whenever thin contact films prevent electrical conductivity between closed contacts. Fritting is a process which generates (A-fritting) and/or widens (B-fritting) a conducting path through such a semi-conducting film on a contact surface. During A-fritting, electrons are injected into the undamaged film. The electron current alters the condition of the film producing a ''conductive channel.'' During the following B-fritting, the current widens the channel increasing the conductivity.

Inrush Current

The inrush current of a machine or apparatus is the maximum current which flows after being suddenly and fully energized.

Insulation Resistance

The minimum allowable DC resistance between two parts electrically independent of each other, case at a specified voltage, usually 500 V. Usually, this specifies the insulation resistances between the coil and contact pin, between open contact pins, and between adjacent contact pins (if the relay has two or more contacts). In addition, the insulation resistance between the pins of the contacts that are open in the operate state is also specified.

Leakage Current

Error current that can degrade sensitive measurements. Even high resistance paths between low current conductors and nearby voltage sources can generate significant leakage currents. Leakage in insulating material, micro-contamination on insulating surfaces, and moisture (humidity) can have catastrophic effects on picoamp and sub-picoamp (femtoamp) measurements.

Limiting Continuous Current (Steady State Current Limit)

The highest value of the current (effective value for alternating current) that the previously closed output circuit can permanently carry under specified conditions.

Load Life

The minimum number of cycles the relay will make, carry, and break the specified load without contact sticking or welding, and without exceeding the electrical specifications of the device.

Load life is established using various methods including Weibull probability methods.

Maximum Carry Current

Maximum current that can flow between contacts when the contacts are closed.

Maximum Coil Voltage

The maximum voltage that can be applied to the coil. Usually, the ambient temperature is specified as a condition.

Maximum Switching Current

Maximum current switchable with relay contact.

Maximum Switching Power

Maximum load power switchable with relay contact.

The value under DC load is expressed in W, and that under AC load is expressed in VA.

Maximum Voltage

The highest permissible input (coil) voltage at the reference temperature at which the relay, with continuous energization, heats up to its maximum permissible coil temperature.

Maximum Switching Voltage

Maximum voltage switchable with relay contact.

The peak value is indicated in the catalog under DC load. The effective value (rms) is indicated under AC load.

Mechanical Life

Life expressed as the number of operations that can be performed when the nominal coil voltage is applied to the relay with the contacts not loaded and the relay is operated at the rated operating frequency.

Mechanical Shock, Nonoperating

That mechanical shock level (amplitude, duration, and wave shape) to which the relay may be subjected without permanent electrical or mechanical damage (during storage or transportation).

Minimum Energization Time

The minimum impulse length at the height of the nominal voltage that is required to change the switching position of a bistable relay.

Minimum Switching Power

Minimum load power through relay contact necessary for normal operation. Expressed as the minimum values of voltage and current.

Minimum Voltage

The lowest permissible input voltage at which the relay operates reliably at the reference temperature even after continuous energization (preenergizing) and brief deenergizing.

Must Operate Voltage

Minimum voltage required to place the make contact in operate state from the release state. Normally, the contact should be driven by a rectangular waveform voltage. The maximum value is specified. In the case of a latching relay, this term means a voltage (set voltage) that is required to place the relay in the set state from the reset state.

Must Release Voltage

Maximum voltage to place the relay in the release state (the break contact is closed) from the operate state. The minimum value is specified. In the case of a latching relay, the maximum value necessary for placing the relay in the reset state from the set state, and is expressed as a reset voltage. The maximum value is specified.

Nominal Coil Voltage

A standard voltage applied to the coil to use the relay.

Operate Time

The time interval from input (coil) energization to the functioning of the last output (contact) to function. This includes time for the coil to build up its magnetic field (a significant limiting factor) and transfer time of the moveable contact between stationary contact(s), and bounce time after the initial contact make. For a solid-state or hybrid relay in a nonoperated state, the time from the application of the pickup voltage to the change of state of the output.

Operating State

Switch position of a monostable relay in the energized state. For bistable relays the switch position specified by the manufacturer.

Operating Temperature Range

The ambient temperature range over which an unmounted relay is specified to operate.

Operating Voltage Range

Permissible range of the input voltage depending on the ambient temperature.

Pickup Value

The minimum input that will cause a device to complete contact operation or similar designated action.

Pickup Voltage (or Current)

The voltage (or current) at which the device starts to operate when its operating coil is energized under conditions of normal operating temperatures.

Power Dissipation Rating of Coil

A product of the coil voltage rating and coil current. Normal power dissipation to operate the relay.

Protection Classes for Relays (according to IEC 60. 529)

Class IP 54: nonsealed relays which are protected against flux by their base plate and cover (dust-proof).
Class IP 67: describes sealed (immersion cleanable) relays.

Rated Burden

The power of burden (*watts* if DC or *volt–amperes* if AC) absorbed under the reference conditions by a given energizing circuit of a relay and determined under specified conditions.

Rated Coil Voltage

The coil voltage at which the relay is intended to operate for the prescribed duty cycle. Note: The use of any coil voltage less than rated may compromise the performance of the relay.

Rating

The nominal value of an energizing quantity, which appears in the designation of a relay.

Release

Process in which a monostable relay shifts from the operating state back to the rest state.

Release Time

The time interval from input (coil) deenergization to the functioning of the last output (contact) to function. This includes time for the coil to dropout its magnetic field (a significant limiting factor) and transfer time of the moveable contact between stationary contact(s), and bounce time after the initial contact brake. For a solid-state or hybrid relay in an operated state, the time from the application of the drop-out voltage to the change of state of the output.

Response

Process in which a relay shifts from the rest state to the operating state.

Reset

Process in which a bistable relay returns from the operating state back to the rest state.

Rest State (Release state)

Switch position of a monostable relay in the unenergized state. In bistable relays this is the switch position specified by the manufacturer.

Reset Time

The time interval that elapses from the point of time at which a bistable relay in the operating state has the nominal voltage applied in the opposite direction to the point of time at which the last output circuit has closed or opened (not including the bounce time).

Return

A relay returns when sequentially: it disengages; it passes from an operated condition towards the prescribed initial condition; and it resets.

Returning Ratio

The ratio of the returning value to the operating value.

Setting

The limiting value of a ‘characteristic’ or ‘energizing’ quantity at which the relay is designed to operate under specified conditions.

Such values are usually marked on the relay and may be expressed as direct values, percentages of rated values, or multiples.

Shock Resistivity

Threshold value indicating that no abnormality occurs even when semisine wave pulsating mechanical shock has been applied to the relay. Even after the shock has been applied, the contacts that have been opened do not close or the contacts that have been closed are not opened.

Vibration Resistivity

In the same manner as shock, threshold value when sine-wave vibration has been repeatedly applied to the relay.

4. Contact Systems and Other Relay Components

According to the different switching functions of the relay contacts, a difference is made between the various contact configurations whose design and description are specified in DIN 41020, ANSI C83.16.

SP, single pole; **DP**, double pole; **ST**, single throw; **NO**, normally open; **NC**, normally closed; **C**, changeover; **B**, break; **M**, make; **DM**, double make; **DB**, double break; **DT**, double throw

Some additional forms:

2C, DPDT; **4C**, 4PDT; **P**, SPST-Latching; **R**, SPDT-Latching.

Armature

The moving magnetic member of an electromagnetic relay structure.

Armature Balanced

A relay armature that rotates about its center of mass and is therefore approximately in balance with both gravitational (static) and accelerative (dynamic) forces.

Armature End-On

A relay armature whose principal motion is parallel to the longitudinal axis of a core having a pole face at one end.

Armature Lever

The distance through which the armature buffer moves divided by the armature travel. Also, the ratio of the distance from the armature bearing pin (or fulcrum) to the armature buffer in relation to the distance from the bearing pin (or fulcrum) to the center of the pole face.

Armature Chatter

The undesired vibration of the armature due to inadequate AC performance or external shock and vibration.

Auxiliary Contact

A contact combination used to operate a visual or audible signal to indicate the position of the main contacts, establish interlocking circuits, or hold a relay operated when the original operating circuit is opened.

Bobbin

A spool or structure upon which a coil is wound.

Bias Electrical

An electrically produced force tending to move the armature towards a given position.

Bias Magnetic

A steady magnetic field (permanent magnet) applied to the magnetic circuit of a relay to aid or impede operations of the armature.

Bias Mechanical

A mechanical force tending to move the armature towards a given position.

Blowout Magnet

A device that establishes a magnetic field in the contact gap to help extinguish the arc by displacing it.

Break Contact (NC Contact)

A contact that is closed in the release (rest) state of a monostable relay and opens (breaks) when the relay coil is energized (operating state).

Bridging Make Contact

Compound contact with two simultaneously operating make contacts connected in series.

Changeover Contact

A combination of two contact circuits including three contact members: a make contact and a break contact with a common terminal. When one of these contact circuits is open, the other is closed and vice versa. On changing the switch position, the contact previously closed opens first followed by the closing of the contact that was previously open.

Coil

An assembly consisting of one or more windings, usually wound over an insulated iron core on a bobbin or spool. May be self-supporting, with terminals and any other required parts such as a sleeve or slugs.

Concentrically Wound — A coil with two or more insulated windings wound one over the other.

Double Wound

A coil consisting of two windings wound on the same core.

Parallel Wound

A coil having multiple windings wound simultaneously, with the turns of each winding being contiguous (see *winding, bifilar*).

Sandwich Wound

A coil consisting of three concentric windings in which the first and third windings are connected series aiding to match the impedance of the second winding. The combination is used to maintain transmission balance.

Tandem Wound

A coil having two or more windings, one behind the other, along the longitudinal axis. Also referred to as a two-, three-, or four-section coil, etc.

Clapper

Sometimes used for an armature that is hinged or pivoted.

Cold Switching

Closing the relay contacts before applying voltage and current, plus removing voltage and current before opening the contacts. (Contacts do not make or break current.) Also see Dry Circuit Switching. Larger currents may be carried through the contacts without damage to the contact area since contacts will not ''arc'' when closed or opened.

Contact Bifurcated

A forked, or branched, contacting member so formed or arranged as to provide some degree of independent dual contacting.

Contact Bounce

An unintentional phenomenon that can occur during the making or breaking of a contact circuit when the contact elements touch successively and separate again before they have reached their final position.

Caused by one or more of the following: impingement of mating contacts; impact of the armature against the coil core on pickup or against the backstop on dropout; momentary hesitation or reversal of the armature motion during the pickup or drop-out stroke.

Contact bounce period depends upon the type of relay and varies from 0.1 to 0.5 ms for small reed relays up to 5 to 10 ms for larger solenoid types. Solid-state or mercury wetted contacts (Hg) do not have a contact bounce characteristic.

Contact Bounce Time

The time from the first to the last closing or opening of a relay contact.

Contact Break-Before-Make

A contact combination in which one contact opens its connection to another contact and then closes its connection to a third contact.

Contact Carrier

Conductive metal part of the relay where the contact is attached to.

Continuous Current

The maximum current that can be carried by the closed contacts of the relay for a sustained time period. This specification is determined by measuring the resistance heating effect on critical relay components.

Contact Erosion

Material loss at the contact surfaces, for example, due to material evaporation by an arc.

Contact Force

The force which two contact tips (points) exert against each other in the closed position under specified conditions.

Contact Gap

The distance between a pair of mating relay contacts when the contacts are open.

Contact Chatter

Externally caused, undesired vibration of mating contacts during which there may or may not be actual physical contact opening. If there is no actual opening but only a change in resistance, it is referred to as dynamic resistance.

Contact Late

A contact combination that is adjusted to function after other contact combinations when the relay operates.

Contact Member

A conductive part of a contact assembly which is electrically isolated from other such parts when the contact circuit is open.

Contact Potential

A voltage produced between contact terminals due to the temperature gradient across the relay contacts, and the reed-to-terminal junctions of dissimilar metals. (The temperature gradient is typically caused by the power dissipated by the energized coil.) Also known as contact offset voltage, thermal EMF, and thermal offset (in special contact metal combinations a thermal induced voltage of a few 100 μV is possible). This is a major consideration when measuring voltages in the microvolt range. There are special low thermal relay contacts available to address this need. Special contacts are not required if the relay is closed for a short period of time where the coil has no time to vary the temperature of the contact or connecting materials (welds or leads).

Current Rated Contact

The current which the contacts are designed to handle for their rated life.

Current Surge Limiting

The circuitry necessary to protect relay contacts from excessive and possibly damaging current caused by capacitive loads or loads which have a higher current consumption on switch *on* than in subsequent continuous operation (e.g., light lamps).

Contact Rating

The electrical load-handling capability of relay contacts (voltage, current, and power capacities) under specified environmental conditions and for a prescribed number of operations.

Contact Resistance

The resistance of closed contacts is measured as voltage drop across contacts carrying 1 A at 6 VDC for power relays and smaller carrying current for miniature relays. Actually, this is the sum of the contact resistance and conductor resistance.

The maximum initial value (on delivery) is usually set forth on the catalog.

Contact Roll

When a contact is making, the relative rolling movement of the contact tips (points) after they have just touched.

Contact Tip

That part of a contact member at which the contact circuit closes or opens.

Contact Wipe

When a contact is making, the relative nibbling movement of contact tips (points) after they have just touched.

Contact Weld

A contact failure due to fusing of contacting surfaces to the extent that the contacts fail to separate when intended.

Double Pole (Single Throw Version)

A double pole relay switches two electrically not connected common lines with two electrically independent load lines (like two separate make relays).

Double Throw (Single Pole Version)

A double throw (single pole) relay switches one common line between two stationary contacts, for example, between a NO contact and a NC contact (like changeover relay or form C).

Drop-Out Voltage

The voltage at which all contacts return to their ''normal,'' unoperated positions. (Applicable only to nonlatching relays.)

Dry Switching

Switching below specified levels of voltage and current (usually: <1 mA, <100 mV) to minimize any physical and electrical changes in the contact junction.

Duty Cycle

The ratio between the switch on time and total cycle time during periodical switching. Fifty per cent duty cycle means the switch on time equals the switch off time.

Dynamic Contact Resistance

Variation in contact resistance due to changes in contact pressure during the period in which contacts are motion, before opening or after closing.

Make Contact (NO Contact)

A contact that is open in the release (rest) state of a monostable relay and closes (makes) when the relay coil is energized (operating state).

Maximal Break Current

The highest value of current that can switch an output circuit *off* under specified conditions (voltage, switch off rate, power factor, time constants, etc.).

Maximal Make Current

The highest value of current that can switch an output circuit *on* under specified conditions (voltage, switch on rate, power factor, time constants, etc.). Loads can frequently have a higher current consumption on switch on than in subsequent continuous operation (e.g., light lamps).

Maximal Switching Current

The maximum current that can switch a relay contact *on* and *off*.

Maximum Switching Power

Maximum permissible product of switching current and switching voltage (in W for direct current, in VA for alternating current).

Minimum Switching Capacity

Due to slight corrosion of contacts, a minimum current or voltage is needed to allow fritting to keep the contact resistance low.

Minimum Switching Power

Product of the switching current and switching voltage that should not be undercut to ensure switching.

Movable Contact

The member of a contact combination that is moved directly by the actuating system. This member is also referred to as the armature contact or swinger contact. The moveable contact is mounted on the armature or spring system.

Normally Closed Contact (NC)

A contact combination which is closed when the armature is in its unoperated position.

Normally Open Contact (NO)

A contact combination that is open when the armature is in its unoperated position (generally applies to monostable relays).

Plunger or Solenoid Armature

A relay armature that moves within a tubular core in a direction parallel to its longitudinal axis.

Premake Contact

Twin contact electrically connected where one contact always closes first (premake) and opens last. The premake contact, for example, out of tungsten (high resistive and very resistant to contact erosion), switches the current, while the second, like a low resistive silver contact, carries the load.

Reed Contact

A hermetically enclosed, magnetically operated contact using thin, flexible, magnetic conducting strips as the contacting members which are moved directly by a magnetic force.

Settle Time

The time required for establishing relay connections and stabilizing user circuits. For relay contacts, this includes contact bounce.

Shading Ring

A shorted turn surrounding a portion of the pole of an alternating-current electromagnet that delays the change of the magnetic field in that part, thereby tending to prevent chatter and reduce hum.

Single Contact

Contact configuration with a single stationary and moveable contact pair on the make and/or the break side (compare twin or double contacts).

Single Pole (Single Throw Version)

A single pole (single throw) relay connects one common line (moveable contact) to one load line (stationary contact).

Single Throw (Single Pole Version)

A single throw (single pole) relay connects one common line (moveable contact) to one load line (stationary contact).

Stagger Time

The time interval between the functioning of contacts on the same relay. For example, the time difference between the opening of
normally closed contacts on pickup.

Stationary Contact

Nonmoveable contact, mounted on a contact carrier which is directly connected to a relay pin or faston blade.

Switching current

Current that can switch a relay contact *on* and *off*.

5. Specified Terms for Solid-State Relays

Critical Rate of Rise of Off-State Voltage (Critical d*v*/d*t*)

The minimum value of the rate of rise of the forward voltage which will cause switching from the off-state to the on-state.

Critical Rate of Rise of On-State Current (Critical di/dt)

The maximum value of the rate of rise of on-state current which a thyristor can withstand without deleterious effect.

DIP

Dual inline package.

di/dt

Rate of rise of current.

dv/dt

Rate of rise of voltage.

FET

Field effect transistor. A device in which the gate voltage (not current) controls the ability of the device to conduct or block current flows.

Gate-Controlled Turn-On Time (t_{gt})

The time interval between a specified point at the beginning of the gate pulse and the instant when the forward voltage (current) has dropped (risen) to a specific, low (high) value during switching of a thyristor from the off-state to the on-state by a gate pulse.

Gate Trigger Current, Input Current, Control Current (I_{GT})

The minimum gate current required to switch a thyristor from the off-state to the on-state.

Gate Trigger Voltage (V_{GT})

The gate voltage required to produce the gate trigger current.

GTO

Gate turn-off thyristor. A thyristor which can be turned on and off by control of its gate current.

Holding current (I_H)

The minimum forward current required to maintain the thyristor in the on-state without control current after its opening.

IGBT

Insulated gate bipolar thyristor. A bipolar power transistor whose gate is voltage-charge controlled in similar manner to the MOSFET.

Latching Current (I_L)

The minimum forward current required to maintain the thyristor in the on-state immediately after switching from the off-state to the on-state has occurred and the triggering signal has been removed.

MOSFET

Metal-oxide-semiconductor field effect transistor. Variety of FET transistor (see FET).

MOV

Metal oxide varistor. Used for transient suppression.

Off-State d*v*/d*t*

The rate of rise of voltage, expressed in volts per microsecond (V/msec), that the SRR output switching device can withstand without turning on.

Off-State Voltage

The maximum effective steady state voltage that the output is capable of withstanding when in off-state without breakover or damage.

On-State Resistance

In a power-FET relay, this is the intrinsic resistance of the output circuit in the on-state.

On-State Voltage or Voltage Drop (V_T, V_{DROP})

The voltage at maximum load current developed across the output switching element (thyristor, triac, etc.) when the relay is in the ON state.

Over-Voltage Rating

The guaranteed transient peak blocking (or breakdown) voltage rating of the SSR.

Peak Gate Power Dissipation

The maximum power which may be dissipated between the gate and main terminal (or cathode) for a specified time duration.

Power Dissipation

The maximum power dissipated by the SSR for a given load current.

Repetitive Overload Current

The maximum allowable repetitive RMS overload current that may be applied to the output for a specific duration and duty cycle while still maintaining output control.

Repetitive Peak Forward Voltage of an SCR (V_{FRM})

The maximum instantaneous cyclic voltage occurs across a thyristor in off-state which it can withstand without turn-on (without control signal).

Repetitive Peak Off-State Current (I_{DRM})

The maximum instantaneous value of the off-state current that results from the application of repetitive peak off-state voltage.

Repetitive Peak Off-State Voltage (V_{DRM})

The maximum instantaneous value of the off-state voltage which occurs across a thyristor, including all repetitive transient voltages, but excluding all nonrepetitive transient voltages.

Repetitive Peak Reverse Current of an SCR (I_{RRM})

The maximum instantaneous value of the reverse current that results from the application of repetitive peak reverse voltage.

Repetitive Peak Reverse Voltage of an SCR (V_{RRM})

The maximum instantaneous value of the reverse voltage which occurs across a thyristor, including all repetitive transient voltages, but excluding all nonrepetitive transient voltages.

SCR

Silicon controlled rectifier. Synonym of word ''thyristor.''

SIP

Single inline package.

SMD

Surface mounted device.

Snubber

RC-circuit placed in parallel with a solid-state commutation device to protect against overvoltage transients.

Surge (Nonrepetitive) On-State Current (I_{TSM})

The maximum nonrepetitive surge (or overload) on-state current of short-time duration and specified waveshape that the SCR can safely withstand without causing permanent damage or degradation.

Thermal Resistance, Junction to Ambient

The temperature difference between the thyristor junction and the ambient divided by the power dissipation causing the temperature difference under conditions of thermal equilibrium. Note: Ambient is defined as the point where the temperature does not change as a result of the dissipation.

Triac

Variety of SCR (more complex) especially intended for use in AC circuits.

Voltage Reverse Polarity

The maximum allowable reverse voltage which may be applied to the input of a solid-state relay without permanent damage.

Zero-Voltage Turn On Relay

A relay with isolated input and output in which added control circuitry delays the output turn-on until a zero-voltage transition of the AC sine wave is detected.