3. Relays

Contents

Chapter 1

Relay

This article is about the electrical component. For other uses, see Relay (disambiguation).

A **relay** is an electrically operated switch. Many relays
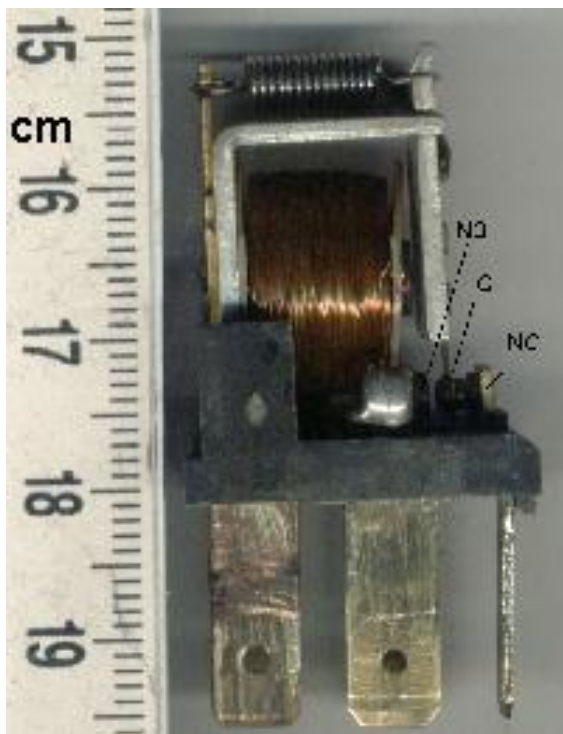
Automotive-style miniature relay, dust cover is taken off

use an electromagnet to mechanically operate a switch, but other operating principles are also used, such as solid-state relays. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal. The first relays were used in long distance telegraph circuits as amplifiers: they repeated the signal coming in from one circuit and re-transmitted it on another circuit. Relays were used extensively in telephone exchanges and early computers to perform logical operations.

A type of relay that can handle the high power required to directly control an electric motor or other loads is called a contactor. Solid-state relays control power circuits with no moving parts, instead using a semiconduc-

tor device to perform switching. Relays with calibrated operating characteristics and sometimes multiple operating coils are used to protect electrical circuits from overload or faults; in modern electric power systems these functions are performed by digital instruments still called "protective relays".

1.1 Basic design and operation
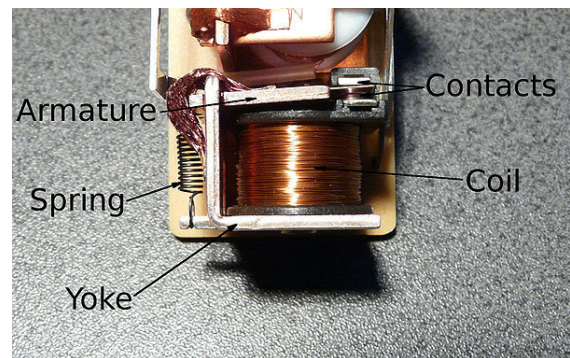
Simple electromechanical relay.

A simple electromagnetic relay consists of a coil of wire wrapped around a soft iron core, an iron yoke which provides a low reluctance path for magnetic flux, a movable iron armature, and one or more sets of contacts (there are two in the relay pictured). The armature is hinged to the yoke and mechanically linked to one or more sets of moving contacts. It is held in place by a spring so that when the relay is de-energized there is an air gap in the magnetic circuit. In this condition, one of the two sets of contacts in the relay pictured is closed, and the other set is open. Other relays may have more or fewer sets of contacts depending on their function. The relay in the picture also has a wire connecting the armature to the yoke. This ensures continuity of the circuit between the moving contacts on the armature, and the circuit track on the printed circuit board (PCB) via the yoke, which is soldered to the PCB.

When an electric current is passed through the coil it generates a magnetic field that activates the armature, and the consequent movement of the movable contact(s) either
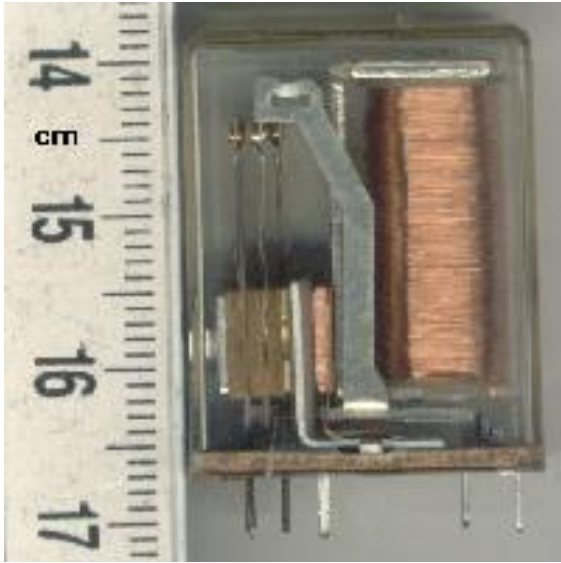
Small "cradle" relay often used in electronics. The "cradle" term refers to the shape of the relay's armature.

Latching relay with permanent magnet

makes or breaks (depending upon construction) a connection with a fixed contact. If the set of contacts was closed when the relay was de-energi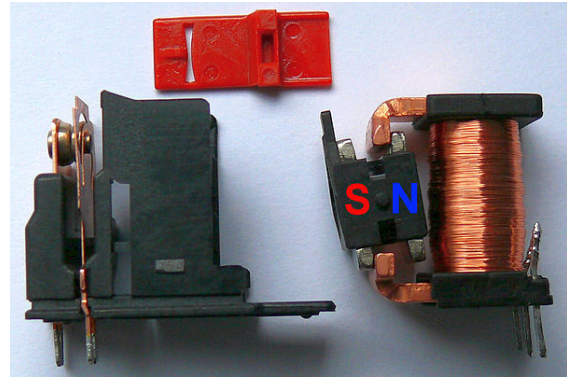zed, then the movement opens the contacts and breaks the connection, and vice versa if the contacts were open. When the current to the coil is switched off, the armature is returned by a force, approximately half as strong as the magnetic force, to its relaxed position. Usually this force is provided by a spring, but gravity is also used commonly in industrial motor starters. Most relays are manufactured to operate quickly. In a low-voltage application this reduces noise; in a high voltage or current application it reduces arcing.

When the coil is energized with direct current, a diode is often placed across the coil to dissipate the energy from the collapsing magnetic field at deactivation, which would otherwise generate a voltage spike dangerous to semiconductor circuit components. Some automotive relays include a diode inside the relay case. Alternatively, a contact protection network consisting of a capacitor and resistor in series (snubber circuit) may absorb the surge. If the coil is designed to be energized with alternating current (AC), a small copper "shading ring" can be crimped to the end of the solenoid, creating a small out-of-phase current which increases the minimum pull on the armature during the AC cycle.[1]

1.2   Types

1.2.1   Latching relay

A *latching relay* (also called "impulse", "keep", or "stay" relays) maintains either contact position indefinitely without power applied to the coil. The advantage is that one coil consumes power only for an instant while the relay is being switched, and the relay contacts retain this setting across a power outage. A latching relay allows remote control of building lighting without the hum that may be produced from a continuously (AC) energized coil.

In one mechanism, two opposing coils with an over-center spring or permanent magnet hold the contacts in position after the coil is de-energized. A pulse to one coil turns the relay on and a pulse to the opposite coil turns the relay off. This type is widely used where control is from simple switches or single-ended outputs of a control system, and such relays are found in avionics and numerous industrial applications.

Another latching type has a remanent core that retains the contacts in the operated position by the remanent magnetism in the core. This type requires a current pulse of opposite polarity to release the contacts. A variation uses a permanent magnet that produces part of the force required to close the contact; the coil supplies sufficient force to move the contact open or closed by aiding or opposing the field of the permanent magnet.[2] A polarity controlled relay needs changeover switches or an H bridge drive circuit to control it. The relay may be less expensive than other types, but this is partly offset by the increased costs in the external circuit.

In another type, a ratchet relay has a ratchet mechanism that holds the contacts closed after the coil is momentarily energized. A second impulse, in the same or a separate coil, releases the contacts.[2] This type may be found in certain cars, for headlamp dipping and other functions where alternating operation on each switch actuation is needed.

A stepping relay is a specialized kind of multi-way latching relay designed for early automatic telephone exchanges.

An earth leakage circuit breaker includes a specialized latching relay.

Very early computers often stored bits in a magnetically latching relay, such as ferreed or the later memreed in the 1ESS switch.

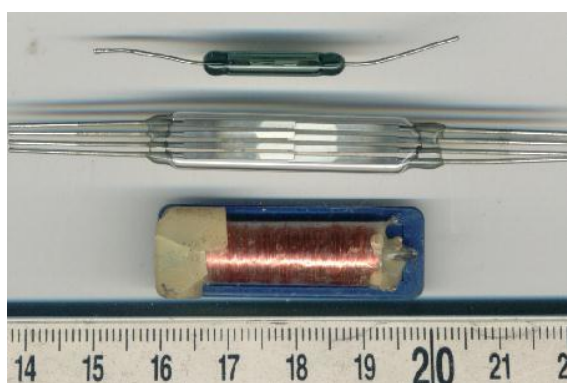Some early computers used ordinary relays as a kind of

latch—they store bits in ordinary wire spring relays or reed relays by feeding an output wire back as an input, resulting in a feedback loop or sequential circuit. Such an electrically-latching relay requires continuous power to maintain state, unlike magnetically latching relays or mechanically racheting relays.

In computer memories, latching relays and other relays were replaced by delay line memory, which in turn was replaced by a series of ever-faster and ever-smaller memory technologies.

1.2.2 Reed relay

Main article: reed relay
A reed relay is a reed switch enclosed in a solenoid. The

A mercury-wetted reed relay that has AC/DC switching specifications of 100 W, 500 V, 2 A maximum

Top, middle: reed switches, bottom: reed relay

switch has a set of contacts inside an evacuated or inert gas-filled glass tube which protects the contacts against atmospheric corrosion; the contacts are made of magnetic material that makes them move under the influence of the field of the enclosing solenoid or an external magnet.

Reed relays can switch faster than larger relays and require very little power from the control circuit. However, they have relatively low switching current and voltage ratings. Though rare, the reeds can become magnetized over time, which makes them stick 'on' even when no current is present; changing the orientation of the reeds with respect to the solenoid's magnetic field can resolve this problem.

Sealed contacts with mercury-wetted contacts have longer operating lives and less contact chatter than any other kind of relay.[3]

1.2.3 Mercury-wetted relay

See also: mercury switch

A **mercury-wetted reed relay** is a form of reed relay in which the contacts are wetted with mercury. Such relays are used to switch low-voltage signals (one volt or less) where the mercury reduces the contact resis-

tance and associated voltage drop, for low-current signals where surface contamination may make for a poor contact, or for high-speed applications where the mercury eliminates contact bounce. Mercury wetted relays are position-sensitive and must be mounted vertically to work properly. Because of the toxicity and expense of liquid mercury, these relays are now rarely used.

The mercury-wetted relay has one particular advantage, in that the contact closure appears to be virtually instantaneous, as the mercury globules on each contact coalesce. The current rise time through the contacts is generally considered to be a few picoseconds, however in a practical circuit it will be limited by the inductance of the contacts and wiring. It was quite common, before the restrictions on the use of mercury, to use a mercury-wetted relay in the laboratory as a convenient means of generating fast rise time pulses, however although the rise time may be picoseconds, the exact timing of the event is, like all other types of relay, subject to considerable jitter, possibly milliseconds, due to mechanical imperfections.

The same coalescence process causes another effect, which is a nuisance in some applications. The contact resistance is not stable immediately after contact closure, and drifts, mostly downwards, for several seconds after closure, the change perhaps being 0.5 ohm.

1.2.4 Mercury relay

A mercury relay is a relay that uses mercury as the switching element. They are used where contact erosion would be a problem for conventional relay contacts. Owing to environmental considerations about significant amount of mercury used and modern alternatives, they are now comparatively uncommon.

1.2.5   Polarized relay

A **polarized relay** places the armature between the poles of a permanent magnet to increase sensitivity. Polarized relays were used in middle 20th Century telephone exchanges to detect faint pulses and correct telegraphic distortion. The poles were on screws, so a technician could first adjust them for maximum sensitivity and then apply a bias spring to set the critical current that would operate the relay.

1.2.6   Machine tool relay

A **machine tool relay** is a type standardized for industrial control of machine tools, transfer machines, and other sequential control. They are characterized by a large number of contacts (sometimes extendable in the field) which are easily converted from normally-open to normally-closed status, easily replaceable coils, and a form factor that allows compactly installing many relays in a control panel. Although such relays once were the backbone of automation in such industries as automobile assembly, the programmable logic controller (PLC) mostly displaced the machine tool relay from sequential control applications.

A relay allows circuits to be switched by electrical equipment: for example, a timer circuit with a relay could switch power at a preset time. For many years relays were the standard method of controlling industrial electronic systems. A number of relays could be used together to carry out complex functions (relay logic). The principle of relay logic is based on relays which energize and de-energize associated contacts. Relay logic is the predecessor of ladder logic, which is commonly used in programmable logic controllers.

1.2.7   Coaxial relay

Where radio transmitters and receivers share a common antenna, often a coaxial relay is used as a TR (transmit-receive) relay, which switches the antenna from the receiver to the transmitter. This protects the receiver from the high power of the transmitter. Such relays are often used in transceivers which combine transmitter and receiver in one unit. The relay contacts are designed not to reflect any radio frequency power back toward the source, and to provide very high isolation between receiver and transmitter terminals. The characteristic impedance of the relay is matched to the transmission line impedance of the system, for example, 50 ohms.[4]

1.2.8   Time delay

Timing relays are arranged for an intentional delay in operating their contacts. A very short (a fraction of a second) delay would use a copper disk between the armature and moving blade assembly. Current flowing in the disk maintains magnetic field for a short time, lengthening release time. For a slightly longer (up to a minute) delay, a dashpot is used. A dashpot is a piston filled with fluid that is allowed to escape slowly; both air-filled and oil-filled dashpots are used. The time period can be varied by increasing or decreasing the flow rate. For longer time periods, a mechanical clockwork timer is installed. Relays may be arranged for a fixed timing period, or may be field adjustable, or remotely set from a control panel. Modern microprocessor-based timing relays provide precision timing over a great range.

1.2.9   Contactor

Main article: Contactor

A **contactor** is a heavy-duty relay used for switching electric motors and lighting loads, but contactors are not generally called relays. Continuous current ratings for common contactors range from 10 amps to several hundred amps. High-current contacts are made with alloys containing silver. The unavoidable arcing causes the contacts to oxidize; however, silver oxide is still a good conductor.[5] Contactors with overload protection devices are often used to start motors. Contactors can make loud sounds when they operate, so they may be unfit for use where noise is a chief concern.

A contactor is an electrically controlled switch used for switching a power circuit, similar to a relay except with higher current ratings.[6] A contactor is controlled by a circuit which has a much lower power level than the switched circuit.

Contactors come in many forms with varying capacities and features. Unlike a circuit breaker, a contactor is not intended to interrupt a short circuit current. Contactors range from those having a breaking current of several amperes to thousands of amperes and 24 V DC to many kilovolts. The physical size of contactors ranges from a device small enough to pick up with one hand, to large devices approximately a meter (yard) on a side.

1.2.10   Solid-state relay

Main article: Solid-state relay

A **solid state relay** or **SSR** is a solid state electronic component that provides a similar function to an electromechanical relay but does not have any moving components, increasing long-term reliability. A solid-state relay uses a thyristor, TRIAC or other solid-state switching device, activated by the control signal, to switch the controlled load, instead of a solenoid. An optocoupler (a light-emitting diode (LED) coupled with a photo transistor) can be used to isolate control and controlled circuits.
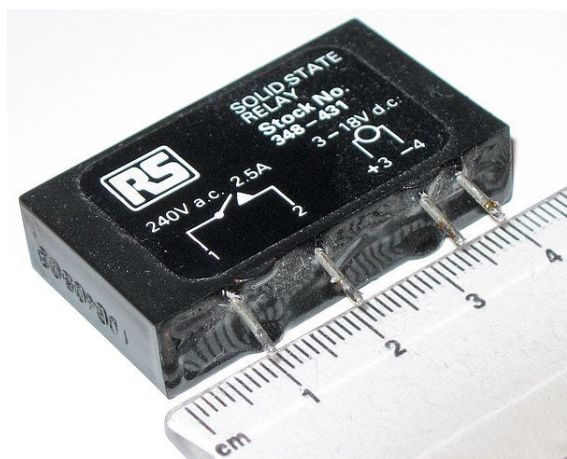
Solid state relay with no moving parts
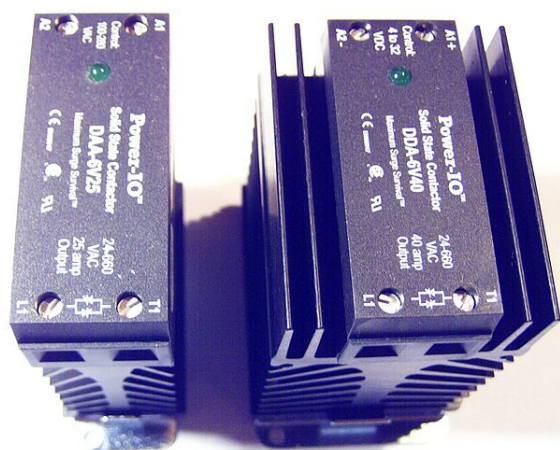
25 A or 40 A solid state contactors

As every solid-state device has a small voltage drop across it, this voltage drop limits the amount of current a given SSR can handle. The minimum voltage drop for such a relay is a function of the material used to make the device. Solid-state relays rated to handle as much as 1,200 amperes have become commercially available. Compared to electromagnetic relays, they may be falsely triggered by transients and in general may be susceptible to damage by extreme cosmic ray and EMP episodes.

1.2.11 Solid state contactor relay

A **solid state contactor** is a heavy-duty solid state relay, including the necessary heat sink, used where frequent on/off cycles are required, such as with electric heaters, small electric motors, and lighting loads. There are no moving parts to wear out and there is no contact bounce due to vibration. They are activated by AC control signals or DC control signals from Programmable logic controller (PLCs), PCs, Transistor-transistor logic (TTL) sources, or other microprocessor and microcontroller controls.

1.2.12 Buchholz relay

Main article: Buchholz relay

A **Buchholz relay** is a safety device sensing the accumulation of gas in large oil-filled transformers, which will alarm on slow accumulation of gas or shut down the transformer if gas is produced rapidly in the transformer oil. The contacts are not operated by an electric current but by the pressure of accumulated gas or oil flow.

1.2.13 Forced-guided contacts relay

A **forced-guided contacts relay** has relay contacts that are mechanically linked together, so that when the relay coil is energized or de-energized, all of the linked contacts move together. If one set of contacts in the relay becomes immobilized, no other contact of the same relay will be able to move. The function of forced-guided contacts is to enable the safety circuit to check the status of the relay. Forced-guided contacts are also known as "positive-guided contacts", "captive contacts", "locked contacts", "mechanically-linked contacts", or "safety relays".

These safety relays have to follow design rules and manufacturing rules that are defined in one main machinery standard EN 50205 : Relays with forcibly guided (mechanically linked) contacts. These rules for the safety design are the one that are defined in type B standards such as EN 13849-2 as Basic safety principles and Well-tried safety principles for machinery that applies to all machines.

Forced-guided contacts by themselves can not guarantee that all contacts are in the same state, however they do guarantee, subject to no gross mechanical fault, that no contacts are in opposite states. Otherwise, a relay with several normally open (NO) contacts may stick when energised, with some contacts closed and others still slightly open, due to mechanical tolerances. Similarly, a relay with several normally closed (NC) contacts may stick to the unenergised position, so that when energised, the circuit through one set of contacts is broken, with a marginal gap, while the other remains closed. By introducing both NO and NC contacts, or more commonly, changeover contacts, on the same relay, it then becomes possible to guarantee that if any NC contact is closed, all NO contacts are open, and conversely, if any NO contact is closed, all NC contacts are open. It is not possible to reliably ensure that any particular contact is closed, except by potentially intrusive and safety-degrading sensing of its circuit conditions, however in safety systems it is usually the NO state that is most important, and as explained above, this is reliably verifiable by detecting the closure of a contact of opposite sense.

Forced-guided contact relays are made with different main contact sets, either NO, NC or changeover, and one

or more auxiliary contact sets, often of reduced current or voltage rating, used for the monitoring system. Contacts may be all NO, all NC, changeover, or a mixture of these, for the monitoring contacts, so that the safety system designer can select the correct configuration for the particular application. Safety relays are used as part of an engineered safety system.

1.2.14   Overload protection relay

Electric motors need overcurrent protection to prevent damage from over-loading the motor, or to protect against short circuits in connecting cables or internal faults in the motor windings.[7] The overload sensing devices are a form of heat operated relay where a coil heats a bimetallic strip, or where a solder pot melts, releasing a spring to operate auxiliary contacts. These auxiliary contacts are in series with the coil. If the overload senses excess current in the load, the coil is de-energized.

This thermal protection operates relatively slowly allowing the motor to draw higher starting currents before the protection relay will trip. Where the overload relay is exposed to the same environment as the motor, a useful though crude compensation for motor ambient temperature is provided.

The other common overload protection system uses an electromagnet coil in series with the motor circuit that directly operates contacts. This is similar to a control relay but requires a rather high fault current to operate the contacts. To prevent short over current spikes from causing nuisance triggering the armature movement is damped with a dashpot. The thermal and magnetic overload detections are typically used together in a motor protection relay.

Electronic overload protection relays measure motor current and can estimate motor winding temperature using a "thermal model" of the motor armature system that can be set to provide more accurate motor protection. Some motor protection relays include temperature detector inputs for direct measurement from a thermocouple or resistance thermometer sensor embedded in the winding.

1.2.15   Vacuum relays

A sensitive relay having its contacts mounted in a highly evacuated glass housing, to permit handling radio-frequency voltages as high as 20,000 volts without flashover between contacts even though contact spacing is but a few hundredths of an inch when open.

1.3   Pole and throw

Since relays are switches, the terminology applied to switches is also applied to relays; a relay switches one or
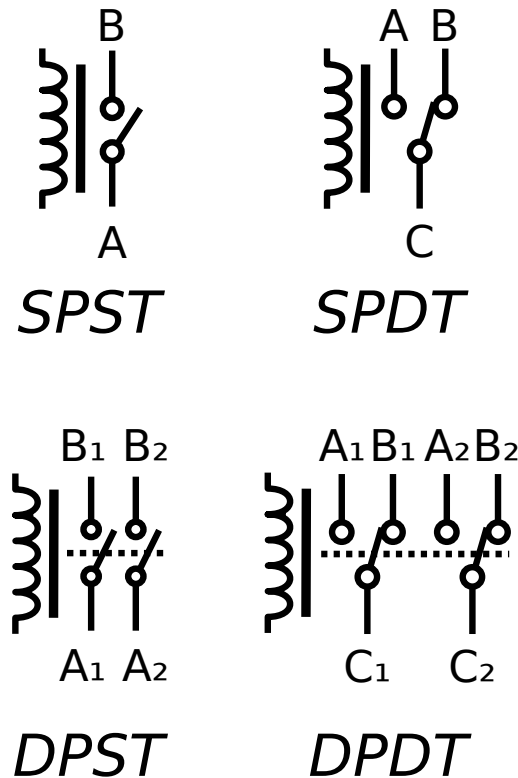
Circuit symbols of relays. (C denotes the common terminal in SPDT and DPDT types.)

more *poles*, each of whose contacts can be *thrown* by energizing the coil.

Normally-open (NO) contacts connect the circuit when the relay is activated; the circuit is disconnected when the relay is inactive. It is also called a "Form A" contact or "make" contact. NO contacts may also be distinguished as "early-make" or "NOEM", which means that the contacts close before the button or switch is fully engaged.

Normally-closed (NC) contacts disconnect the circuit when the relay is activated; the circuit is connected when the relay is inactive. It is also called a "Form B" contact or "break" contact. NC contacts may also be distinguished as "late-break" or "NCLB", which means that the contacts stay closed until the button or switch is fully disengaged.

Change-over (CO), or double-throw (DT), contacts control two circuits: one normally-open contact and one normally-closed contact with a common terminal. It is also called a "Form C" contact or "transfer" contact ("break before make"). If this type of contact has a "make before break" action, then it is called a "Form D" contact.

The following designations are commonly encountered:

- **SPST** – Single Pole Single Throw. These have two terminals which can be connected or disconnected. Including two for the coil, such a relay has four terminals in total. It is ambiguous whether the pole is

normally open or normally closed. The terminology "SPNO" and "SPNC" is sometimes used to resolve the ambiguity.

- **SPDT** – Single Pole Double Throw. A common terminal connects to either of two others. Including two for the coil, such a relay has five terminals in total.

- **DPST** – Double Pole Single Throw. These have two pairs of terminals. Equivalent to two SPST switches or relays actuated by a single coil. Including two for the coil, such a relay has six terminals in total. The poles may be Form A or Form B (or one of each).

- **DPDT** – Double Pole Double Throw. These have two rows of change-over terminals. Equivalent to two SPDT switches or relays actuated by a single coil. Such a relay has eight terminals, including the coil.

The "S" or "D" may be replaced with a number, indicating multiple switches connected to a single actuator. For example 4PDT indicates a four pole double throw relay that has 12 switch terminals.

EN 50005 are among applicable standards for relay terminal numbering; a typical EN 50005-compliant SPDT relay's terminals would be numbered 11, 12, 14, A1 and A2 for the C, NC, NO, and coil connections, respectively.

DIN 72552 defines contact numbers in relays for automotive use;

- 85 = relay coil -

- 86 = relay coil +

- 87 = common contact

- 87a = normally closed contact

- 87b = normally open contact

1.4 Applications

Relays are used wherever it is necessary to control a high power or high voltage circuit with a low power circuit. The first application of relays was in long telegraph systems, where the weak signal received at an intermediate station could control a contact, regenerating the signal for further transmission. High-voltage or high-current devices can be controlled with small, low voltage wiring and pilots switches. Operators can be isolated from the high voltage circuit. Low power devices such as microprocessors can drive relays to control electrical loads beyond their direct drive capability. In an automobile, a starter relay allows the high current of the cranking motor to be controlled with small wiring and contacts in the ignition key.
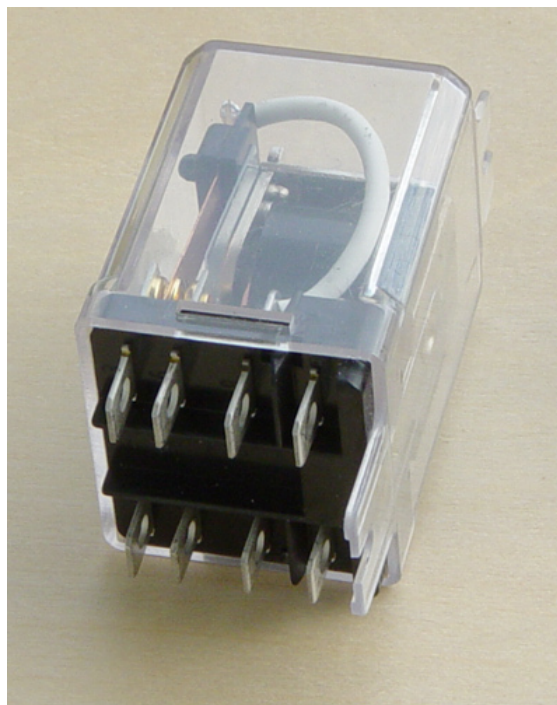
A DPDT AC coil relay with "ice cube" packaging

Electromechanical switching systems including Strowger and Crossbar telephone exchanges made extensive use of relays in ancillary control circuits. The Relay Automatic Telephone Company also manufactured telephone exchanges based solely on relay switching techniques designed by Gotthilf Ansgarius Betulander. The first public relay based telephone exchange in the UK was installed in Fleetwood on 15 July 1922 and remained in service until 1959.[8][9]

The use of relays for the logical control of complex switching systems like telephone exchanges was studied by Claude Shannon, who formalized the application of Boolean algebra to relay circuit design in A Symbolic Analysis of Relay and Switching Circuits. Relays can perform the basic operations of Boolean combinatorial logic. For example, the boolean AND function is realised by connecting normally open relay contacts in series, the OR function by connecting normally open contacts in parallel. Inversion of a logical input can be done with a normally-closed contact. Relays were used for control of automated systems for machine tools and production lines. The Ladder programming language is often used for designing relay logic networks.

Early electro-mechanical computers such as the ARRA, Harvard Mark II, Zuse Z2, and Zuse Z3 relays for logic and working registers. However, electronic devices proved faster and easier to use.

Because relays are much more resistant than semiconductors to nuclear radiation, they are widely used in safety-critical logic, such as the control panels of radioactive waste-handling machinery. Electromechanical protective

relays are used to detect overload and other faults on electrical lines by opening and closing circuit breakers.

1.5 Relay application considerations
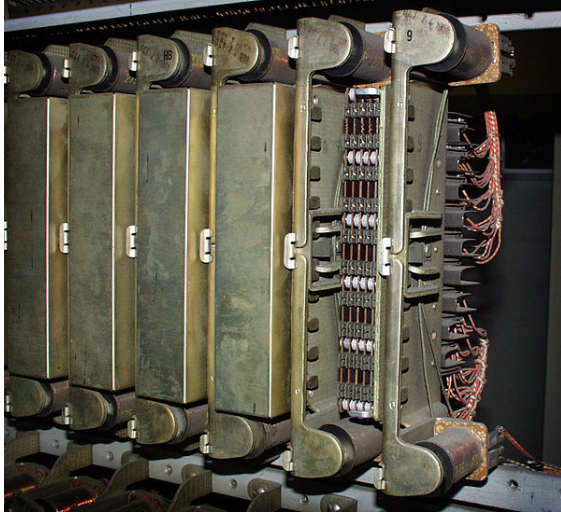
Several 30-contact relays in "Connector" circuits in mid 20th century 1XB switch and 5XB switch telephone exchanges; cover removed on one

Selection of an appropriate relay for a particular application requires evaluation of many different factors:

- Number and type of contacts – normally-open, normally-closed, (double-throw)

- Contact sequence – "Make before Break" or "Break before Make". For example, the old style telephone exchanges required Make-before-break so that the connection didn't get dropped while dialing the number.

- Rating of contacts – small relays switch a few amperes, large contactors are rated for up to 3000 amperes, alternating or direct current

- Voltage rating of contacts – typical control relays rated 300 VAC or 600 VAC, automotive types to 50 VDC, special high-voltage relays to about 15,000 V

- Operating lifetime, useful life - the number of times the relay can be expected to operate reliably. There is both a mechanical life and a contact life. The contact life is affected by the kind of load being switched. Breaking load current causes undesired arcing between the contacts, eventually leading to contacts that weld shut or contacts that fail erosion by the arc.[10]

- Coil voltage – machine-tool relays usually 24 VDC, 120 or 250 VAC, relays for switchgear may have 125

V or 250 VDC coils, "sensitive" relays operate on a few milliamperes

- Coil current - including minimum current required to operate reliably and minimum current to hold. Also effects of power dissipation on coil temperature at various duty cycles.

- Package/enclosure – open, touch-safe, double-voltage for isolation between circuits, explosion proof, outdoor, oil and splash resistant, washable for printed circuit board assembly

- Operating environment - minimum and maximum operating temperatures and other environmental considerations such as effects of humidity and salt

- Assembly – Some relays feature a sticker that keeps the enclosure sealed to allow PCB post soldering cleaning, which is removed once assembly is complete.

- Mounting – sockets, plug board, rail mount, panel mount, through-panel mount, enclosure for mounting on walls or equipment

- Switching time – where high speed is required

- "Dry" contacts – when switching very low level signals, special contact materials may be needed such as gold-plated contacts

- Contact protection – suppress arcing in very inductive circuits

- Coil protection – suppress the surge voltage produced when switching the coil current

- Isolation between coil contacts

- Aerospace or radiation-resistant testing, special quality assurance

- Expected mechanical loads due to acceleration – some relays used in aerospace applications are designed to function in shock loads of 50 *g* or more

- Size - smaller relays often resist mechanical vibration and shock better than larger relays, because of the lower inertia of the moving parts and the higher natural frequencies of smaller parts.[3] Larger relays often handle higher voltage and current than smaller relays.

- Accessories such as timers, auxiliary contacts, pilot lamps, and test buttons

- Regulatory approvals

- Stray magnetic linkage between coils of adjacent relays on a printed circuit board.

There are many considerations involved in the correct selection of a control relay for a particular application. These considerations include factors such as speed of operation, sensitivity, and hysteresis. Although typical control relays operate in the 5 ms to 20 ms range, relays with switching speeds as fast as 100 us are available. Reed relays which are actuated by low currents and switch fast are suitable for controlling small currents.

As for any switch, the current through the relay contacts (unrelated to the current through the coil) must not exceed a certain value to avoid damage. In the particular case of high-inductance circuits such as motors, other issues must be addressed. When an inductance is connected to a power source, an input surge current or electromotor starting current larger than the steady current exists. When the circuit is broken, the current cannot change instantaneously, which creates a potentially damaging spark across the separating contacts.

Consequently for relays which may be used to control inductive loads, we must specify the maximum current that may flow through the relay contacts when it actuates, the *make rating*; the continuous rating; and the *break rating*. The make rating may be several times larger than the continuous rating, which is itself larger than the break rating.

1.5.1 Derating factors

Control relays should not be operated above rated temperature because of resulting increased degradation and fatigue. Common practice is to derate 20 degrees Celsius from the maximum rated temperature limit. Relays operating at rated load are also affected by their environment. Oil vapors may greatly decrease the contact tip life, and dust or dirt may cause the tips to burn before their normal life expectancy. Control relay life cycle varies from 50,000 to over one million cycles depending on the electrical loads of the contacts, duty cycle, application, and the extent to which the relay is derated. When a control relay is operating at its derated value, it is controlling a lower value of current than its maximum make and break ratings. This is often done to extend the operating life of the control relay. The table lists the relay derating factors for typical industrial control applications.

1.5.2 Undesired arcing

Main article: Arc suppression

Switching while "wet" (under load) causes undesired arcing between the contacts, eventually leading to contacts that weld shut or contacts that fail due to a buildup of contact surface damage caused by the destructive arc energy.[10]

Inside the 1ESS switch matrix switch and certain other high-reliability designs, the reed switches are always switched "dry" to avoid that problem, leading to much longer contact life.[11]

Without adequate contact protection, the occurrence of electric current arcing causes significant degradation of the contacts in relays, which suffer significant and visible damage. Every time a relay transitions either from a closed to an open state (break arc) or from an open to a closed state (make arc & bounce arc), under load, an electrical arc can occur between the two contact points (electrodes) of the relay. In many situations, the break arc is more energetic and thus more destructive, in particular with resistive-type loads. However, inductive loads can engender more destructive make arcs: for example, with standard electric motors, the start-up (inrush) current tends to be much greater than the running current. This translates into enormous make arcs.

During an arcing event, the heat energy contained in the electrical arc is very high (tens of thousands of degrees Fahrenheit), causing the metal on the contact surfaces to melt, pool and migrate with the current. The extremely high temperature of the arc cracks the surrounding gas molecules creating ozone, carbon monoxide, and other compounds. The arc energy slowly destroys the contact metal, causing some material to escape into the air as fine particulate matter. This very activity causes the material in the contacts to degrade quickly, resulting in device failure. This contact degradation drastically limits the overall life of a relay to a range of about 10,000 to 100,000 operations, a level far below the mechanical life of the same device, which can be in excess of 20 million operations.[12]

## 1.6 Protective relays

Main article: protective relay

For protection of electrical apparatus and transmission lines, electromechanical relays with accurate operating characteristics were used to detect overload, short-circuits, and other faults. While many such relays remain in use, digital devices now provide equivalent protective functions.

1.7 Railway signalling

Railway signalling relays are large considering the mostly small voltages (less than 120 V) and currents (perhaps 100 mA) that they switch. Contacts are widely spaced to prevent flashovers and short circuits over a lifetime that may exceed fifty years. BR930 series plug-in relays[13] are widely used on railways following British practice. These are 120 mm high, 180 mm deep and 56 mm wide and weigh about 1400 g, and can have up to 16 separate contacts, for example, 12 make and 4 break contacts.
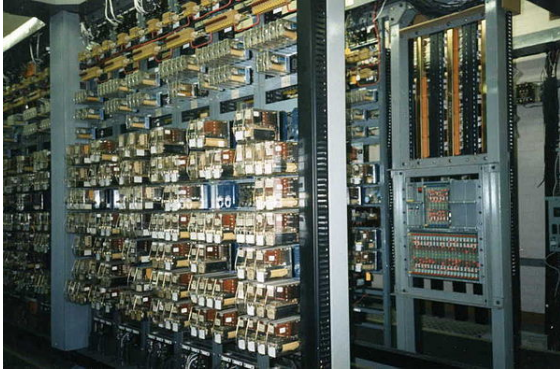
Part of a relay interlocking using UK Q-style miniature plug-in relays.
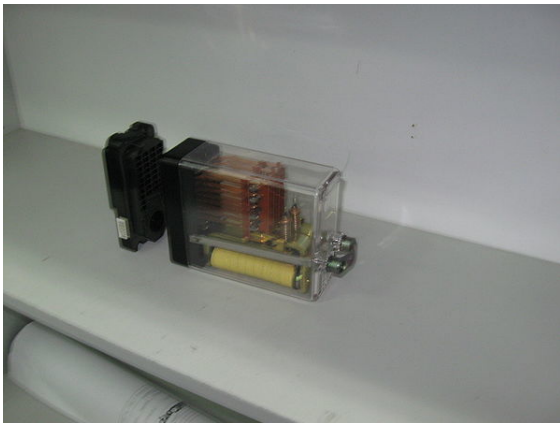
UK Q-style signalling relay and base.

Many of these relays come in 12V, 24V and 50V versions.

The BR Q-type relay are available in a number of different configurations:

- QN1 Neutral

- QL1 Latched - see above

- QNA1 AC-immune

- QBA1 Biased AC-immune - see above

- QNN1 Twin Neutral 2x4-4 or 2x6-2

- QBCA1 Contactor for high current applications such as point motors. Also DC biased and AC immune. [14]

- QTD4 - Slow to release timer [15]

- QTD5 - Slow to pick up timer [16]

Since rail signal circuits must be highly reliable, special techniques are used to detect and prevent failures in the relay system. To protect against false feeds, double switching relay contacts are often used on both the positive and negative side of a circuit, so that two false feeds are needed to cause a false signal. Not all relay circuits

can be proved so there is reliance on construction features such as carbon to silver contacts to resist lightning induced contact welding and to provide AC immunity.

Opto-isolators are also used in some instances with railway signalling, especially where only a single contact is to be switched.

Signalling relays, typical circuits, drawing symbols, abbreviations & nomenclature, etc. come in a number of schools, including the United States, France, Germany, and the United Kingdom.

1.8   History

The American scientist Joseph Henry invented a relay in 1835 in order to improve his version of the electrical telegraph, developed earlier in 1831.[17][18][19][20]

It is claimed that the English inventor Edward Davy *"certainly invented the electric relay"*[21] in his electric telegraph c.1835.

A simple device, which we now call a relay, was included in the original 1840 telegraph patent[22] of Samuel Morse. The mechanism described acted as a digital amplifier, repeating the telegraph signal, and thus allowing signals to be propagated as far as desired. This overcame the problem of limited range of earlier telegraphy schemes.

The word *relay* appears in the context of electromagnetic operations from 1860.[23]

1.9   See also

- Contactor

- Digital protective relay

- Dry contact

- Race condition

- Stepping switch - a kind of multi-position relay

- Wire spring relay

- Analogue switch

- Nanoelectromechanical relay

1.10   References

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- Electromagnetic relays and Solid-State Relays (SSR), general technical descriptions, functions, shutdown behaviour and design features

- The Electromechanical Relay

- Information about relays and the Latching Relay circuit

- "Harry Porter's Relay Computer", a computer made out of relays.

- "Relay Computer Two", by Jon Stanley.

- Interfacing Relay To Microcontroller.

- Relays Technical Write

- http://relays.te.com/schrack/pdf/C0_v4bg_5.pdf

Chapter 2

Solid-state relay

A **solid-state relay (SSR)** is an electronic switching device that switches on or off when a small external voltage is applied across its control terminals. SSRs consist of a sensor which responds to an appropriate input (control signal), a solid-state electronic switching device which switches power to the load circuitry, and a coupling mechanism to enable the control signal to activate this switch without mechanical parts. The relay may be designed to switch either AC or DC to the load. It serves the same function as an electromechanical relay, but has no moving parts.

Solid-state relays are composed of semiconductor materials, including thyristors and transistors, and have current ratings that extend from a few microamps for low-power packages up to around a hundred amps for high-power packages. They have extremely fast switching speeds usually ranging between 1 to 100 nanoseconds and are not easily affected by contact wear. Solid-state relays have several shortcomings: a high susceptibility to damage (a relatively high vulnerability to overloads in comparison to electromechanical relays); limited switching arrangements (SPST switching); a need for finer tuning due to high "on" resistances.

2.1 Coupling

The control signal must be coupled to the controlled circuit in a way which provides galvanic isolation between the two circuits.

Many SSRs use optical coupling. The control voltage energizes an internal LED which illuminates and switches on a photo-sensitive diode (photo-voltaic); the diode current turns on a back-to-back thyristor, SCR, or MOSFET to switch the load. The optical coupling allows the control circuit to be electrically isolated from the load.

2.2 Operation

An SSR based on a single MOSFET, or multiple MOSFETs in a paralleled array, can work well for DC loads.

MOSFETs have an inherent substrate diode that conducts in the reverse direction, so a single MOSFET cannot block current in both directions. For AC (bi-directional) operation two MOSFETs are arranged back-to-back with their source pins tied together. Their drain pins are connected to either side of the output. The substrate diodes are alternately reverse biased to block current when the relay is off. When the relay is on, the common source is always riding on the instantaneous signal level and both gates are biased positive relative to the source by the photo-diode.

It is common to provide access to the common source so that multiple MOSFETs can be wired in parallel if switching a DC load. Usually a network is provided to speed the turn-off of the MOSFET when the control input is removed.

One significant advantage of a solid-state SCR or TRIAC relay over an electromechanical device is its natural tendency to open the AC circuit only at a point of zero load current. Because SCR's and TRIAC's are thyristors, their inherent hysteresis maintains circuit continuity after the LED is de-energized until the AC current falls below a threshold value (the holding current). In practical terms what this means is the circuit will never be interrupted in the middle of a sine wave peak. Such untimely interruptions in a circuit containing substantial inductance would normally produce large voltage spikes due to the sudden magnetic field collapse around the inductance. This will not happen in a circuit broken by an SCR or TRIAC. This feature is called zero-crossover switching.[1]

2.3 Parameters

SSRs are characterised by a number of parameters including the required activating input voltage, current, output voltage and current, whether it is AC or DC, voltage drop or resistance affecting output current, thermal resistance, and thermal and electrical parameters for safe operating area (e.g., derating according to thermal resistance when repeatedly switching large currents).

2.4 Advantages over mechanical relays

Most of the relative advantages of solid state and electromechanical relays are common to all solid-state as against electromechanical devices.

- Slimmer profile, allowing tighter packing.

- Totally silent operation

- SSRs are faster than electromechanical relays; their switching time is dependent on the time needed to power the LED on and off, of the order of microseconds to milliseconds

- Increased lifetime, even if it is activated many times, as there are no moving parts to wear and no contacts to pit or build up carbon

- Output resistance remains constant regardless of amount of use

- Clean, bounceless operation

- No sparking, allows it to be used in explosive environments, where it is critical that no spark is generated during switching

- Inherently smaller than a mechanical relay of similar specification (if desired may have the same "casing" form factor for interchangeability).

- Much less sensitive to storage and operating environment factors such as mechanical shock, vibration, humidity, and external magnetic fields.

2.5 Disadvantages

- Voltage/current characteristic of semiconductor rather than mechanical contacts:

  - When closed, higher resistance (generating heat), and increased electrical noise

  - When open, lower resistance, and reverse leakage current (typically μA range)

  - Voltage/current characteristic is not linear (not purely resistive), distorting switched waveforms to some extent. An electromechanical relay has the low ohmic (linear) resistance of the associated mechanical switch when activated, and the exceedingly high resistance of the air gap and insulating materials when open.

  - Some types have polarity-sensitive output circuits. Electromechanical relays are not affected by polarity.

- Possibility of spurious switching due to voltage transients (due to much faster switching than mechanical relay)

- Isolated bias supply required for gate charge circuit

- Higher transient reverse recovery time (Trr) due to the presence of the body diode

- Tendency to fail "shorted" on their outputs, while electromechanical relay contacts tend to fail "open".

2.6 Images

2.7 See also

- Solid State Relay Inventor and Early Patents

- Push-button telephone

2.8 References

[1] allaboutcircuits.com

2.9 External links

- A DC Fault Protection Circuit for Audio Amplifiers

- Solid state relay glossary of terminology

- National Instruments Solid State Relays

- Solid State Relays vs Electromechanical Relays

Chapter 3

Contactor

AC contactor for pump application.

*In **semiconductor testing**, **contactor** can also refer to the specialised socket that connects the device under test.*

*In process industries a **contactor** is a vessel where two streams interact, for example, air and liquid. See Gas-liquid contactor.*

A **contactor** is an electrically controlled switch used for switching a power circuit, similar to a relay except with higher current ratings.[1] A contactor is controlled by a circuit which has a much lower power level than the switched circuit.

Contactors come in many forms with varying capacities and features. Unlike a circuit breaker, a contactor is not intended to interrupt a short circuit current. Contactors range from those having a breaking current of several amperes to thousands of amperes and 24 V DC to many

kilovolts. The physical size of contactors ranges from a device small enough to pick up with one hand, to large devices approximately a meter (yard) on a side.

Contactors are used to control electric motors, lighting, heating, capacitor banks, thermal evaporators, and other electrical loads.

3.1 Construction
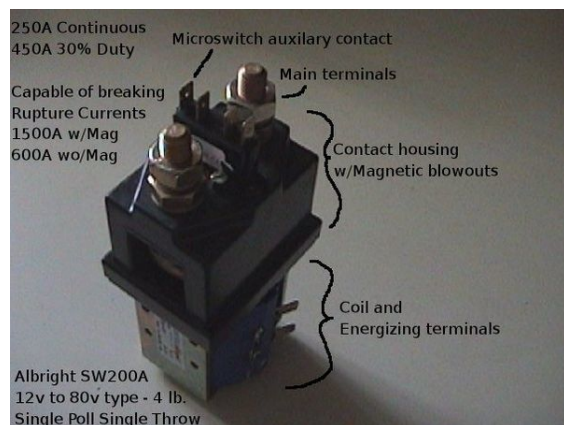
Albright SPST DC contactor,
sometimes used in Electric vehicle (EV) conversions

Powerful DC contactor with electro-pneumatic drive

A contactor has three components. The *contacts* are the current carrying part of the contactor. This includes

15

power contacts, auxiliary contacts, and contact springs. The *electromagnet* (or "*coil*") provides the driving force to close the contacts. The *enclosure* is a frame housing the contact and the electromagnet. Enclosures are made of insulating materials like Bakelite, Nylon 6, and thermosetting plastics to protect and insulate the contacts and to provide some measure of protection against personnel touching the contacts. Open-frame contactors may have a further enclosure to protect against dust, oil, explosion hazards and weather.

Magnetic blowouts use blowout coils to lengthen and move the electric arc. These are especially useful in DC power circuits. AC arcs have periods of low current, during which the arc can be extinguished with relative ease, but DC arcs have continuous high current, so blowing them out requires the arc to be stretched further than an AC arc of the same current. The magnetic blowouts in the pictured Albright contactor (which is designed for DC currents) more than double the current it can break, increasing it from 600 A to 1,500 A.

Sometimes an economizer circuit is also installed to reduce the power required to keep a contactor closed; an auxiliary contact reduces coil current after the contactor closes. A somewhat greater amount of power is required to initially close a contactor than is required to keep it closed. Such a circuit can save a substantial amount of power and allow the energized coil to stay cooler. Economizer circuits are nearly always applied on direct-current contactor coils and on large alternating current contactor coils.

A basic contactor will have a coil input (which may be driven by either an AC or DC supply depending on the contactor design). The coil may be energized at the same voltage as a motor the contactor is controlling, or may be separately controlled with a lower coil voltage better suited to control by programmable controllers and lower-voltage pilot devices. Certain contactors have series coils connected in the motor circuit; these are used, for example, for automatic acceleration control, where the next stage of resistance is not cut out until the motor current has dropped.[2]

3.2   Operating principle

Unlike general-purpose relays, contactors are designed to be directly connected to high-current load devices. Relays tend to be of lower capacity and are usually designed for both *normally closed* and *normally open* applications. Devices switching more than 15 amperes or in circuits rated more than a few kilowatts are usually called contactors. Apart from optional auxiliary low current contacts, contactors are almost exclusively fitted with normally open ("form A") contacts. Unlike relays, contactors are designed with features to control and suppress the arc produced when interrupting heavy motor currents.

When current passes through the electromagnet, a magnetic field is produced, which attracts the moving core of the contactor. The electromagnet coil draws more current initially, until its inductance increases when the metal core enters the coil. The moving contact is propelled by the moving core; the force developed by the electromagnet holds the moving and fixed contacts together. When the contactor coil is de-energized, gravity or a spring returns the electromagnet core to its initial position and opens the contacts.

For contactors energized with alternating current, a small part of the core is surrounded with a shading coil, which slightly delays the magnetic flux in the core. The effect is to average out the alternating pull of the magnetic field and so prevent the core from buzzing at twice line frequency.

Because arcing and consequent damage occurs just as the contacts are opening or closing, contactors are designed to open and close very rapidly; there is often an internal tipping point mechanism to ensure rapid action.

Rapid closing can, however, lead to increase contact bounce which causes additional unwanted open-close cycles. One solution is to have bifurcated contacts to minimize contact bounce; two contacts designed to close simultaneously, but bounce at different times so the circuit will not be briefly disconnected and cause an arc.

A slight variant has multiple contacts designed to engage in rapid succession. The first to make contact and last to break will experience the greatest contact wear and will form a high-resistance connection that would cause excessive heating inside the contactor. However, in doing so, it will protect the primary contact from arcing, so a low contact resistance will be established a millisecond later.

Another technique for improving the life of contactors is contact wipe; the contacts move past each other after initial contact on order to wipe off any contamination.

3.3   Arc suppression

Main article: Arc suppression

Without adequate contact protection, the occurrence of electric current arcing causes significant degradation of the contacts, which suffer significant damage. An electrical arc occurs between the two contact points (electrodes) when they transition from a closed to an open (break arc) or from an open to a closed (make arc). The break arc is typically more energetic and thus more destructive.[3]

The heat developed by the resulting electrical arc is very high, ultimately causing the metal on the contact to migrate with the current. The extremely high temperature of the arc (tens of thousands of degrees Celsius) cracks the surrounding gas molecules creating ozone, carbon

monoxide, and other compounds. The arc energy slowly destroys the contact metal, causing some material to escape into the air as fine particulate matter. This activity causes the material in the contacts to degrade over time, ultimately resulting in device failure. For example, a properly applied contactor will have a life span of 10,000 to 100,000 operations when run under power; which is significantly less than the mechanical (non-powered) life of the same device which can be in excess of 20 million operations.[4]

Most motor control contactors at low voltages (600 volts and less) are air break contactors; air at atmospheric pressure surrounds the contacts and extinguishes the arc when interrupting the circuit. Modern medium-voltage AC motor controllers use vacuum contactors. High voltage AC contactors (greater than 1000 volts) may use vacuum or an inert gas around the contacts. High Voltage DC contactors (greater than 600V) still rely on air within specially designed arc-chutes to break the arc energy. High-voltage electric locomotives may be isolated from their overhead supply by roof-mounted circuit breakers actuated by compressed air; the same air supply may be used to "blow out" any arc that forms.[5][6]

3.4 Ratings

Contactors are rated by designed load current per contact (pole),[7] maximum fault withstand current, duty cycle, design life expectancy, voltage, and coil voltage. A general purpose motor control contactor may be suitable for heavy starting duty on large motors; so-called "definite purpose" contactors are carefully adapted to such applications as air-conditioning compressor motor starting. North American and European ratings for contactors follow different philosophies, with North American general purpose machine tool contactors generally emphasizing simplicity of application while definite purpose and European rating philosophy emphasizes design for the intended life cycle of the application.

3.4.1 IEC utilization categories

The current rating of the contactor depends on utilization category. Example IEC categories in standard 60947 are described as:

- **AC-1** - Non-inductive or slightly inductive loads, resistance furnaces

- **AC-2** - Starting of slip-ring motors: starting, switching-off

- **AC-3** - Starting of squirrel-cage motors and switching-off only after the motor is up to speed. (Make Locked Rotor Amps (LRA), Break Full Load Amps (FLA))

- **AC-4** - Starting of squirrel-cage motors with inching and plugging duty. Rapid Start/Stop. (Make and Break LRA)

Relays and auxiliary contact blocks are rated according to IEC 60947-5-1.

- **AC-15** - Control of electromagnetic loads (>72 VA)

- **DC-13** - Control of electromagnets

3.4.2 NEMA

NEMA contactors for low-voltage motors (less than 1000 volts) are rated according to NEMA size, which gives a maximum continuous current rating and a rating by horsepower for attached induction motors. NEMA standard contactor sizes are designated 00,0,1,2,3,4,5,6,7,8,9.

The horsepower ratings are based on voltage and on typical induction motor characteristics and duty cycle as stated in NEMA standard ICS2. Exceptional duty cycles or specialized motor types may require a different NEMA starter size than the nominal rating. Manufacturer's literature is used to guide selection for non-motor loads, for example, incandescent lighting or power factor correction capacitors. Contactors for medium-voltage motors (greater than 1000 volts) are rated by voltage and current capacity.

Auxiliary contacts of contactors are used in control circuits and are rated with NEMA contact ratings for the pilot circuit duty required. Normally these contacts are not used in motor circuits. The nomenclature is a letter followed by a three digit number, the letter designates the current rating of the contacts and the current type (i.e., AC or DC) and the number designates the maximum voltage design values.[8]

3.5 Applications

3.5.1 Lighting control

Contactors are often used to provide central control of large lighting installations, such as an office building or retail building. To reduce power consumption in the contactor coils, latching contactors are used, which have two operating coils. One coil, momentarily energized, closes the power circuit contacts, which are then mechanically held closed; the second coil opens the contacts.

3.5.2 Magnetic starter

Main article: Magnetic starter

A **magnetic starter** is a device designed to provide power to electric motors. It includes a contactor as an essential component, while also providing power-cutoff, undervoltage, and overload protection.

3.5.3 Vacuum contactor

Vacuum contactors utilize vacuum bottle encapsulated contacts to suppress the arc. This arc suppression allows the contacts to be much smaller and use less space than air break contacts at higher currents. As the contacts are encapsulated, vacuum contactors are used fairly extensively in dirty applications, such as mining.

Vacuum contactors are only applicable for use in AC systems. The AC arc generated upon opening of the contacts will self-extinguish at the zero-crossing of the current waveform, with the vacuum preventing a re-strike of the arc across the open contacts. Vacuum contactors are therefore very efficient at disrupting the energy of an electric arc and are used when relatively fast switching is required, as the maximum break time is determined by the periodicity of the AC waveform.

3.6 References

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Chapter 4

Reed relay
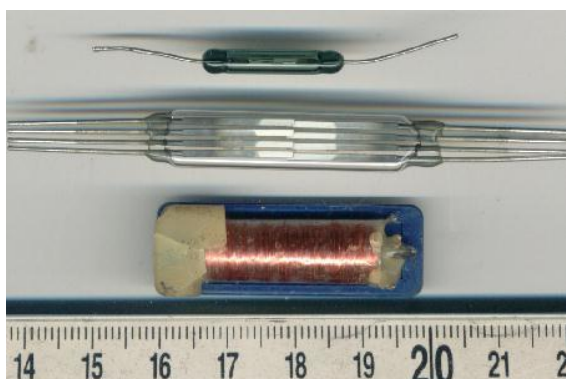
Reed relay and reed switches

A **reed relay** is a type of relay that uses an electromagnet to control one or more reed switches. The contacts are of magnetic material and the electromagnet acts directly on them without requiring an armature to move them. Sealed in a long, narrow glass tube, the contacts are protected from corrosion, and are usually plated with silver, which has very low resistivity but is prone to corrosion when exposed, rather than corrosion-resistant but more resistive gold as used in the exposed contacts of high quality relays. The glass envelope may contain multiple reed switches or multiple reed switches can be inserted into a single bobbin and actuate simultaneously. Reed switches have been manufactured since the 1930s.

As the moving parts are small and lightweight, reed relays can switch much faster than relays with armatures.[1] They are mechanically simple, making for reliability and long life.

4.1   Memory device

A few million reed relays were used from the 1930s to the 1960s for memory functions in Bell System electromechanical telephone exchanges. Often a multiple-reed relay was used, with one of the reeds latching the relay, and the other or others performing logic or memory functions. Most reed relays in the crossbar switching systems of the 1940s through the 1970s were packaged in groups of five. Such a "reed pack" was able to store one decimal digit, encoded in a two-out-of-five code (74210 variant) for easy validity checking by wire spring relay logic.

Such an electrically-latching reed relay requires continuous power to maintain state, unlike magnetically latching relays, such as ferreed (ferrite and reed relay) or the later remreed (remanent reed relay).

4.2   Crosspoint switch

In the Bell System Stored Program Control exchange systems of the 1970s, reed relays were no longer needed for data storage, but tens of millions of them were packaged in arrays for voice path switching. In the 1ESS switch, the cores were made of a magnetically remanent alloy, so the relay could latch magnetically instead of latching electrically. This "Ferreed" method reduced power consumption and allowed both contacts to be used for voice path. The coils were wired for coincident current selection similar to a magnetic core memory, so operating the contacts for one crosspoint would release the other crosspoints in its row and column.

Each input of the array had, besides the two talk wires, a P lead for controlling the crosspoints on that level. Two coils on each crosspoint were wired in series with all the others on that level, to the P lead. Each output of the array also had a P lead with two coils on each crosspoint of that output level. The two windings controlled by the same level were unequal, and were wound around opposite ends of the reed, in opposing polarity. When a pulse passed through the crosspoints of a level, the two ends of each reed were magnetized north to north or south to south, thus repelled each other and opened the crosspoint in all except the selected crosspoint.

The selected crosspoint had current passing through both its input P lead and its output P lead, thus through all four windings. On each end of the ferreed, the windings provided by the two different P leads were opposed to each other, and the greater one predominated when both were energized. This being the input P lead at one end of the ferreed, and the output P lead at the other end, the two ends of that particular ferreed were magnetized north to south, hence attracted each other and closed the contact.

Current was applied by the pulser only to set up the connection. The P leads remained dry and the crosspoint remained closed until such time as another connection was made involving one of the levels.

Because the individual crosspoints were more expensive than those of crossbar switches, while the control circuitry was cheaper, reed arrays usually had fewer crosspoints and were more numerous. This required them to be arranged in more stages. Thus, while a telephone call in a typical crossbar exchange like 5XB passed through four switches, a call in a reed system such as 1ESS typically passed through eight.

In the later 1AESS, the reeds themselves were of remanent magnetic material. This "Remreed" design allowed further reduction in size and power consumption. A "grid" of 1024 2-wire crosspoints, arranged as two stages of eight 8x8 switches, was permanently packaged in a box. Despite the sealed contacts, plating with silver rather than with precious metals resulted in reed arrays being less reliable than crossbar switches. When one crosspoint failed, the grid box was quickly replaced whole, and either repaired at a local workbench or shipped to a repair shop.

Stromberg-Carlson made the similar ESC system, whose reeds were called **crossreed**.

Reed relays were extensively used in the British TXE family of telephone exchanges.

4.3   Other uses

Reed arrays passed out of use in the mid-1990s, being unnecessary in true electronic (digital) telephone systems such as DMS-100 and 5ESS switch. Reed relays have continued in their uses outside the telephone industry such as for automatic test equipment and electronic instrumentation due to their hermetic seal, fast operate time, extended life to 10^9 operations and highly consistent contact performance. Reed relays have also found numerous applications in RF and microwave switching applications.[2] They are also used in applications which make use of their extremely low leakage current (in the order of femtoamperes) such as photomultiplier detectors and other extremely low current handling circuits. Reed switches can also be manufactured to withstand several kilovolts and are still used as high-voltage relays in place of more costly sulfur hexafluoride or vacuum relays.

4.4   See also

- Mercury-wetted reed relay

- PRX

- TXE

4.5   References

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4.6   External links

- Glossary of Reed Switch, Magnet and Related Terms

- Advanced information about Reed Switches

- Patent for remanent reed relay (remreed) design

- Bell System Journal article on ferreed ferrite reed relay

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- **Reed relay** *Source:* http://en.wikipedia.org/wiki/Reed%20relay?oldid=643142304 *Contributors:* DavidCary, Alistair1978, Hooperbloob, Wtshymanski, Pol098, Slimey.limey, Elkman, ThinkingInBinary, Mark126, Oli Filth, Courcelles, Shrimp wong, Requestion, Alphachimpbot, John a s, Sitethief, Jim.henderson, Rwessel, DorganBot, Alchaemist, Addbot, Olli Niemitalo, Lightbot, ScAvenger, Yobot, Piano non troppo, FrescoBot, Vrenator, NameIsRon, Makecat, ClueBot NG, YiFeiBot, MasterTriangle12, Spiderjerky and Anonymous: 29

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