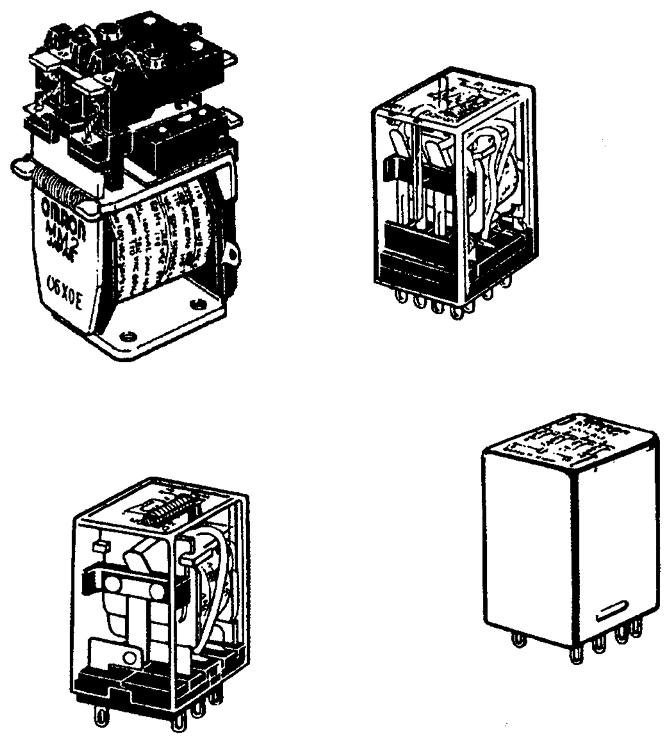
Relay User's Guide



Notice:

OMRON products are manufactured for use according to proper procedures by a qualified operator and only for the purposes described in this manual.

The following conventions are used to indicate and classify warnings in this manual. Always heed the information provided with them.

DANGER! Indicates information that, if not heeded, could result in loss of life or serious injury.

Caution Indicates information that, if not heeded, could result in minor injury or damage to the product.

OMRON Product References

All OMRON products are capitalized in this manual. The word "Unit" is also capitalized when it refers to an OMRON product, regardless of whether or not it appears in the proper name of the product.

The abbreviation "Ch," which appears in some displays and on some OMRON products, means "word" and is abbreviated "Wd" in documentation.

Visual Aids

The following headings appear in the left column of the manual to help you locate different types of information.

Note Indicates information of particular interest for efficient and convenient operation of the product.

1, 2, 3... Indicates lists of one sort or another, such as procedures, precautions, etc.

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SECTION 1
Basics

1–1 What is a Relay?

1–1–1 Basic Construction and Principle of Operation

A relay is defined as a device in which predefined changes occur rapidly in single or multiple electrical output circuits, when the control electrical input circuit fulfills a certain condition.

An electromagnetic relay is defined as a relay that operates or resets due to electromagnetic effects caused by a current flowing in the coil, which makes up the control input circuit.

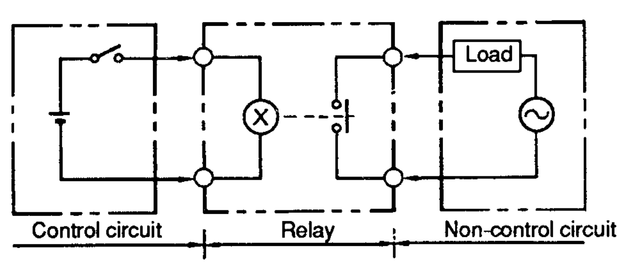
The most important relay functions from the user's point of view are discussed below.

One important function is that the input and output circuits are electrically insulated from each other, so that the relay can transfer signals and control output signals. This function means that the relay can be used make circuits with particular features which are not possible with transistorized sequence circuits or load control circuits. In particular, the relay can provide safety, noise cutting, bypass-circuit prevention, interlock, and other functions. (*Refer to Section 1–2 Relay Operations.*)

The Japan Industrial Standards (JIS) categorize electromagnetic relays as hinged type relays (JIS C 4530) and contactor type relays (JIS C 4531). However, relays are also categorized according to their function and construction.

This Relay User's Guide is mainly concerned with the hinged type relay, which will be referred to simply as "relay" from here on.

Relay Schematic Diagram



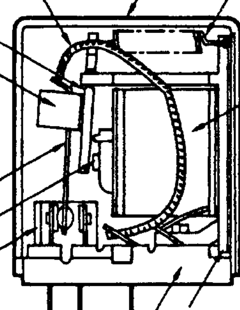
The relay is basically composed of the electromagnet section and the switching section.

The electromagnet section is made up of a coil, core, yoke, and armature.

When a current flows in the coil, it causes a magnetic flux to flow in the magnetic path, which is composed of the core, yoke, and moveable armature. The magnetic flux attracts the moveable armature to the face of the core.

The switching section is driven by the armature to open and close the contacts.

Appearance of a General-Purpose Relay



The diagram shows that the relay operates by a chain of energy conversions: the electrical energy supplied to the coil is converted to magnetic energy, which is further converted into mechanical energy, and is then finally converted back into electrical energy.

The relay is designed to offer stable contact pressure and contact follow, provided that the ambient temperature and power supply fluctuations are held within specified limits.

The contact resistance when the contact is closed is normally expressed by the equation below. The equation shows that an appropriate contact pressure is required to ensure reliable electrical contact.

$$R \propto \varrho \sqrt{\frac{Hv}{P}}$$

where:

R : contact resistance
Hv: contact hardness
P : contact pressure
ϱ : inherent resistance of contact material

The contact resistance depends on the inherent resistance of the contact material itself.

The moveable armature is attracted to the coil when a current flows in the coil, but another force is required to reset the armature when the current flow stops. This force is provided by the reset spring shown in the diagram above. The relay is designed such that the attractive force overcomes the spring force to permit stable operation of the armature when it is moving toward the coil.

The curve in the diagram shows the relationship between the load and attractive force in a normal relay. The magnetomotive force calculated from the coil current is used as the parameter to represent the attractive force.

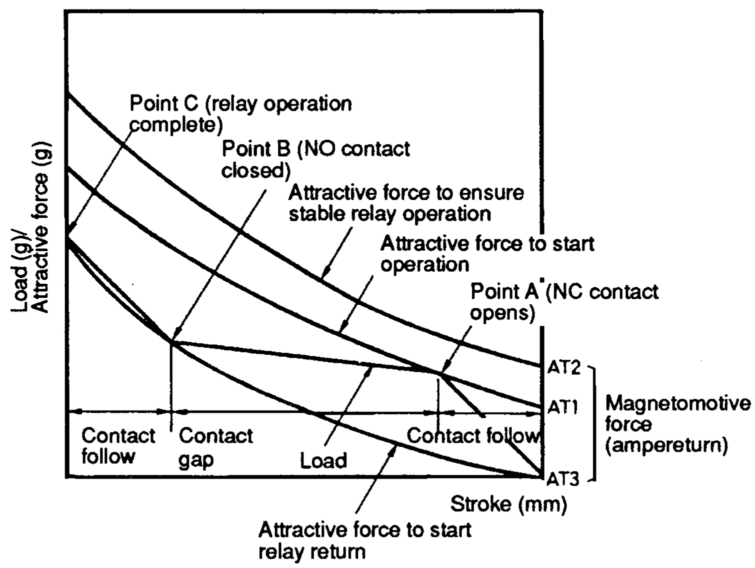
If the coil current is gradually increased, when the magnetomotive force reaches the level AT1, the attractive force overcomes the load and the moveable armature is attracted toward the coil.

The magnetomotive force AT2 is required to overcome temperature variations and input fluctuations to ensure stable operation of the armature.

Conversely, if the input current is gradually reduced until the magnetomotive drops to level AT3, at point C the attractive force becomes less than the load and the moveable armature immediately resets.

The load is provided by the combined forces due to deflections of the reset spring and the contact spring (which is the moveable arm in this type of relay). Up to point A where the NC contact opens, the force is a combination of negative forces from the reset spring and contact spring. From point A to point B, where the moveable contact is not touching the NO or NC contact, the force is provided by the reset spring only. Between point B to point C, where the NO contact is closed, the force is a combination of positive forces from the reset spring and contact spring. Consequently, we can draw the representative type of curve shown in the diagram.

Relationship between Load and Attractive Force in a Normal Relay

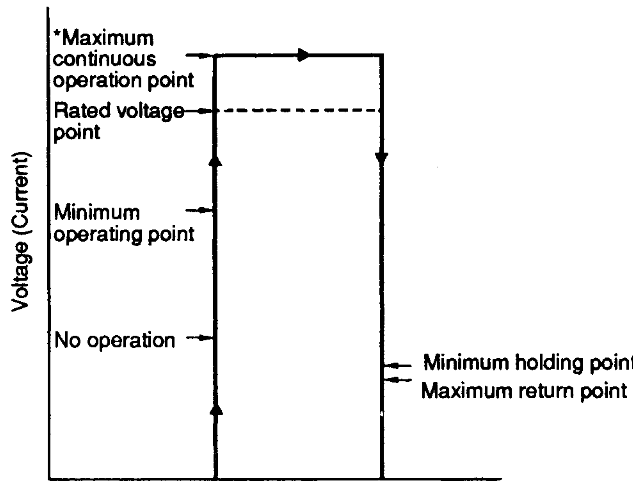


1-1-2 Characteristics of the Relay Coil

The operation of the relay is determined by a balance between the spring forces and the attractive force resulting from the magnetomotive force generated in the electromagnet coil.

Therefore, the condition of the relay changes in stages as the current, which generates the magnetomotive force, is gradually increased from zero.

Relationship between Voltage (Current) and Relay Operation



*This value is only guaranteed for a short time for some types of relay.

The relay does not operate in the first area of the curve. The point of maximum voltage of this area is known as the maximum non-operating point. The attractive force is effectively zero in this area because of the large gap between the core and armature (as shown in the diagram on the previous page).

The relay operation is described below in terms of the voltage. Note however, that the same explanation applies for current operation.

If the voltage is further increased, eventually the point is reached where the relay operates. This is the must-operate point. This point corresponds to point A in the curve on the previous page.

Although the relay operates at point A, stable operation cannot be maintained at this voltage level because of fluctuations in ambient temperature and input voltage, and changes in the relay characteristics due to heat generation in the coil and other causes. Therefore, a larger voltage than the must-operate voltage must be applied to ensure stable operation when the relay is used for practical applications. This is the rated voltage of the relay and is the point where operation of the relay is most stable.

Any further increase of the voltage causes an increase of the coil power consumption, resulting in a temperature rise of the coil. This can lead to deterioration of the insulation of the coil winding and other overheating problems in the relay. The upper limit of the voltage (current) is therefore set at a level slightly lower than the level causing thermal damage. This level is called the maximum continuous operation point. However, care is required when selecting a relay as some relays can withstand the heat generated at this input level only for a short time, so that continuous operation is not possible at this voltage.

If the applied voltage is gradually reduced, the relay will not reset until a certain point is reached. This point is known as the minimum holding point. This point is equivalent to point C in the curve on the previous page. Until the voltage drops to point C, the magnetomotive force provides sufficient holding force to overcome the load.

The relay resets when the magnetomotive force drops below point C. This is the maximum reset point. Relays are normally designed such that the minimum holding point and the maximum reset point coincide.

A relay is operated by an applied voltage, so that it is normally assumed that the magnetomotive force is directly proportional to the applied voltage. However, because the coil resistance varies with temperature, the magnetomotive force is not directly proportional to the voltage.

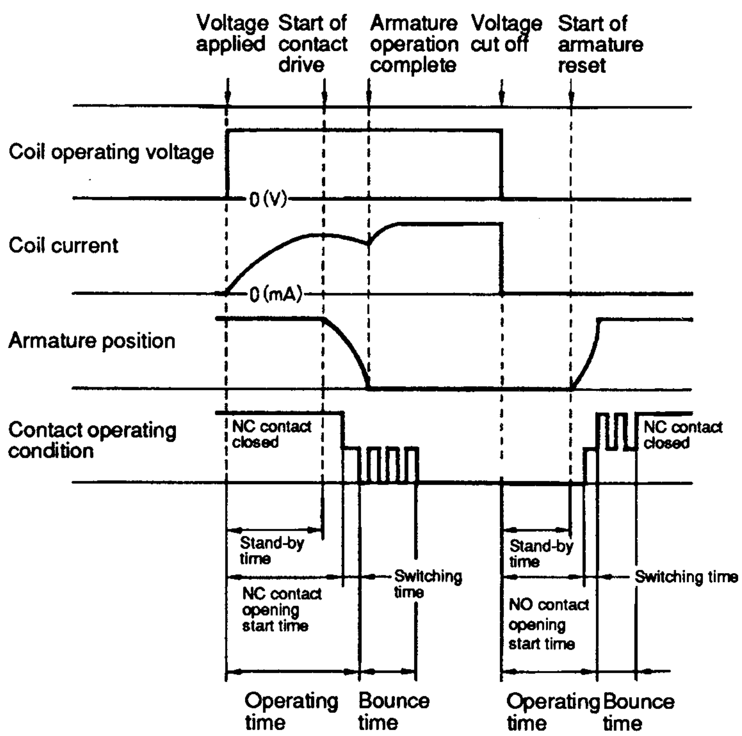
When a relay is used for a practical application, it is very important to rapidly switch the applied voltage from zero to the rated voltage, and from the rated voltage to zero. If the rise time and breaking time of the applied voltage are too long, problems will occur with the time characteristics (described on the next page), particularly with the bounce time. This reduces the relay contact life expectancy and tends to cause fusing of the contacts. It may also cause abnormal signals to be transferred to the next stage of the circuit.

1-1-3 Relay Time Characteristics

The operating time of a relay, from the time the input is applied until the NO contact closes, and the reset time, from the time the input is cut off until the NC contact closes, are both fixed.

The curve in the diagram shows a detailed break-down of the operation time and reset time for each operation of the armature and contacts.

Relay Operation and Reset



The time lag from the input until the armature starts moving is caused by two factors: the delay due to the electromagnet time constant (L/R), and mechanical inertia. This time lag is called the stand-by time or NC contact opening time.

The time after the switching contact separates from the NC contact until it touches the NO contact is the contact switching time.

Immediately after the switching contact touches the NO contact, the electrical contact is unstable because the switching contact rebounds and mechanical vibrations occur in the contact spring. The time taken for this instability to die out is called the bounce time.

A time lag also occurs when the armature resets. This time lag arises due to the mechanical inertia of the moving parts and the time required to disperse the inertial energy of the current in the coil. Consequently, the reset time is affected by the way the input is interrupted and by the presence of a diode to absorb the counter electromotive voltage.

When using an AC-specification relay for practical applications, it is important to understand that the time characteristics of the relay are affected by the phase of the voltage at this time it is applied or cut off. For reference, the time characteristics of each product are shown in the Product Guide section at the end of this User's Guide.

If a relay is used to transfer signals to a transistor or other electronic circuit, it is important to provide a compensating circuit to prevent the bounce being misinterpreted as a signal.

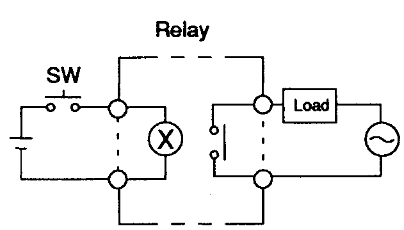
1-2 Relay Operations

The contacts of a relay switch when a voltage (or current) is applied to the coil. Despite this simple operation, relays can be used to for wide variety of purposes. Some of the functions offered by relays are described in this section.

1-2-1 Amplification Function

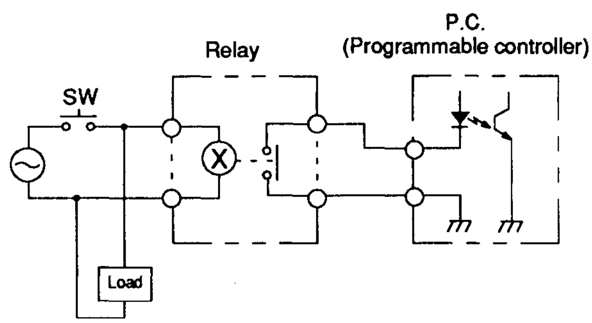
The amplification ratio of a relay is the ratio of the coil power consumption to the contact load switching capacity. A relay provides an amplification ratio from 1 to 1000.

However, unlike a vacuum-tube or transistor circuit, a relay is not able to amplify transient signal waveforms; rather, it should be thought of as a digital amplifier.



1-2-2 Conversion Function

As the coil and contacts are electrically independent from each other, the relay is able to handle different types of input and output signals. It can be used for conversion, such as analog to digital conversion, AC to DC conversion, voltage to current conversion, and frequency conversion.

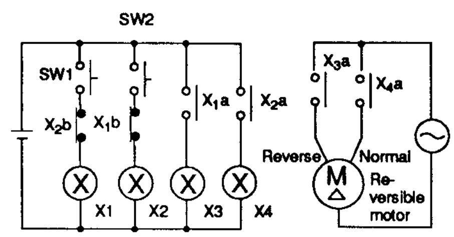


1-2-3 Transfer, Interlock, and Gang Control Functions

Relays are often used in counting circuits and signal circuits, where the operation is mainly to cut off, connect, and switch signals for sequence control and similar applications.

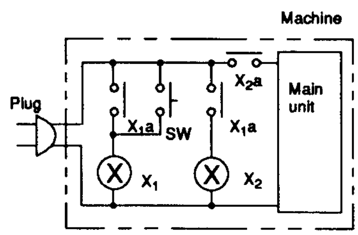
As the NO contact and NC contact cannot be closed simultaneously, a relay also provides an interlock function. The contacts of a multipole relay operate together, so that this type of relay can simultaneously switch separate signals.

Example of Interlock Function



Note
When either switch (SW1 or SW2) is turned ON, the direction of motor rotation is selected. It is not possible for coils X_3 and X_4 to operate simultaneously.

Example of Gang Control Function

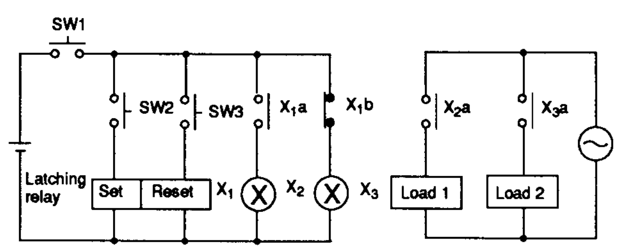


Note
Once the plug has been pulled out to turn OFF the power supply, the machine will not operate after the power supply is re-connected until the momentary switch (SW) has been pressed. This relay provides an important safety feature.

1-2-4 Memory and Computing Functions

To provide computing functions, a relay which saves its operating condition (such as a latching relay) is used as a memory element, and a stepping relay as a counter.

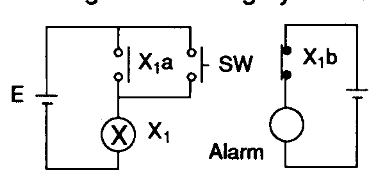
Example of Memory Function



Note
When the operation is restarted after the switch (SW1) is turned OFF, the operation starts from the same condition as immediately before the switch was turned OFF.

1-2-5 Detection Function

The relay detects if the input is too high or too low, and switches another circuit to give a warning by sounding an alarm or flashing a lamp.



Note
Relay coil X1 turns ON when the switch SW is turned ON, closing the NO contact X1a, which holds this condition after the switch (SW) is turned back OFF. If the level of the power supply (E) drops, the relay resets, closing the NC contact (X1b), which is connected to some alarm device. The alarm warns that the power supply is low.

1-3 Types of Relay

1-3-1 Classification by Mechanism, Functions, and Characteristics

General-purpose relay

The contacts turn ON and OFF instantaneously as the coil is energized and re-energized. These relays do not have any special functions.

They are used for a wide variety of applications, such as circuit branching, turning power supplies ON and OFF, and as general relays.

Latching Relay

After the relay operates, the contacts of these relays are mechanically or magnetically locked until the relay is reset manually or electrically.

A mechanical latching relay is used in situations where the relay status is held for a long period, with little variation with time. A separate coil is required to release the mechanical latch, so that the construction of this type of relay tends to be large.

A magnetic latching relay is easy to use because of its compact and simple construction. This type of relay is used principally in situations where the relay condition must be held during a breakdown and when the power supply is cut off, and as a memory element in a computing circuit.

Ratchet relay

The relay operates when a particular ON/OFF pulse is input to the coil. Any type of contact switching operation can be obtained by correct selection of the shape of the gear or cam and of the combination of contacts.

These relays are used for switching a number of circuits, counting pulses, and selecting a circuit.

Timer relay

Two types of timer relay are commonly used.

One type is the on-delay relay. The contacts operate a fixed time after the input voltage is applied. Some on-delay relays have a dial for adjusting the delay time.

The other type is the off-delay relay. With this type, the contacts operate a fixed time after the input voltage is turned OFF.

Safety relay

This is a multiple relay with both NO and NC contacts. The mechanism of this relay is designed such that if one NO (or NC) contact fuses, the other contacts will not operate. A relay where the NO (or NC) contact of the other pole opens is known as a semi-interlocked type, and a relay where the other contact does not open is known as a full-interlocked type.

Interlock relay

This type of relay is constructed with two sets of coils and moveable parts, with related contacts. The relay is designed such that when one of the relay contacts operates, the other contacts cannot operate until the original contacts reset. Used in situations where it is essential that two relays do not operate simultaneously.

Polarized relay

This type of relay is normally constructed with a permanent magnet and operates according to the polarity of the input signal. It is used for rectifying signal waveforms and detecting positive or negative polarity.

High-frequency relay

The shape and material quality of the components are chosen to minimize losses in high-frequency circuits. These relays are widely used for communication applications. The important characteristics of this type or relay are the isolation in the OFF condition, the insertion loss in the ON condition, and the standing wave ratio.

Limit relay

When the applied voltage (current) reaches a specified value, the contacts immediately turn ON or OFF. This type of relay is mainly used for analog to digital conversion, protecting electrical devices, signal detection, and for maintaining a specified condition.

Differential relay

This is a multiple-coil relay. The contacts operate when the difference between the inputs to the coils reaches a specified value. It is used for comparing signals and for detecting abnormal conditions.

This type of relay also provides AND, OR, NOT, and other functions in a computing circuit.

High-sensitivity relay

These relays have an extremely small operating power consumption. They are used mainly in combination with semiconductor circuits.

High-speed relay

These relays have an extremely short operating time.

Current relay

These relays operate and reset at specific current values.

Make-before-break relay

The NO contact turns ON before the NC contact turns OFF. These relays are widely used for communication applications. (Also called Overlap relay.)

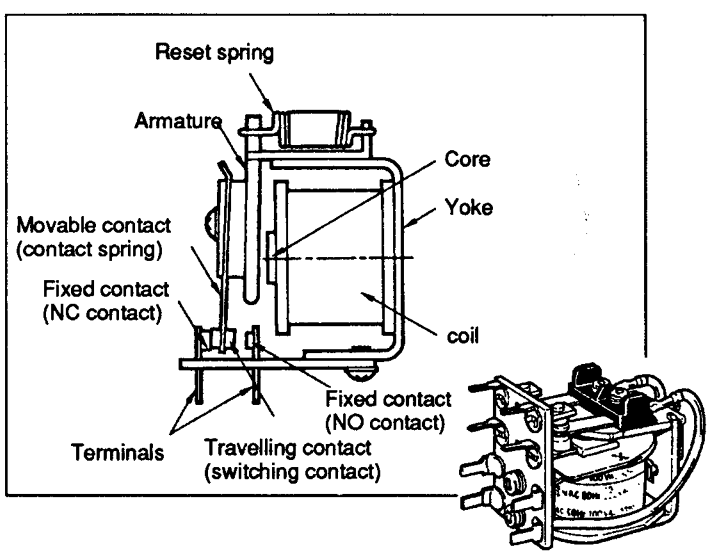
1-3-2 Classification by Construction

Classification by Electromagnet Construction

Hinged Type Relay

The movement of an armature rotating about the pivot, directly or indirectly opens and closes the contact.

This type of construction is commonly used for miniature relays as it allows the attraction face of the armature and the contacts to be any distance from the pivot, and permits the spring contact pressure and contact follow to be freely chosen.

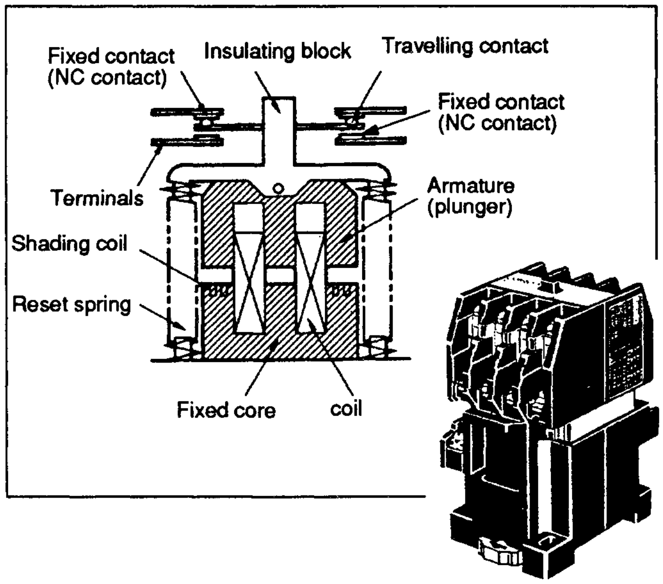


Plunger Type Relay

The armature (plunger) is in the center of the coil, and moves along the coil axis.

Normally, the plunger movement directly becomes the contact movement, so that the construction tends to be bulky with large gaps in the magnetic circuit. This type of relay is almost always AC operated as a large electromagnet is required for DC operation.

This construction is often used in contactor relays as it provides a larger attractive force than a hinged type relay when the operating stroke is relatively long.



Comparison of Hinge and Plunger Type Relays

To reduce breakdowns and ensure correct operation, it is important to select the correct relay features for the application.

Comparative Features

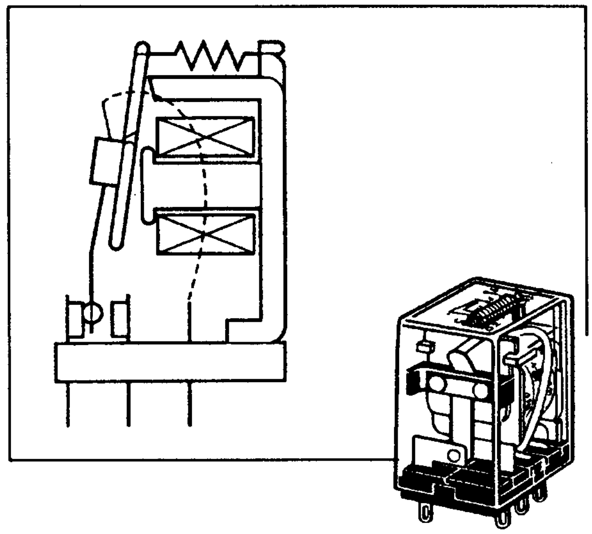
Item		Hinge lever type	Pin plunger type
Electromagnet	Armature movement	Rotation	Direct
	Attractive force	Comparatively small	Comparatively large
	AC operation	O	O
	DC operation	O	Δ (Normally quite bulky)
	Response speed	Fast	Slow
	Operational shocks	Low	High
Relay	External	Normally compact	Normally bulky
	Switching mechanism	Switching contact normal	Double-break contact normal
	Contact current	Comparatively small current	Comparatively large current
	Mechanical life expectancy	Long	Short
	Others	Short operation and reset times	Resistant to current overload
			Good insulating properties Example of the Card Lift-off System

Classification by Contact Drive System

Direct Drive

The contact spring is directly or indirectly connected to the armature through an insulating material. The ON and OFF operations of the electromagnet are transmitted directly to the contacts. The deflection of the contact spring generates the contact pressure.

This drive system is used in most miniature relays because of the simplicity of its construction.



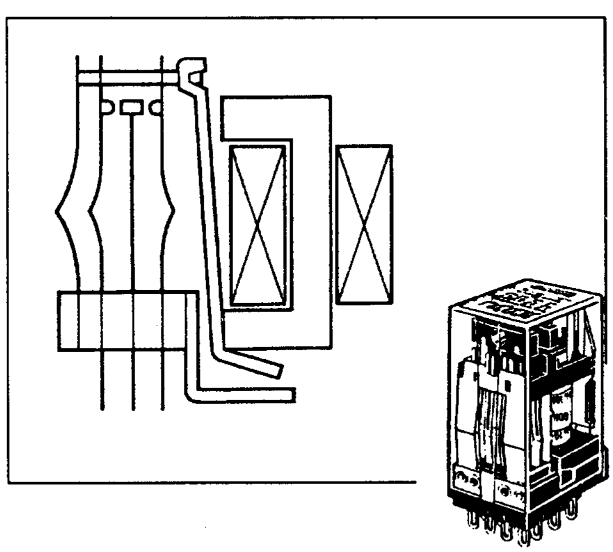
Indirect Drive

The movement of the armature is transmitted indirectly to the contacts through a card.

Two types of indirect drive are used. One is the flexure type drive, where the card presses on the contact spring and the resulting deflection of the contact spring provides the contact pressure.

The other type of indirect drive is the card lift-off type, where the contact spring is pre-curved to provide the contact pressure. The card presses up the contact spring to lift off the spring and open the contacts.

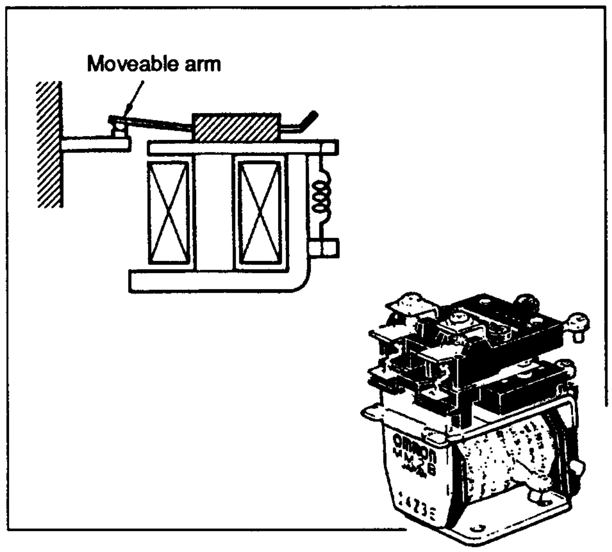
The indirect drive system is often used in signal transmission circuits as it ensures simultaneous operation of each contact and achieves a comparatively short bounce time.



Classification by Contact Pressure System

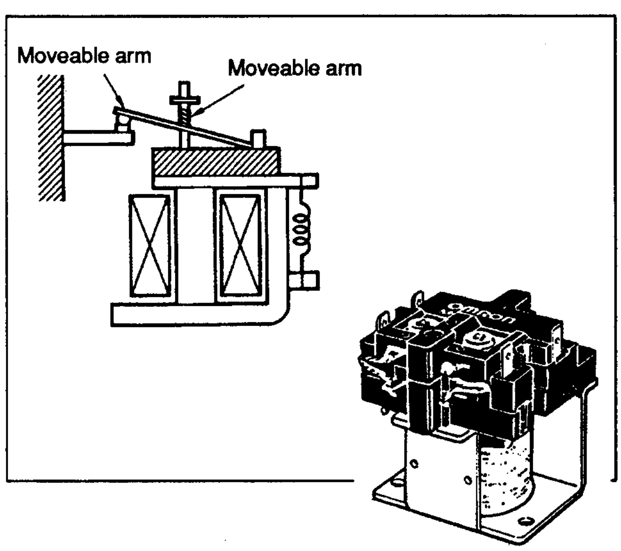
Moveable Arm Acts as Contact Spring

The contact force and contact follow are provided by the moveable arm, which doubles as the contact spring. This system is used in miniature relays with a medium rated carry current.



External Contact Spring

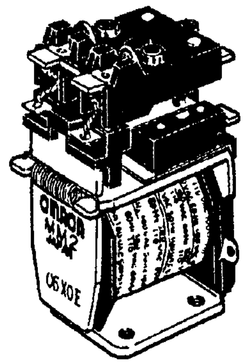
The contact spring is external from the moveable arm which conducts the current. Deflection of the contact spring provides the contact pressure, so that the area of the moveable arm can be increased for use in relays with larger current flows.



Classification by Appearance and Construction

Open Type

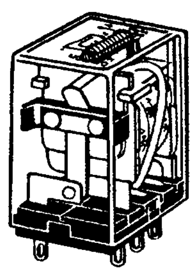
The electromagnet and switching section are exposed and the mechanisms can be touched. This construction is compact and cheap, but offers the mechanisms no protection from dust, foreign objects, or gases.



Encapsulated Type

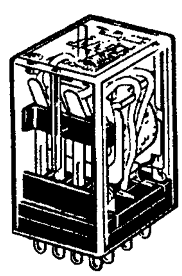
The relay is protected by a case to suppress the adverse effects of operating the relay in a dusty environment.

Some types have a hole in the case (for example, MM☐XP types). With these types, care must be taken that no dust enters the case.



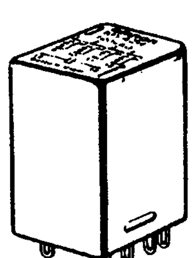
Plastic-sealed Type

The relay is sealed in a plastic case to protect the mechanisms from the effects of corrosive atmospheres. This type should be used in atmospheres containing corrosive gases, such as H_2S or NH_3, or in very dusty conditions.



Hermetically Sealed Type

Corrosive gases are prevented from entering the relay by a sealed metal or glass case which is filled with inert nitrogen (N_2). The external surface of the case is also extremely corrosion resistant. This type is used in adverse environmental conditions, such as in an atmosphere of organic gases.



1–4 Materials Used in Relays

1–4–1 Conducting Materials

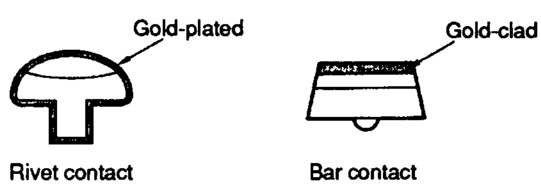
Contacts

In general, silver or silver alloy is used for contacts.

Contact Material Selection Parameters

Small load	PGS alloy (Platinum, gold, silver)	Offers excellent corrosion resistance. Mainly used in circuits with minute current flows. The alloy composition is Au:Ag:Pt = 69:25:6.
↑	AgPd (Silver palladium)	Offers good corrosion resistance and sulfurization resistance. However, when used in a dry circuit, the metal tends to become sticky because of polymers created due to the absorption of organic gases.
	Ag (Silver)	Offers the best electrical and thermal conduction properties of any metal. The contact resistance is extremely low, but the contacts tend to form a sulfide film when used in a sulfidizing gas atmosphere. Defective contact occurs easily with low voltages and low currents.
	AgCdO (Silver, cadmium oxide)	Offers the good conductivity and low contact resistance of silver, combined with excellent resistance to fusing together of the contacts. Tends to form a sulfide film when used in a sulfidizing gas atmosphere.
	AgNi (Silver, nickel)	Offers equivalent electrical conductivity to silver, and excellent resistance to arcing.
↓ Large load	AgInSn (Silver, indium, tin)	Offers high hardness and melting-point, combined with excellent resistance to arcing. Good resistance to fusing and deposition, but the contact resistance and rate of contact wear are high.

Some contacts are plated or clad with gold to protect the surface and improve the reliability of the electrical contact.



Contact Spring and Terminals

In general, copper or copper alloy is used for contact springs and terminals.

The spring characteristics, electrical conductivity, maximum operating temperature, and life expectancy are taken into account when choosing the spring material.

Surface treatment, such as plating, is carried out when required.

1–4–2 Magnetic Materials

The core, moveable armature, and yoke are normally made from a soft iron. To improve the efficiency of the electromagnet, a material with high magnetic permeability and low losses, such as silicon steel or permalloy, is often used. To improve and stabilize the properties of these materials, they are annealed in a non-oxidizing atmosphere.

1–4–3 Winding Materials

The winding material used for the electromagnet coil is annealed copper wire coated with a baked insulating film. At present, polyurethane-coated copper wire is most commonly used.

Temperature grades of winding materials

Insulation grade	Maximum permitted temperature	Representative winding material (code)
A	105°C	Enameled copper wire (EW)
E	120°C	Polyurethane/copper wire (UEW)
B	130°C	Heat-resistant polyurethane/copper wire (UEW–B) Polyester/copper wire (PEW)

1–4–4 Insulation Materials

The relay terminal block, insulating block, and spool, are made from materials with excellent electrical-insulation properties.

One of the following materials is normally used, depending on the application: phenol resin, polyester resin, diallyl phthalate resin, polybutylene / terphthalate resin, polyacetal resin, polyamide resin, polycarbonate resin, or glass-reinforced material.

1–4–5 Case Materials

One of the following materials is normally used for the case, depending on the required degree of heat resistance, transparency, and ease of molding: polybutylene / terphthalate resin, polycarbonate resin, or polyphenylene-oxide resin.

Metals, such as steel sheet and brass sheet, are also used for hermetically sealed relays.

SECTION 2
Relay Test Methods

Note Miniature relays are normally tested according to JIS C 5442 or JIS C 5440. As JIS C 5442 and JIS C 5440 are based on IEC 255, these Japanese standards and IEC 255 share many points in common.

Carry out the tests under the following conditions if no other test conditions are specified:

temperature : + 15° to +35°C
relative humidity : 25% to 85%
atmospheric pressure : 86 to 106 KPa

OMRON conducts all tests at +23°C, unless otherwise stated.

2-1 Operation Characteristics

2-1-1 Rated Coil Current

Apply the rated voltage to the operating coil (at the rated frequency when testing for AC operation) and measure the current flowing. The rated coil current is the current measured in the coil at a temperature of +23°C. The measuring tolerance is specified for each individual relay, but is normally either a range written as being +15% to –20% or ±20%.

2-1-2 Rated Power Consumption

Calculate the rated power consumption by multiplying the rated current by the rated voltage. For AC operation it is expressed in VA, and for DC operation it is given in W.

2-1-3 Coil Resistance

The coil resistance is the DC resistance of the relay coil measured at a temperature of +23°C. The measuring tolerance is specified for each individual relay.

Convert the measured value using the equation below if the temperature during the measurement differs from 23°C. (The equation only applies to temperatures in the range +10° to +100°C.)

$$Rt = Rt0\,[1 + a(t-to)]$$

where:

Rt : the resistance at temperature t°C
Rto : the resistance at temperature to°C
a : mass temperature coefficient of resistance (0.00393 for annealed copper)

(Refer to JIS C 5442–1986 for details.)

2-1-4 Must-Operate Voltage (or Current)

Gradually increase the applied voltage and measure the voltage when the relay operates. The must-operate voltage is set to 70% and 85% of the rated voltage, to take into account the power supply fluctuations, variations in relay characteristics, and ambient temperature fluctuations.

For a latching relay the set voltage and reset voltage are both measured using this procedure.

To measure the must-operate current, increase the applied current in the procedure above and measure the current instead of the voltage.

2-1-5 Reset Voltage or Reset Current

Apply the rated voltage to the coil and gradually decrease it. Measure the voltage when the relay resets.

To measure the reset current, decrease the applied current and measure the current instead of the voltage.

2-1-6 Operating Time and Reset Time

Operating Time

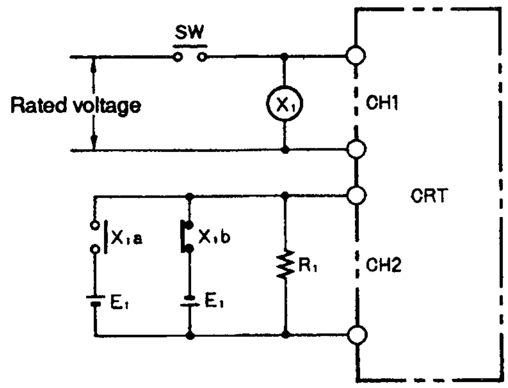
Instantaneously apply the rated voltage to the relay coil (at the rated frequency when testing for AC operation) and measure the time for the NO contact to close. If the relay only has an NC contact, measure the time for this contact to open.

Reset Time

When the rated voltage is applied to the relay coil (at the rated frequency when testing for AC operation), instantaneously turn it off and measure the time for the NC contact to close. If the relay only has an NO contact, measure the time for this contact to open.

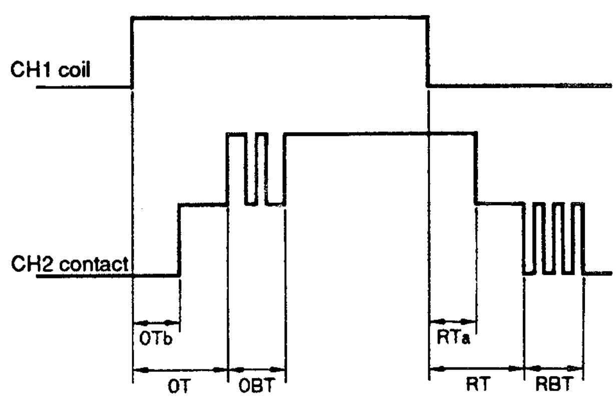
In these cases, the operating time and reset time do not include the bounce time.

Measuring Circuit for Time Characteristics



SW : Switch with low contact bounce (mercury switch)
X1 : Tested relay coil
X1a : NO contact of tested relay coil
X1b : NC contact of tested relay coil
E1 : DC power supply or battery (approx. 1.5 V)
R1 : Resistor (approx. 1.5 kΩ
CRT : Oscilloscope, electromagnetic oscillograph, or digital clock

Example of a Measured Waveform



OT : Operating time
OTb : Relay operating time for NC contact only
RT : Reset time RTa : Relay reset time for NO contact only
OBT : Operate bounce time
RBT : Reset bounce time

2-1-7 Coil Temperature Rise

Apply the rated voltage to the relay coil (at the rated frequency when testing for AC operation) such that the specified current flows through the contacts. Measure the temperature after the temperature of all parts of the relay stabilizes.

Connect covered copper wire (with the cross-sectional area as shown in the table below) to the terminals.

Covered Copper Wire Cross-sectional Areas

Rated carry current (A)		under 6	6 to 10	10 to 15	15 to 20	20 to 30
Thickness of connected wiring	Nominal diameter (mm)	1.6			2	2.6
	Nominal cross-sectional area (mm2)	0.75	1.25	2	3.5	5.5
Type of connected wiring		Rubber covered wire, vinyl coated wire, vinyl insulated wire				
Length of connected wiring (m)		at least 1.5 m per wire				

Note
1. * The length may be reduced to 0.4 m when testing miniature relays which are not affected by heating of the connected wiring.
2. For relays rated less than 6 A, thinner wiring than specified may be used, provided this does not interfere with the test results.

In the case of a DC-operated relay, the temperature rise is determined only by the losses in the coil copper wires. With AC operation, however, the losses in the magnetic circuit are added to the losses in the wires, so that the temperature rise is normally higher with AC operation than with DC operation.

Calculate the coil temperature rise value from the DC resistance of the coil before and after the test, using the equation below.

$$T = \frac{R_2 - R_1}{R_1}(234.5 + t_1) - (t_2 - t_1)$$

where,

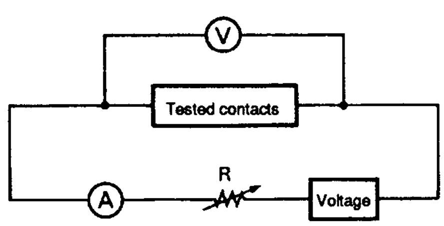
T : coil temperature rise
R_1: DC resistance of coil at ambient temperature (t_1)
R_2: DC resistance of coil at ambient temperature (t_2)

2–2 Contact Characteristics

2–2–1 Contact Resistance

Pass the test current indicated below through the circuit with the contacts closed, and measure the voltage across the terminals. Supply the test current with a voltage not exceeding 6 V.

Use a 4328A milli-ohmmeter, manufactured by YHP, to obtain more reliable test results or to measure the resistance without breaking down the film on the contact surfaces.



V : Voltmeter
A : Ammeter
R : Variable resistor
PS : Power supply, AC or DC (normally 5 V DC)

Test Current

Rated (or switching) current (A)	Test current (mA)
under 0.01	1
0.01 to 0.1	10
0.1 to 1	100
Over 1	1,000

2–2–2 Contact Temperature Rise

Apply the rated voltage to the coil (at the rated frequency when testing for AC operation) such that the rated carry current flows continuously through the contacts. Measure the temperature of the contacts (or near the contacts, on a miniature relay) with a thermocouple after the temperature of all parts of the relay approximately stabilizes.

The contact temperature rise is calculated by subtracting the ambient temperature from the measured contact temperature.

2–3 Insulation

2–3–1 Insulation Resistance

Measure the resistance of the insulation with a megger, using the test voltage corresponding to the rated insulation voltage class from the table below.

Test Voltage

Rated insulation voltage class (V)	Test voltage (V)
under 30	100
30 to 60	250
60 to 250	500

2–3–2 Withstand Voltage

Apply the prescribed voltage (as a 50 Hz or 60 Hz sinusoidal wave, or equivalent) to each prescribed part of the relay for one minute. Check that no breakdown of the insulation or flashover occurs.

For most relays the detection leak voltage is prescribed as 3 mA, but 1 mA, 2 mA, or 10 mA is used for some types.

2–3–3 Impulse Withstand Voltage

Apply the standard JEC–212–1981 waveform ±1.2 x 50 µs impulse voltage to the prescribed parts of the relay and measure to make sure that no breakdown of the insulation or flashover occurs.

The impulse voltage peak value is specified for each type of relay.

2–4 Environmental Characteristics

2–4–1 Temperature Resistance

Heat Accumulation

Leave the relay at a temperature of 85°C ± 2° continuously for 16 hours with no current flowing. Return to room temperature and leave for 2 hours. Check for changes in characteristics and external appearance.

If the temperature or time for this test is specified for a relay, use the specified value in preference to the value above.

High-temperature Operation Apply the rated voltage to the relay coil (at the rated frequency when testing for AC operation, or 60 HZ for dual 50/60 Hz operation) at the upper limit of the operational temperature range, such that the specified current flows through the contacts, and leave for 2 hours. Measure the coil voltage, check for interruption of the coil current, and then measure the operating voltage and reset voltage (or current) in the high-temperature environment.

2–4–2 Cold Resistance

Cold Accumulation Leave the relay at a temperature of –55°C ± 3° continuously for 72 hours with no current flowing. Return to room temperature and leave for 2 hours. Check for changes in characteristics and external appearance.

If the temperature or time for this test is specified for a relay, use the specified value in preference to the value above.

Low-temperature Operation Leave the relay continuously for 2 hours at the lower limit of the operational temperature range with no current flowing. Measure the operating voltage and reset voltage (or current) in this environment.

2–4–3 Humidity Resistance

Leave the relay at a temperature of +40°C ±2° and 90% to 95% relative humidity continuously for 48 hours with no current flowing. Return to normal room temperature and humidity and leave for 2 hours. Check for changes in characteristics and external appearance. An insulation resistance of greater than 5MΩ is prescribed for this test.

If the temperature, humidity, or time for this test is specified for a relay, use the specified value in preference to the value above.

2–4–4 Vibration Resistance

Two types of vibration testing are carried out on relays:

- endurance testing for the comparatively large vibrations during transport and installation
- malfunction testing to detect faulty operation due to contact chattering or other problems resulting from vibrations

Endurance Testing Apply the vibrations of the prescribed amplitude and frequency for 2 hours in each of the X, Y, and Z directions. After 6 hours of vibration, check for changes in characteristics and external appearance.

Malfunction Testing Apply the vibrations of the prescribed amplitude and frequency for 10 minutes (5 minutes with the relay energized, 5 minutes de-energized) in each of the X, Y, and Z directions and check if contact chattering occurs for more than the time prescribed for the relay.

Table of Chattering Detection Levels

Detection level	a	b	c	d	e
Continuous chattering time	10 µs	100 µs	1 ms	5 ms	20 ms

Calculate the vibration acceleration using the following equation:

$$\alpha = 0.002 f^2 a$$

where,

α : vibration acceleration
f : frequency
a : amplitude

G's

2-4-5 Shock Resistance

Two types of shock testing are carried out on relays:

- endurance testing for the comparatively large shocks during transport and when the relay is dropped
- malfunction testing to detect faulty operation due to contact chattering or other problems resulting from shocks

Endurance Testing

Apply the prescribed shock acceleration as a sinusoidal half-wave pulse 3 times in both directions along each of the 3 axes, a total of 18 shocks. Check for changes in characteristics and external appearance.

Malfunction Testing

Apply the prescribed shock acceleration as a sinusoidal half-wave pulse 6 times (3 times with the relay energized, 3 times de-energized) in both directions along each of the 3 axes, a total of 36 shocks. Check if contact chattering occurs for more than the time prescribed for the relay.

The chattering detection levels and times are the same as for the vibration resistance testing.

2-5 Life Expectancy

2-5-1 Mechanical Life Expectancy

With no load applied to the contacts, apply the rated voltage (at the rated frequency when testing for AC operation) to the coil and operate the relay at the rated switching frequency. Check for changes in characteristics and external appearance.

2-5-2 Electrical Life Expectancy

With the rated load applied to the contacts, apply the rated voltage (at the rated frequency when testing for AC operation) to the coil and operate the relay at the rated switching frequency. Check for changes in characteristics and external appearance.

The evaluation of relay life expectancies depends on how the relay is used.

The values are presented in the following table for reference.

Guidelines for Evaluating the Life-expectancy Tests

Item	Value		
Appearance	No looseness, deformation, or damage		
Insulation resistance	1 MΩ, unless otherwise specified.		
Withstand voltage	At least 75% of the initial value.		
Coil resistance	Between 95% of initial specified lower limit and 105% of initial specified upper limit.		
Operating voltage	Not exceeding 1.2 times the initial specified value.		
Reset voltage	At least 0.5 times the initial specified value.		
Operating time	Not exceeding 1.2 times the initial specified value.		
Reset time	Not exceeding 2 times the initial specified value.		
Contact resistance	Rated coil current or switching current (A)	Measured current (A)	Contact resistance after test (Ω)
	under 0.01	0.001	100
	0.01 to 0.1	0.01	20
	0.1 to 1	0.1	5
	over 1	1	2

SECTION 3
External Influences

This section discusses the effects of external influences such as power supply and the effects of environmental and atmosphere conditions.

3–1 Coil

3–1–1 Influences of the Power Supply

DC Relay

For a DC relay the relationship is as follows:

$$Coil\ \ current = \frac{applied\ \ voltage}{coil\ \ resistance}$$

AC Relay

Because of the inductance effects of the coil in an AC relay, the coil impedance must be taken into consideration.

The coil impedance changes with frequency. If the characteristics at 60 Hz are taken as 100%, then the characteristics at 50 Hz are as shown in the table below. These figures vary somewhat from relay to relay and should be carefully checked before use.

Rated current, power consumption, max. temperature	117% approx.
Operating current	100% approx.
Operating voltage, reset voltage	85% approx.

Connection

Be sure to correctly connect the polarity of a DC-operated latching relay or a relay marked as having a surge-absorption diode connected. Damage to parts of the relay or malfunction may result if the poles are wrongly connected.

Overheating and burn damage to the coil may occur if a DC voltage is applied to an AC relay. Conversely, if an AC voltage is applied to a DC relay, the armature will vibrate and not operate correctly.

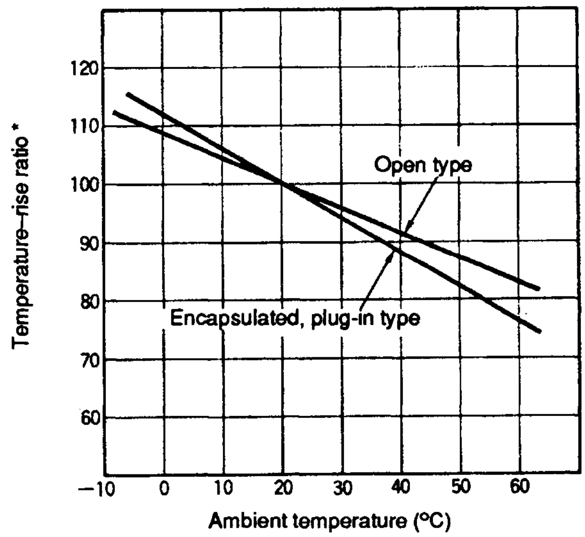
3–1–2 Influences of Temperature

The resistance of the copper wire used in coils varies approximately 0.4% per degree (°C) of temperature. This variation directly influences the operating characteristics of the relay because resulting changes in the coil current produce fluctuations in the electromagnet attractive force.

In the case of an AC-operated relay, the DC resistance of the coil represents only a small proportion of the total coil impedance, so that fluctuations of the operating characteristics (operating voltage, reset voltage) with temperature are also relatively small.

With a DC-operated relay, changes in the coil resistance affect the coil temperature rise. If the coil current changes while the applied voltage is constant, the coil power consumption also changes. Therefore, the coil temperature rise changes according to the proportion of change of the coil current caused by the temperature.

Representative example of this relationship are shown in the diagram below.

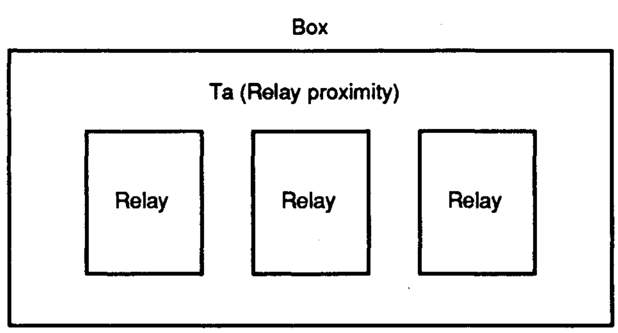


* Relationship of coil temperature rise to ambient temperature. Expressed as a percentage (%) of the temperature rise at an ambient temperature of +20°C.

Definition of Ambient Temperature

The temperature in the box rises due to heat generated by the relays and other apparatus.

The operational ambient temperature is the temperature in the box, near the relays.



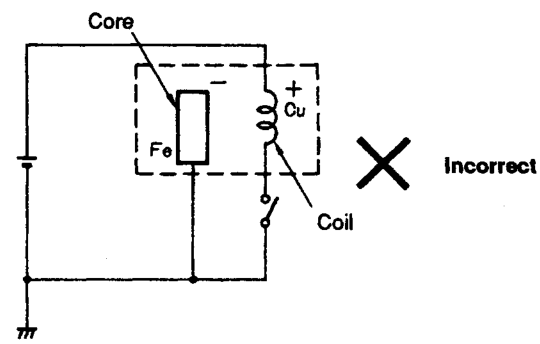
3-1-3 Electrolytic Corrosion

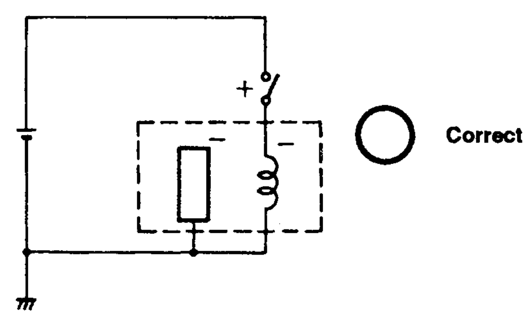
When a relay coil is in the non-operating condition in a high-temperature, humid environment and in particular, if parts such as the coil windings and core have an electrical potential difference with other metal parts and insufficient insulation between them, the ionization current flowing between the different metals can corrode the copper wire windings of the coil. This is the same effect as plating a metal with another metal. The effect becomes more pronounced in the presence of an acid or base.

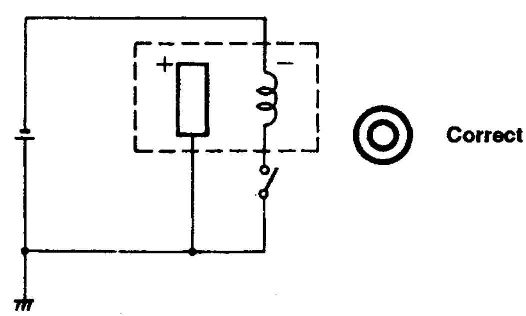
This phenomena was mostly ignored in old-fashioned relays, but the problem has now been largely eliminated through the recent development of plastics with excellent properties as spool materials, and of exceptional insulating materials for the windings, such as polyurethane, polyester, polyamide, and teflon.

To prevent electrolytic corrosion, avoid storing or using relays in a hot, humid environment. At the circuit design stage, select the position of the switch to prevent the windings having a positive potential. A positive ground connection may also be effective.

Some good and bad examples of relay connections are shown in the diagrams below.







3-2 Operating Time

3-2-1 Relationship between Shape and Operating Time

The operating time of a relay is determined by the coil time constant, delay due to moment of inertia, and the contact switching time. However, these values all depend on the shape of the relay. For example, a relay with a large clearance between the core and moveable armature or with an electromagnet made of materials with high magnetic resistance has low inductance, which reduces the time constant but also reduces the attractive force, so that more time is required for the armature to be pulled to the core. This type of effect is especially significant for DC-operated relays, because the attractive force is inversely proportional to the square of the clearance between the core and the armature. Conversely, for a high-speed relay this clearance is made narrower, materials with good magnetic permeability are used, and the number of coil windings is reduced.

As the current flowing is larger than the rated current when an AC-operated relay is started, the effects of the relay shape are less significant than for a DC-operated relay.

An indirect drive system, applying a small load to start the armature movement, is effective in reducing loads due to the moment of inertia. Also, the contact switching time is almost directly determined by the armature movement, so that this movement is kept as small as possible, and the balance between the load and attractive force is carefully chosen to make the movement as smooth as possible throughout the entire stroke.

The speed of armature movement, mass of the moving parts, and spring characteristics of the contact spring are important factors in determining the bounce time.

The construction of the stopper and the shape of the armature and moveable arm are carefully chosen to absorb shock energy during operation.

3–2–2 Relationship between Applied Voltage and Operating Time

The operating time of the relay is affected by the voltage (current) applied to the coil.

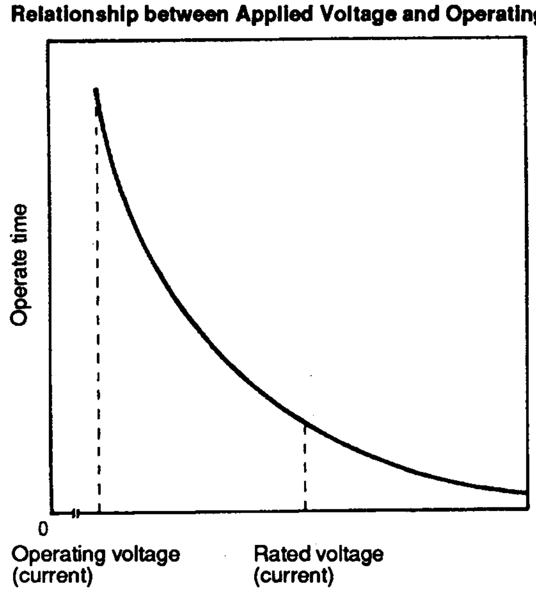
The diagram below shows that the operating time becomes very long if the applied voltage is only slightly higher than the operating voltage, due to the following factors:

- the time required for the coil current to reach the operating current
- the time required for the moving parts to overcome their inertia and start moving
- the time required for the attractive force to overcome the load, accelerate the contacts, and switch the contacts

If the applied voltage is greatly increased, all three of these times is decreased, resulting in a faster operation time.

As describe above, a large applied voltage decreases the relay operation time. However, because the voltage also affects other characteristics, a rated voltage is prescribed for the coil.

Relationship between Applied Voltage and Operating Time



3–2–3 Relationship between Coil Temperature and Operating Time

Fluctuations in the relay coil temperature lead to changes in other parts of the relay, such as the spring characteristics, wear conditions of the contacts, and coil resistance. Of these changes, fluctuations in coil resistance have the greatest influence on the operating time.

The operation of the electromagnet is related to the current flowing, as described in the Principle of Operation section of this User's Guide. In the case of a DC current, the current is determined by the equation below:

$$i = \frac{E}{R}\left(1 - e^{\frac{t}{\tau}}\right)$$

where,

i : coil current
R : coil resistance
E : coil applied voltage
τ : coil time constant (L/R)
t : time elapsed since the voltage was applied

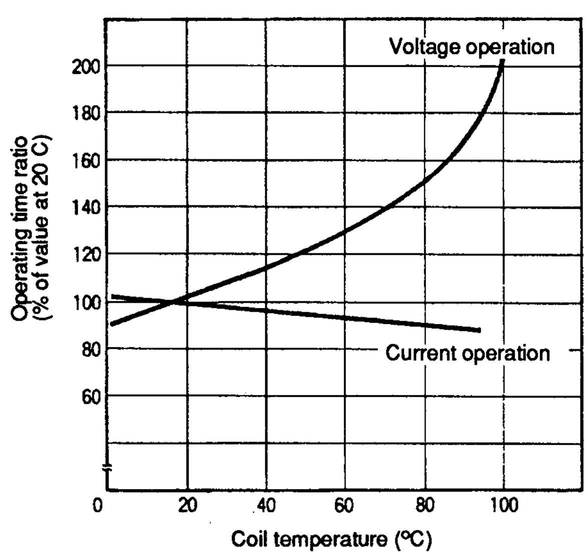
As the coil temperature rises, the coil resistance increases by 0.4% per degree (°C) (as described previously), and, as R (the coil DC resistance) increases, then the time constant (L/R) decreases, leading to a reduced contact stand-by time, and consequently a faster relay operating time.

On the other hand, the increased coil resistance tends to reduce the coil current, which increases the operating time of a voltage-operated relay.

The relationships of the operating time to the coil temperature for voltage-operated and current-operated relays are shown in the diagram.

Temperature fluctuations do not have a significant effect on heavy-duty relays with an operating time of the order of several tens of milliseconds. However, the variation of operating time is apparent for miniature relays with an operating time of under 10 ms.

Relationship between Coil Temperature and Operating Time

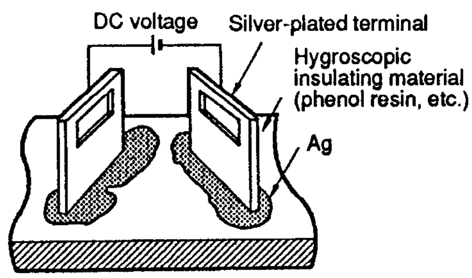


3–3 Environment and Atmosphere

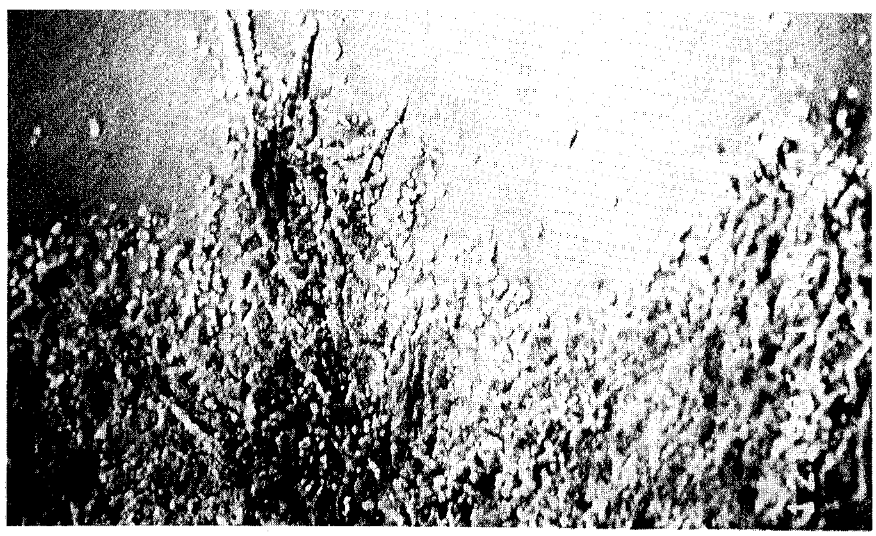
3–3–1 Silver Migration

The phenomenon of silver migration occurs when a DC voltage is applied between silver terminals (electrodes) over a long period of time in the presence of humidity or an oxidation-reduction atmosphere. If this phenomenon is allowed to progress, it can lead to deterioration of insulation properties, and even to short-circuiting in some rare cases.

Progress of Silver Migration



Enlargement of Silver Migration



Many points regarding the causes and factors accelerating silver migration are still unclear and cannot be precisely defined, but they are generally thought to be as shown in the table below.OMRON does not silver plate the terminals of general-purpose relays, so that the problem of silver migration does not occur.

Cause	Accelerating factor
Presence of silver	High applied voltage, short insulation distance (high potential gradient)
DC voltage applied for long time	High water absorption of insulating material
Hygroscopic insulating materials	Oxidation-reduction gas (SO_2, H_2S, NH_3, etc.)
Use in humid, high-temperature atmosphere	

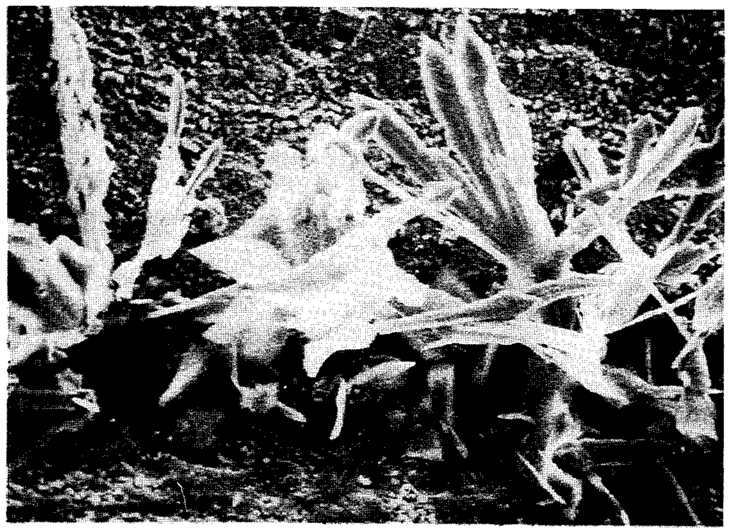
3–3–2 Whiskers

Whiskers occur when needle-shaped crystals grow on the surface of plated parts which are stored for a long time. These crystals are known as "whiskers" because the shape is reminiscent of a cat's whisker's. These crystals can cause short-circuit problems if they grow long enough.

Many points about the causes of growth of these whisker crystals are still not fully understood. However, the crystals are known to occur readily if the base metal is brass or zinc and the plating metal is tin or zinc. The whiskers in this case are intrinsic whiskers.

Care is also required as the silver can sulfurize and grow as whisker crystals in some cases. This can occur due to sulfidizing gases from rubber packing used in the control panel, for example, so careful choice of the environmental conditions and type or relay is important to increase the reliability of operation.

Example of Silver Sulfide Whiskers



OMRON uses solder plating and special zinc plating to prevent the formation of whiskers in general-purpose relays. However, when designing parts, the printed circuit board and pattern, care must be taken to allow sufficient insulation distance from zinc-plated and tin-plated parts to the electric circuit.

3–3–3 Resistance to Tropical Environment

Individual relays or relays mounted in apparatus are subjected to high temperature and humidity if they are shipped through tropical regions. To protect metal parts from this environment, a tropical-specification relay is available with a special casing.

3–4 Contacts

3–4–1 Inherent Characteristics of Contacts

From the point of view of relay operation, it might be thought that the only characteristics required of contacts are a stable contact resistance and long life expectancy. However, to achieve these desirable characteristics, it is necessary to deal with the important factors of contact pressure and contact follow.

For the most commonly used contact materials, silver and silver alloy, a contact pressure of 5 g to 50 g is normal. For a noble metals, such as gold, platinum, or palladium, a contact pressure of 3 g to 10 g is normal. The contact pressure is lower for noble-metal contacts, because the switching capacity is also lower and the resistance to environmental factors comparatively good.

The contact follow is important because good electrical contact must be maintained even if wear occurs in the relay switching section. The contact follow is closely related to the contact pressure. The work done by the switching section is calculated as the product of the contact pressure and contact follow. Therefore, if the work done by the switching section is fixed, the quality of electrical contact depends greatly on whether the contact pressure is high or the contact follow is high.

For example, if the contact pressure is high and the contact follow low, initially the contacts will operate stably, but as contact wear progresses the contact pressure will rapidly drop, destroying the electrical contact. Conversely, the problem does not occur if the contact pressure is low and the contact follow high, but the contact resistance is increased and problems occur with the breakdown of the contact film. Therefore, a good relay is a relay with the correct combination of contact pressure and contact follow.

The contact resistance can be thought of as two factors: constriction resistance and transition resistance (film resistance).

At first glance it seems that the faces of the contacts come into contact with each other. However, due the contact shape and surface roughness, only point contact is achieved between a single point or a number of points on the surface. The resistance arising is known as the constriction resistance, because the current is forced to flow through points of contact.

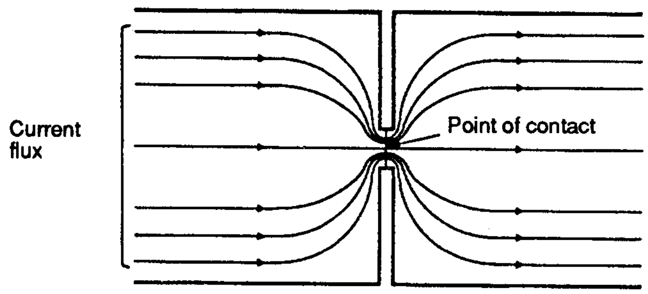
It is apparent from the equation given in *Section 1–1 Basic Construction and Principle of Operation* that the contact hardness, contact pressure, and inherent resistance of the contact material are related to the contact resistance.

A model of the current flow through a point contact is shown in the following diagram below. The current is constricted and forced to flow through a much smaller area than the apparent contact area.

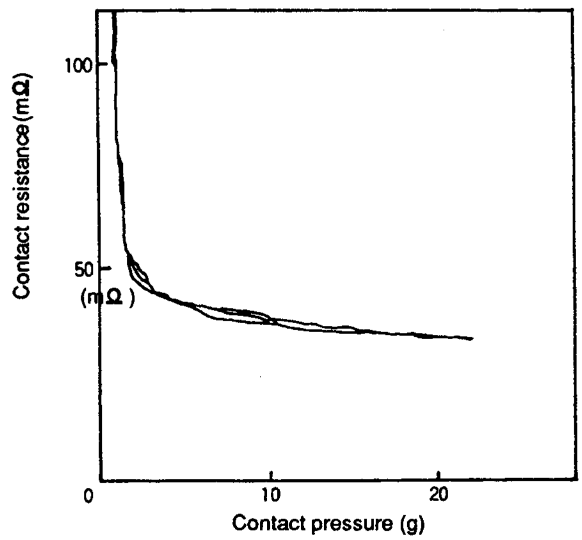
Measurements of the actual relationship between the contact pressure and contact resistance are shown in the second diagram.

With certain types of metal plating of the contacts, a small contact pressure is sufficient to cause plastic deformation of the surface so that the contact resistance improves rapidly with use.

Current Distribution through a Point Contact



Relationship between Contact Pressure and Contact Resistance



Oxide and sulfide films will inevitably form on the surface if the contacts operate in the atmosphere. The electrical resistance caused by these films is known as the transition resistance.

The constriction resistance is normally the major component of the contact resistance in new, unused contacts. However, as the contacts are used, the transition resistance increases to a value larger than the constriction resistance because of wear of the contacts due to arcing, mechanical abrasion, and other factors. The actual proportion of the two components of resistance depends on the number of switching operations the relay has completed. The transition resistance will be small if the contacts are extremely clean after the relay has completed a large number of switching operations. Conversely, relay contacts may develop a high-resistance film after a relatively small number of switching operations.

Contact resistance values are quoted in relay catalogs, but this value only represents an initial value determined using standard test methods.

In practice, contact resistance should be selected to suit the type of equipment in which the relay is used. In general, the level of contact resistance that can be tolerated with respect to the load impedance is the important factor. However, apart from special cases where no distortion or attenuation are permitted, such as transferring audio currents, a contact resistance up to 5% of the load impedance is tolerated.

3-4-2 Effect of Load Conditions on Contacts

The majority of the problems occurring with relays is caused by poor contact between the contacts. The type of problem depends on the load conditions. The load conditions are usually divided into three broad categories: low energy (dry circuit), medium energy, and high energy.

The contact resistance is affected by the voltage and current , as well as the factors described in section 1–1. If no film has developed on the contact surfaces, on a microscopic scale the electrical contact can be considered to be virtually point contact between irregularities in the surfaces. When a current flows through these contacts, the Joule heat generated causes a softening of the contact surfaces. If a contact voltage is now applied, the area of contact increases causing a reduction in the contact resistance.

In practice, however, an oxide or sulfide film forms on the contact surfaces. A current can flow but will depend on physical phenomena related to the thickness of the film. Eventually the film breaks down due to Joule heat and the voltage, and the resistance drops.

The softening voltage mentioned above is approximately 0.09 V for silver, 0.08 V for gold, 0.25 V for platinum, and 0.6 V for tungsten.

If the film becomes thick enough, a phenomenon known as the Zener effect occurs at an electric field intensity of approximately 10^6 V/cm. The Zener effect ,in turn, causes another phenomenon called the Coherer effect.

Under dry circuit conditions, the softening voltage is in the region of 100 mV at a current of less than 100 mA, although the exact values are difficult to pinpoint precisely.

At medium energy levels, the load is sufficient for a small amount of electrical discharge to occur between the contacts. This is the energy region where the softening voltage becomes the arc voltage. The limit voltage and current values where arcing starts are given by the following equation:

$$(I - I_{max})(V - V_{max}) = k$$

where:

V_{max} = arc discharge start voltage
I_{max} = arc discharge start current
k = constant

The film on the electrode breaks down in this region.

Typical arc discharge start voltages for the major contact materials are approximately 12 V for silver, 16 V for gold, 17.5 V for platinum, 15 V for tungsten, and 11 V for 10% palladium-silver alloy.

Voltages in the high energy-level range exceed the arc discharge start voltages.

In this region, effects from the contact film are small but care is required as arcing between the contacts can break down organic gases, causing defective contact and deterioration of the insulation.

Another problem is the generation of nitric acid gas, which is described in the next subsection.

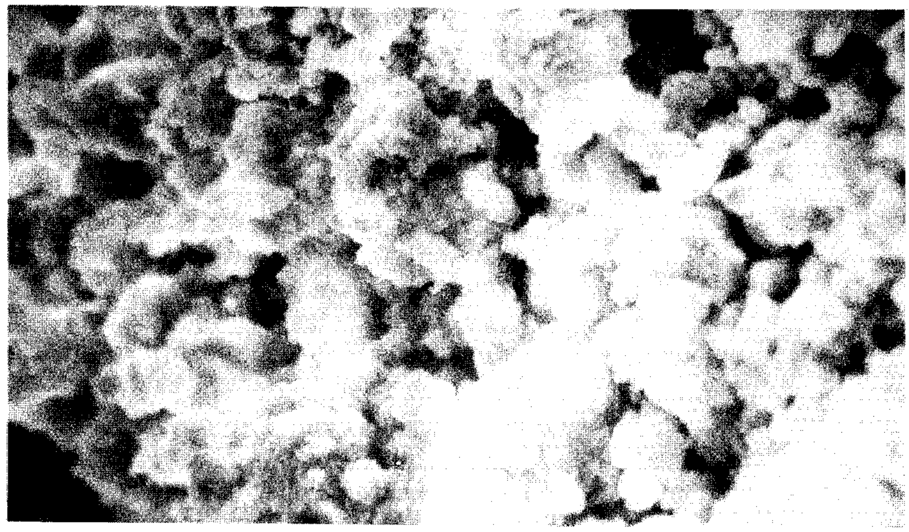
3-4-3 Special Problems Related to Contacts

Special problems can occur with contacts, depending on how they are used.

Abnormal Corrosion during Load Switching.

The arcing during load switching combines the nitrogen (N) and oxygen (O) in the atmosphere, usually to form nitric acid (HNO_3) gas, which corrodes the contacts.

Example of Nitric Acid Corrosion



The following measures can be taken to prevent this phenomenon:

a) provide an arc-extinguishing circuit to reduce the degree of arcing
b) reduce the switching frequency so that the arc is not maintained
c) reduce the humidity of the operating environment.

Coherer Effect

When electrical contact is made through a film developed on the contact surface, the film electrically breaks down when the voltage reaches a certain level, causing a sudden drop in contact resistance.

Thermoelectromotive Force

A number of metals (silver and copper alloy, for example) are used in a relay to provide the desired properties. A thermoelectromotive force is generated if a temperature difference occurs at the junction between two different metals because of differences in distance from a heat generating body (such as the coil) or different thermal conducting pathways. This thermoelectromotive force (from several mV to several tens of mV) acts across the contact terminals and can create problems, especially when the contacts are handling minute signals.

3-4-4 Contact Under Various Loads

The types of phenomena occurring at the contacts at low energy levels are quite different from those at high energy levels. Wear of the contacts is slight at low energy levels although it is difficult to ensure good electrical contact. On the other hand, at high energy levels the main problems with the contacts are due to wear, fusing, and deposition.

The cleanliness of the contacts is the most important factor at extremely low energy levels. The major causes of defective electrical contact are likely to be non-conducting material stuck to a surface or a non-conducting film developed on the contacts.

Non-conducting materials tend to be small particles of sand, fiber, or dust, but the contact wipe and contact pressure of a relay handling minute loads are so low that even a small particle stuck to the surface of the contacts can prevent normal electrical contact. This problem is unrelated to the contact material and can only be solved by selecting a suitable type of relay and method of use.

A non-conducting film forms on the contacts due to the materials used in the constituent parts of the relay and the surroundings in which the relay is used.

The films may be caused by water vapor in the atmosphere, oil or oxides, organic gases produced by the relay itself or the building, automobile or other exhaust gases, smoke from factories, solder flux, or a worker's fingerprint. These films can only be prevented by controlling the relay construction, contact material, and operating environment.

Silver, the most common contact material, readily oxidizes and sulfurizes. Although an oxide film does not have a great effect on the electrical contact, a sulfide film has a very significant effect. Noble metals, which do not readily sulfurize, are used in the contacts to overcome this problem: normally palladium, gold, platinum, or silver alloys.

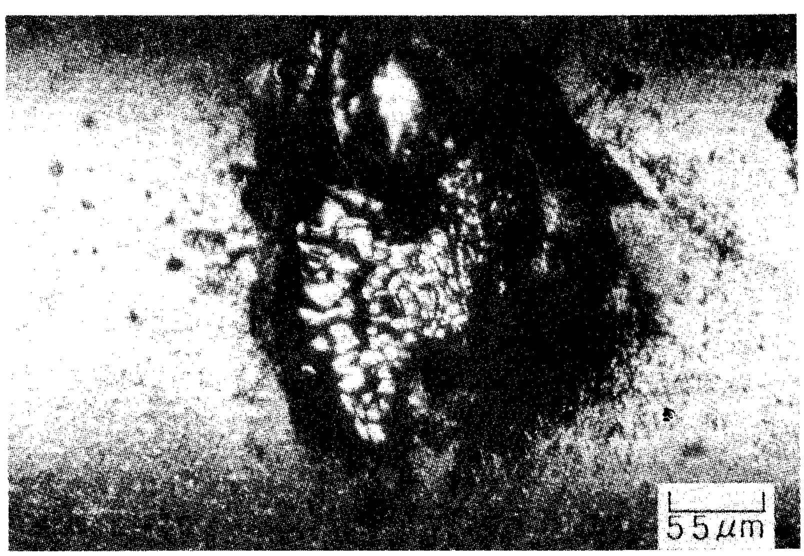
However, platinum-based contacts have a strong catalytic effect when switched under little or no load conditions and the surface tends to adsorb unsaturated organic gases released by benzine and gasoline, for example, and produce a polymer powder (brown powder).

No film forms on gold contacts, so that the electrical contact is stable. However, gold is very soft so that the contact surfaces deform under low contact pressure and cannot withstand periods of use. This problem is often overcome by using a double-layer contact construction with gold over palladium, or by applying a protective gold film to the contact.

If arcing occurs at minute loads, oxidation of the contact may occur, depositing a carbon film on the contact due to the burning of flammable particles in the atmosphere. The carbon film does not form a perfect insulator, but can cause a resistance of several tens to several hundreds of ohms.

For example, when the relay contacts open at high temperature, organic gases given off by the plastics used to make the relay are broken down by the arc and may deposit carbon on the contacts in the form of a black powder. This black powder is comparatively common when a load of several watts is switched. At lower power levels, the arc is not powerful enough to disperse this black powder, so that it tends to accumulate on the contacts.

Contact Surfaces After 18-VDC, 45-mA Load Test



Another problem for contacts is organic silicon resin (silicone). Silicone is also broken down by the heat of the arc, producing inorganic silicon oxide, which can cause defective contact. Silicone is used in many industrial products, such as silicone oil, silicone rubber, and silicone varnish, which is used as a coating on semiconductor devices. As described above for avoiding films due to gases originating from the relay materials, it is important to select the correct type of relay for the environment, and to improve the operating conditions and environment.

High-energy, continuous arcing occurs when the relay is operated at a high energy level. This arcing can cause damage to the contacts, such as wear due to melting and dispersion of metal as a vapor, deposition of melted metal particles from one contact to the other, and the fusing of contact surfaces when the contacts are closed.

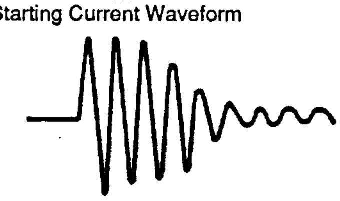
Continuous arcing occurs readily at low loads with a DC current because the current and voltage do not regularly become zero as with an AC current.

Care must be taken when selecting the material and shape of insulators for use under these load conditions, because adhering metal particles and carbonization of the insulators cause deterioration of insulating materials.

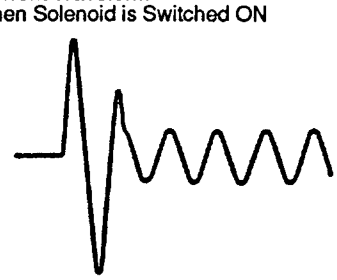
The damage to contacts also differs according to the type of load applied. Loads with a large inrush current, such as transformers, motors, and lamps, tend to cause the contact surfaces to fuse. The inrush current from a lamp, motor, transformer, or solenoid may be more than ten times the normal current.

A large counter electromotive force is generated when the power is cut off to an inductive load, such as a motor, transformer, or solenoid. This voltage is between 4 and 20 times the normal voltage, and can easily cause serious contact wear or damage to the load.

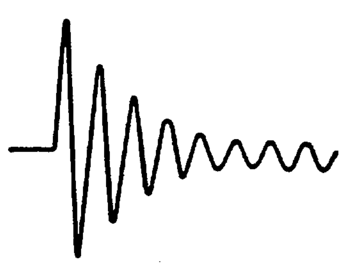
Induction Motor
Starting Current Waveform



Current Waveform
when Solenoid is Switched ON



Current Waveform
when Lamp is Switched ON



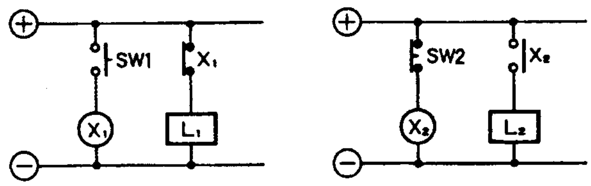
SECTION 4
Circuits

4-1 Basic Relay Circuits

The four basic types of relay circuit are described below. All circuits use an NO contact switch (except for the NOT circuit (b)), but the circuits operate in the same manner if an NC contact is used. The NO contact or NC contact must be selected to suit the type of operation. Consider the following important points:

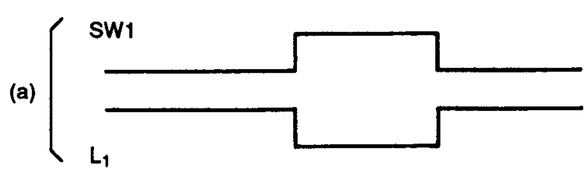
- The NC contact closes (makes the circuit) when the relay power is off.
- Relay failure mode (defective contact, fusing)

4-1-1 NOT Circuit



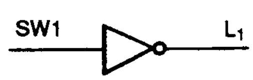
The output turns OFF when the switch is ON.

The output turns ON when the switch is OFF.



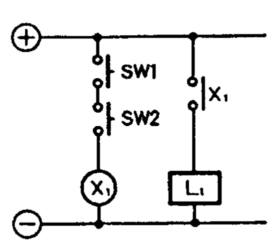
In circuit (b), L2 turns OFF when switch SW2 is pressed (turned OFF).

This circuit is represented by the following symbol in a logic diagram.

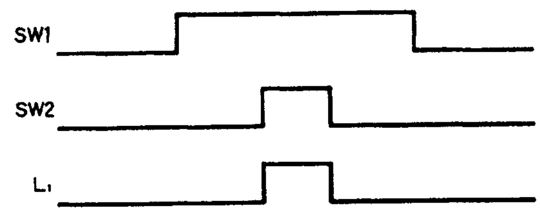


4-1-2 AND Circuit

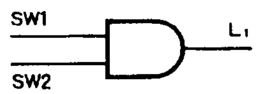
This switch can be used to provide safety functions for a pressing machine, for example, so that the machine will only operate if both switches are pressed.



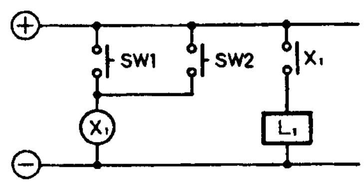
The output turns ON when both switch SW1 and SW2 are ON.



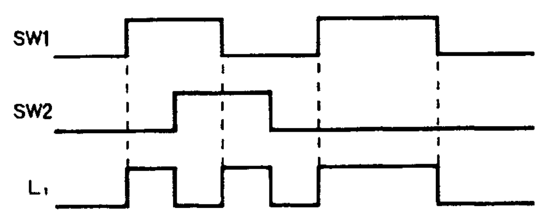
This circuit is represented by the following symbol in a logic diagram.



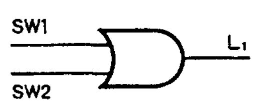
4-1-3 OR Circuit



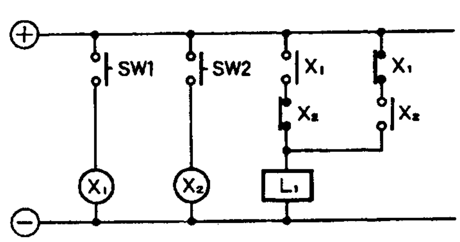
The output turns ON when either switch SW1 or SW2 is ON.



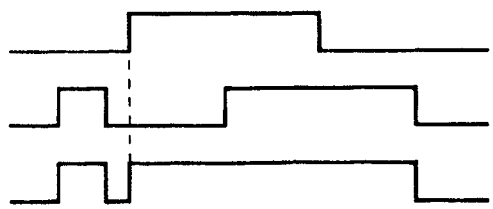
This circuit is represented by the following symbol in a logic diagram.



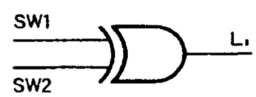
4-1-4 X-OR Circuit



The output turns ON when the statuses of switch SW1 and SW2 are different.



This circuit is represented by the following symbol in a logic diagram.



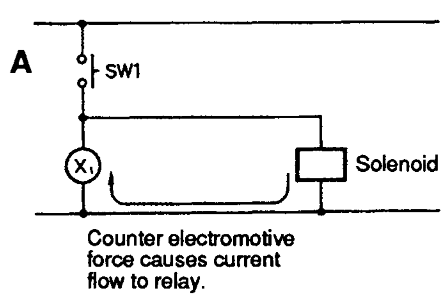
4-2 Applied Relay Circuits

Applied circuits are created from combinations of the basic circuits.

The applied circuits described here are comparatively simple, but in practice circuits with several hundreds of relays are used.

It is important to remember the following points when creating an applied circuit of any size:

- A relay does not operate immediately the voltage is applied. Take the operating time and reset time into account, and use them to advantage.
- The operating time of an AC-operated relay depends on the phase of the AC power supply when it is turned on or cut off.
- Some types of surge absorber connected to a DC relay cause the reset time to become extremely long (several milliseconds).
- Avoid bypass circuits. If a relay is connected in parallel with a large solenoid or motor, the counter electromotive force from the solenoid or motor can increase the relay reset time.



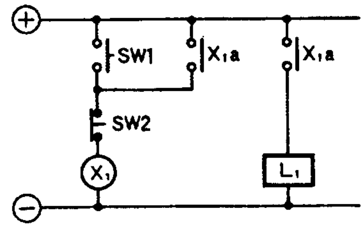
- Bounce occurs when relay contacts close. Beware of this phenomena with self-holding circuits. It is important to understand all relay characteristics when designing a circuit.

4-2-1 Memory Circuit (Self-Holding Circuit)

The most basic circuit is a circuit where coil X1 is held ON after the switch SW1 has been turned ON. The self-holding circuit turns OFF when the power supply is cut off.

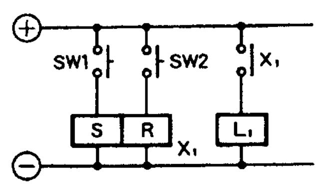
Using this type of circuit for the start signal increases the safety of a machine or piece of equipment. After a power-cut, the self-holding function of the relay is cleared so that the machine will not start working again when the power supply is re-connected.

The self-holding function may not operate if the switch SW1 is closed only for a very short time. The ON time of the switch SW1 must be chosen to be longer than the operating time of the relay.

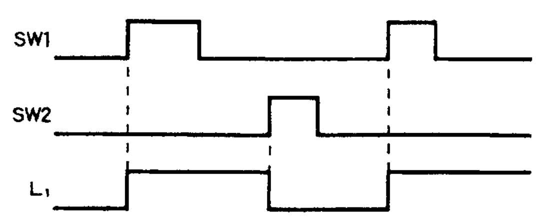


4–2–2 Memory Circuit (Flip-Flop Circuit)

This type of memory circuit uses a latching relay (keep relay), which holds its status when the power supply is turned OFF.



Time chart

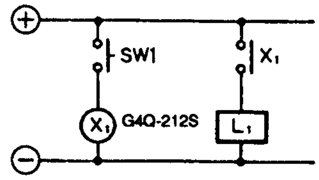


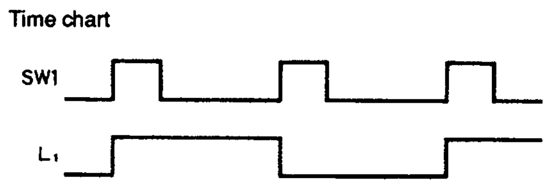
The operation of X1 when both switches SW1 and SW2 are turned ON depends on the type of relay.

4–2–3 Binary Counting Circuit

A binary counting circuit can be simply created using the type G4Q relay.

It is also possible to make this type of circuit using 4 or 5 relays, but because this type of circuit is combined with a self-holding circuit it is very sensitive to contact bounce and fluctuations in supply voltage.

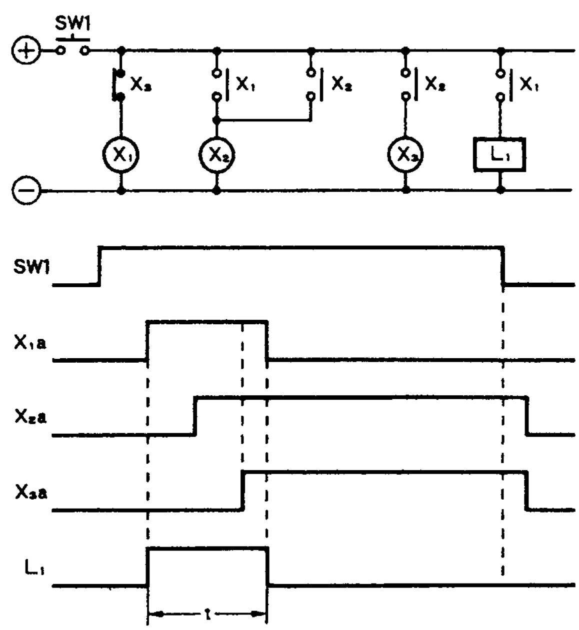




4-2-4 One-Shot Circuit

If a limit switch is pressed and held down, the relay contacts operate to provide a single "one-shot" pulse.

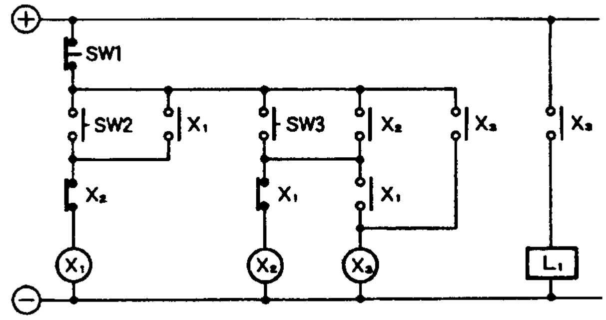
When switch SW1 is turned ON, X1 operates, so that X2 self-holds. When X2 turns ON, it operates X3 which turns X1 OFF.



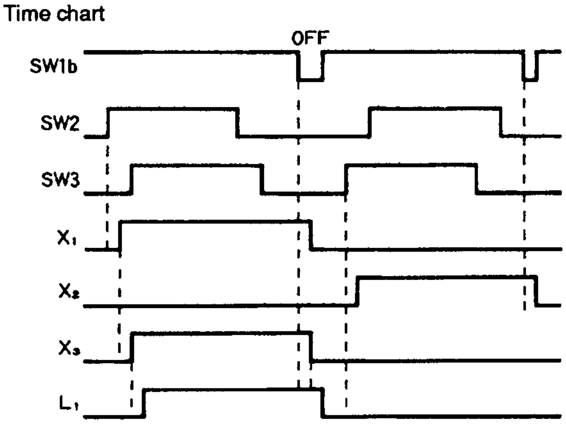
t = (X2 operating time) + (X3 operating time) + (X1 reset time)

4-2-5 Sequence Circuit

The output relay X3 operates if switch SW2 is turned ON first, followed by switch SW3. However, the output relay X3 will not operate if the switching order is reversed: i.e., if switch SW3 is turned ON first, followed by switch SW2.



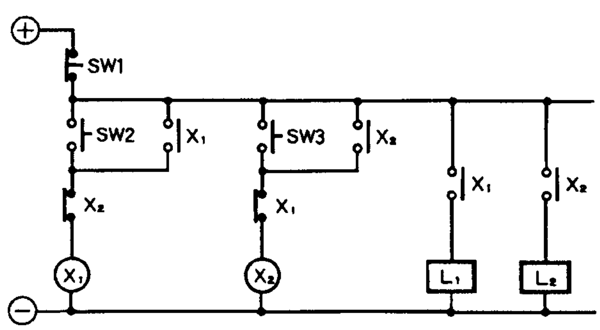
Time chart



4-2-6 Priority Circuit (1)

This circuit prevents both relays X1 and X2 operating simultaneously. The relay which operates first has priority.

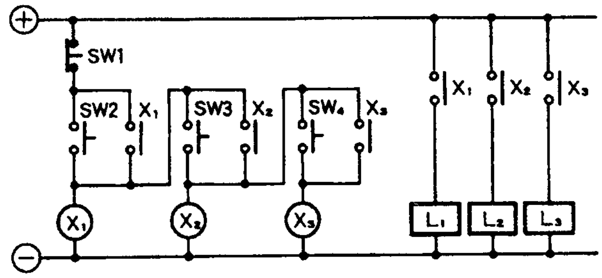
If this type of circuit is used to select the direction of motor rotation or to select a power supply, the load is not switched directly by the contacts of relay X1 or X2, but by a reversible contactor.



4-2-7 Priority Circuit (2)

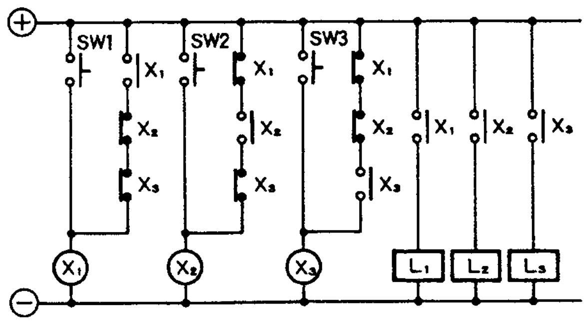
This circuit is used to sequentially start equipment. The relays turn ON in sequence, starting with the relay nearest to the power supply: X1, X2, X3 ...

For example, if switch SW3 is turned ON before switch SW2, the relay X2 cannot operate until relay X1 has operated. Therefore, none of the relays can operate if switch SW1 is OFF. Switch SW1 has priority over all other input signals.



4-2-8 Priority Circuit (3)

If two or more of the switches SW2 to SW4 are turned ON simultaneously, only the relay with the lowest index number operates.



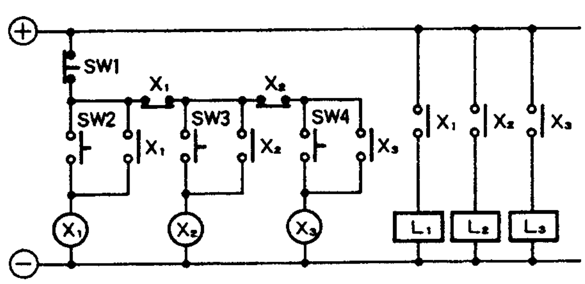
4-2-9 Priority Circuit (4)

If switch SW1 is pressed, X1 only self-holds.

If switch SW2 is pressed, X2 only self-holds.

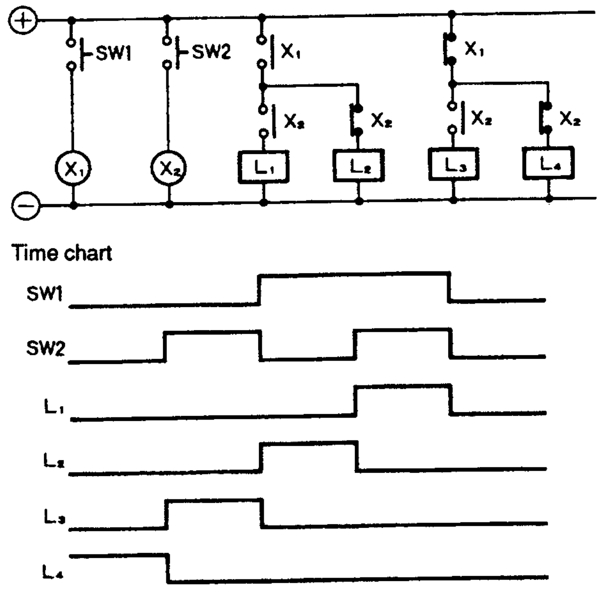
If switch SW3 is pressed, X3 only self-holds.

If all switches are pressed simultaneously, all the relays operate. When the switches are released, only the relay corresponding to the last switch released self-holds, all the other relays turn OFF.



4-2-10 Signal Distinguishing Circuit

This circuit distinguishes the statuses of two switches to produce four output signals. It converts the binary input of the two switches to a base-4 output.



4–3 Combined Relay and Semiconductor Circuits

4–3–1 Comparison of Electromagnetic and Semiconductor Relays

Since the development of semiconductors, there has been a tendency to replace relay circuits with semiconductor circuits. The relay vs. semiconductor debate rages to this day, but in reality they share a peaceful coexistence, each having its own particular merits. Used in combination, they have found an even wider field of application.

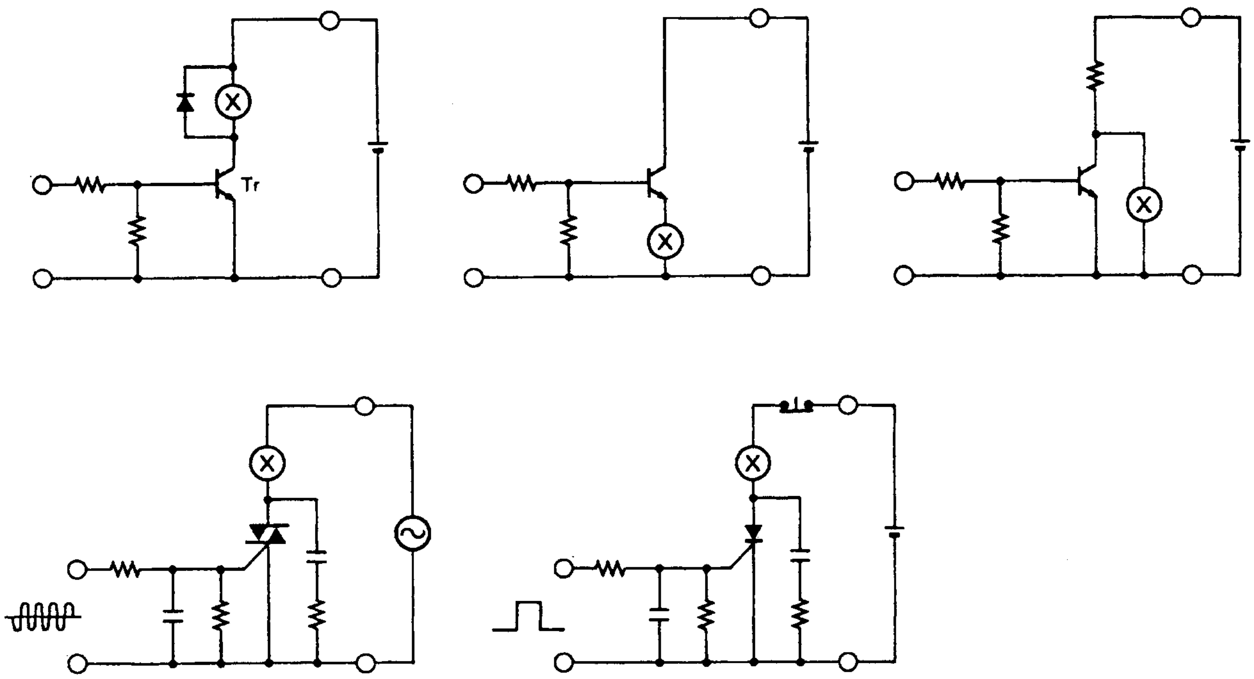
Item		Solid-state relay	Electromagnetic relay
Input characteristics	Operating power source	Input characteristics	Normally of the order from 100 mW to several watts (W). Some special relays, such as reed switches and high-sensitivity relays, operate with only several tens of milliwatts (mW). Power consumption is reduced for a keep relay, as the input turns OFF after the relay operates.
	Operating voltage	Voltages up to the maximum rated input voltage of the semiconductor give a wide range of input voltages for a control circuit.	A wide range of AC or DC input voltages are available through correct coil selection. A relay is normally designed to operate within the following input voltage range: (rated input voltage) + (tolerance).
	Operating current	Determined by the control current of the driven switching element.	Determined by the ampereturn rating of the coil.
	Transient effects	Protective circuit required to prevent damage from surge voltages.	Problems rare
Output characteristics	Multipole switching	The number of semiconductors and control circuits has to be increased, causing problems of increased cost, size, and insulation.	Relatively cheap. Only increase of the number of contacts and the coil electromotive force is required.
	Switching range	Device must suit the voltage, current, and frequency. Frequency and range dependent to a large extent on semiconductor characteristics.	Contacts can handle a wide range of voltage and current.
	Voltage	The maximum output voltage is determined by the maximum permitted voltage of the semiconductor.	Wide range.

Item		Solid-state relay	Electromagnetic relay
Output characteristics	Current	The size of the current and duration time are determined by the semiconductor junction temperature. Protective circuit required to prevent damage from surge currents.	Transient currents can cause fusing of the contacts.
	Transient effects	High voltages for a short time can damage the semiconductor.	Problems rare
	Duty cycle	Reduce the duty (%) to increase the rated current without causing the junction temperature to exceed the maximum limit.	Not relevant
	Contact bounce		Occurs when contacts open and close
	Power loss	Large losses due to high junction resistance. Heat dissipater required to handle large currents.	Small losses due to low contact resistance.
	ON resistance	Higher than a relay.	Normally several mΩ to several tens of mΩ
	ON voltage	Not suitable for a low-voltage circuit because the semiconductor forward voltage drop is normally 0.6 V to 1.5 V.	Determined from the (contact resistance) x (switching current)
	OFF resistance	Not as high as a relay because of the leak current.	Extremely high
	Leakage current	Normally under a few microamperes (µA) for a transistor. Several milliamperes (mA) for a thyristor. The leak current increases as the temperature increases.	Problems rare
Insulation	Output/Input	A high degree of insulation cannot be achieved between the control and output circuits of a junction semiconductor. In practice, magnetism, light, or a reed switch must be used.	High degree of insulation (at least 1000 MΩ) between output circuits, output circuits and control circuits, and between control circuits.
Life-expectancy	Dynamic	A semiconductor has no moving parts subject to wear. The dynamic life-expectancy is determined by the design, manufacture, assembly, and type of semiconductor.	The mechanical life-expectancy of a relay is normally more than 1 million cycles, or up to several billion cycles for a mercury relay. However, the actual life-expectancy depends on the type of relay and the design. The electrical life-expectancy depends on the switching load.
	Static	Determined by chemical and physical changes at the semiconductor junctions. The ambient temperature, type of operation, design, and manufacture of the semiconductor are the major factors determining the static life-expectancy.	Determined by chemical and physical deterioration of all parts of the relay. The design, materials, manufacturing process of the relay, and operational environment are the major factors determining the static life-expectancy.
	Shelf life	Problems rare	Problems rare. Hermetically sealed types preferable to open types.

4-3-2 Relay and Semiconductor Combination Circuits

Circuits created by combining the features of relays and semiconductors, such as transistors, can be applied to a wide range of applications.

The basic circuits shown in the diagram below use semiconductors to drive the relay coil.



Note: Turn OFF the power circuit with the switch SW to cut off the power to the relay.

Consider the following important points when using a semiconductor to drive a relay:

- the voltage applied to the relay coil (upper limit, lower limit, voltage drop in semiconductor)
- surge voltage due to counter electromotive force when the relay coil is cut off
- permitted values of the semiconductor (voltage, current, heat generation, etc.)
- de-rating of the semiconductor due to heat generated by the relay.

SECTION 5
Reliability

5–1 The History of Reliability

5–1–1 Reliability Engineering

The importance of reliability was recognized relatively recently. The institutionalized study of reliability engineering began with the 2nd World War, although it is not possible to exactly pinpoint when or by whom. The reliability doctrine was certainly applied for the first time in the German V2 rocket project, but after the war the whole thing was quietly forgotten.

However, investigations into reliability did proceed amongst the specialists of the IRE (IEEE), ASQC and other organizations, and a reliability program was developed through theses produced by the research division of the Redstone Arsenal Missile Research Laboratory.

Recommendations by AGREE (Advisory Group on the Reliability of Electronic Equipment) in 1957 determined the future direction of reliability engineering.

5–1–2 Reliability of Relays

The results of research carried out on the basis of the AGREE recommendations were published by the Department of Defense in 1960 under the title: Product Specification Management for Reliability. This publication is also referred to as the Darnell Report. It covered all the problems related to relay reliability including the specification problems arising between the user, system manufacturer, and component manufacturer.

The two main themes covered by the Darnell Report are as follows:

1) To increase the reliability of the system, the reliability of each constituent part must be improved, as the reliability of a system is determined by the reliability of its parts.

2) To quantitatively compare the reliability of parts, it is necessary to compare groups of similar parts produced by different manufacturers.

5–2 Basic Concepts

5–2–1 Definition of Reliability

The definition of reliability can be most easily understood using the analogy of human health. For a machine to operate reliability, it must be "healthy," in the same way that a person must be healthy to work reliably. For a person to remain healthy, either the person does not catch diseases, or, if the person should contract a disease, it can soon be cured.

To restate this concept in the terms of a machine: for a machine to operate reliably, it seldom breaks down, or, if it does break down, it can soon be repaired. The first idea is expressed by the word "reliability," and the second by the word "maintainability." In the study of reliability, the word "availability" is used to encompass the two concepts of reliability and maintainability.

These three criteria are defined as follows:

1) Reliability

The probability that a system, or product continues to function without failure for the intended period under the specified conditions.

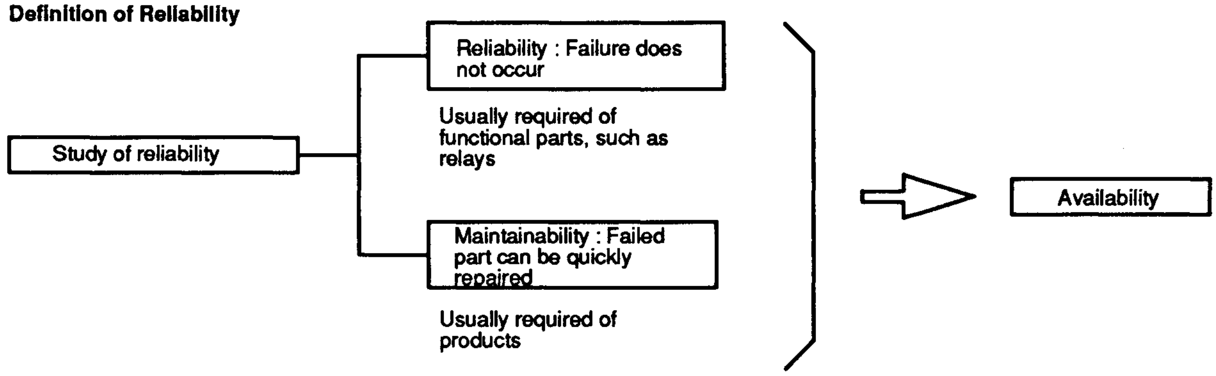
2) Maintainability

The probability that maintenance of a repairable system or part is completed within the specified period when carried out under the specified conditions

3) Availability

The probability that a repairable system or part is functioning correctly at any specified instant.

Definition of Reliability



5-2-2 Time-Dependent Quality Control

In the narrower concept of quality control, the fraction defective is simply determined by whether the products meet standards when they leave the factory.

The study or reliability, however, takes into account the stability of functions over the period of time after the product leaves the factory, measured as the degree of unreliability or as the failure rate. The point underlined below is extremely important. Read it carefully after studying the diagrams below. When considering reliability, the products must be initially functioning correctly, so that the fraction defective is zero. Consequently, in Fig. 1, the reliability when the parts are shipped from the factory is expressed as (1 - fraction defective). In Fig. 2, the progress of the non-defective parts only is traced, so that after a certain elapsed time the reliability is expressed as (1 - fraction defective).

Fig. 1 Simple Quality Control

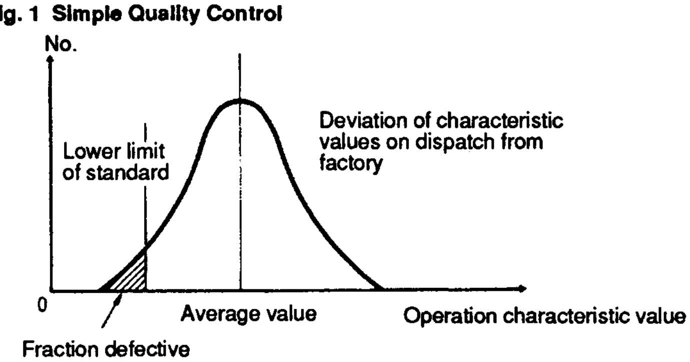
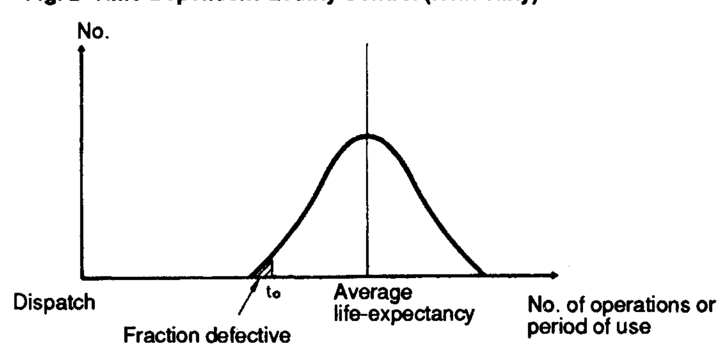


Fig. 2 Time-Dependent Quality Control (Reliability)



5-2-3 Measurement of Reliability

The most commonly used criteria to measure reliability are listed in the table below.

Reliability Measurement Criteria

Reliability Measurement Criterion	Definition from JIS Z 8115	Example of product
Reliability (R)	The probability that a system, equipment or part continues to function without failure for the intended period under the specified conditions.	Aerospace systems
Failure rate (λ)	The probability that a system, equipment or part that was operating up to a certain point of time will fail in the next unit of time.	Electronic components, machine parts
Mean Time Between Failures (MTBF)	The average operating time between consecutive failures of a system, equipment or part which is repaired.	Computers, automobiles
Mean Time To Failure (MTTF)	The average operating time up to failure of a system, equipment or part which is not repaired.	Electronic components
Useful life longevity	The period during which the failure rate is below a specified value.	Domestic appliances, mechanical appliances
Maintainability	The probability that maintenance of a repairable system, equipment or part is completed within the specified period when carried out under the specified conditions.	Automobiles, production plant
Mean Time To Repair MTTR or Mean Down Time (MDT)	The mean value of the duration of repair time (MTTR and MDT may be used interchangeably, but MTTR is often used for post-failure maintenance)	Electronic telephone exchanges
Availability	The probability that a repairable system, equipment or part is functioning correctly at any specified instant. Often determined from the following equation: Availability = (time operation is possible) / (time operation is possible) x (time operation is not possible)	Production plant, computers

5-2-4 Basic Terminology

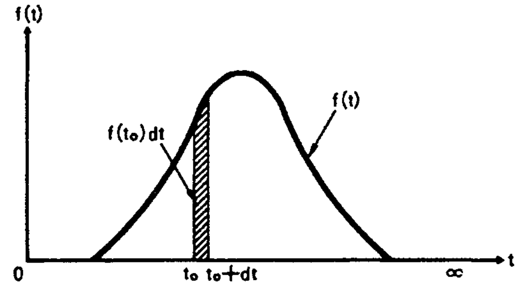
The meaning of some of the basic terminology related to reliability is described below.

1) Failure Probability Density Function f (t)

$$\int_0^\infty f(t)dt = 1$$

The number of failures occurring at time t as a proportion of the total number of samples.

Fig. 1 f (t)

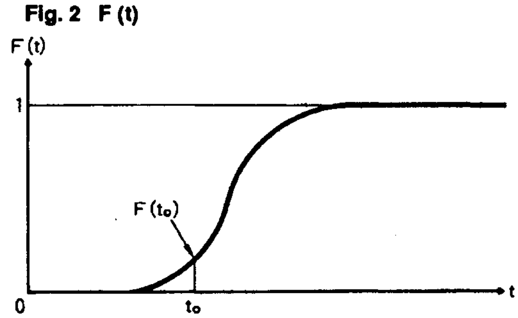


2) Accumulated Failure Distribution Function F(t)

$$F(t) = \int_0^t f(t)dt$$

The number of failures occurring from time 0 to time t as a proportion of the overall number of samples.

Fig. 2 F (t)



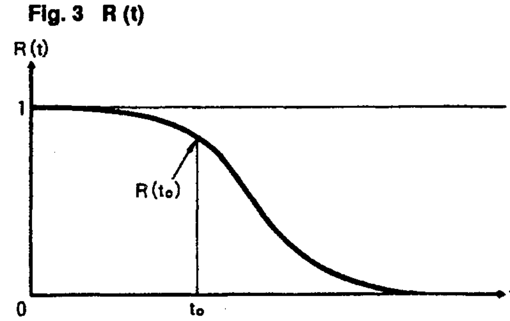
3) Reliability Function R(t)

$$F(t) = \int_t^\infty f(t)dt$$

$$= 1 - F(t)$$

The surviving number at time t as a proportion of the overall number of samples.

Fig. 3 R (t)



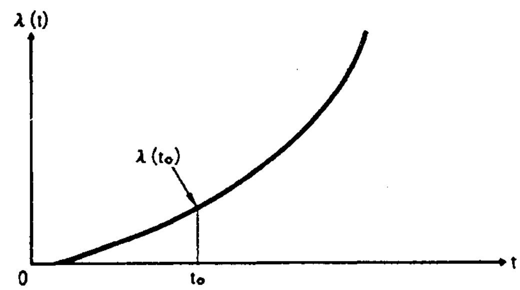
4) Instantaneous Failure Rate $\lambda(t)$

$$\lambda(t) = \frac{f(t)}{R(t)}$$

$$= -\frac{d\{nR(t)\}}{dt}$$

The number of failures occurred at time t as a proportion of the surviving number of samples.

Fig. 4 λ (t)



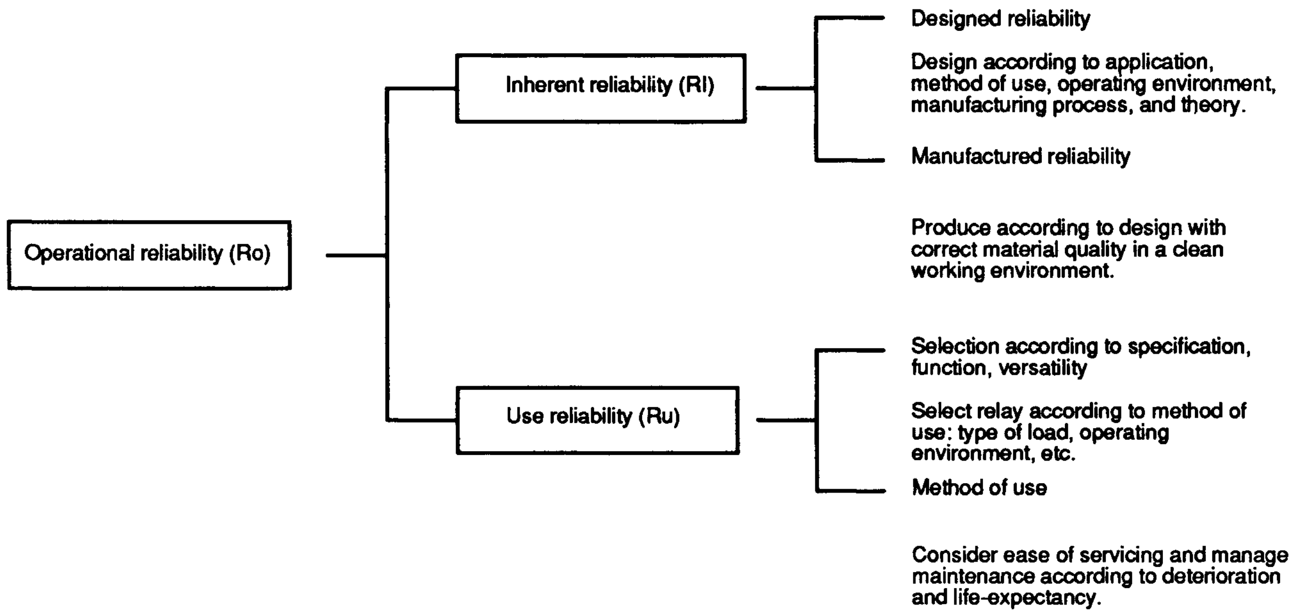
5–2–5 Operational Reliability

The actual reliability of equipment during use is known as the operational reliability (Ro). Operational reliability can be understood from the following equation:

Ro ∝ RI • Ru

where, RI is the inherent reliability (the guaranteed reliability measured by the manufacturer in a standard environment simulating the actual conditions of use), and Ru is the use reliability (dependent on the actual operating environment after delivery, particularly human factors).

The designed reliability must reflect the operating conditions. However, even if the designed RI value is achieved, the Ru value fluctuates a great deal due to the actual conditions of use. Consequently, a number of indicators have been determined which affect the reliability. The relationship between these indicators is shown in the diagram.



5–2–6 Operating Characteristic Curve (OC Curve)

The important points regarding the evaluation of the reliability of an entire production lot are described in this section.

It is not necessary to predict the failure rate (λ) range if each item of the lot is inspected. Straight lines are obtained, such as ABCDE in the diagram.

However, if an entire lot of relays is inspected for reliability, none will remain for actual use. So in practice, a number of samples are selected and the inspection results used to predict the reliability of the entire lot. In this case, the pass-fail line is represented by the curve ACE.

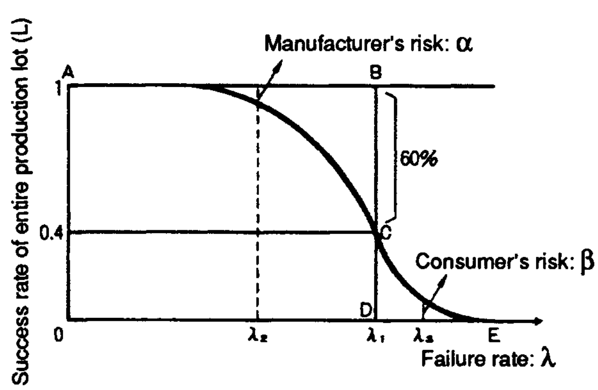
The failure rate (λ1) used as the evaluation standard (point C) represents a reliability level of 60% from the point of view of the end user. In the region ABC, the relay will still fail if the failure rate value on the horizontal axis decreases below λ1, so that this region is known as the “manufacturer's risk.” Conversely, in the region CDE, the relay will still pass if the failure rate value on the horizontal axis increases above λ1, so that this region is known as the “consumer's risk.”

This idea permits the evaluation of reliability, which is impossible if the entire lot is inspected.

It is only possible to fully understand reliability after grasping the concept of λ60.

Destructive testing is often used for reliability tests, and this testing requires a long time because the failure rate is extremely small. As a result, a balance must be drawn between the levels of significance α, β and cost, so that a reliability level of 60% is commonly used. This is the value quoted for reference in relay catalogs. The reliability level must be increased, and the sampling and pass-fail conditions must be changed when a guaranteed failure rate of a lot is required, for aerospace applications, for example.

Before relays are dispatched from the factory, the entire lot is inspected by non-destructive means that cause no deterioration of the relay, including measurement of the must-operate voltage, reset voltage, contact resistance, and dielectric strength. Relays either pass or they fail this inspection, so that the levels of significance α, β are effectively zero.

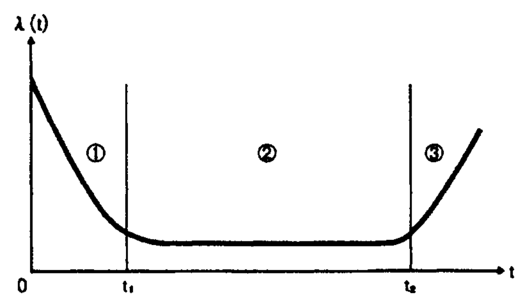


5-3 Failure and Life-Expectancy

5-3-1 Bath-Tub Curve

The shape of the curve in the diagram below may be familiar as the curve representing human death rate. The same trend also applies to other creatures, such as fish. In the case of machines, it is the failure rate, not the death rate, which has this shape, known as a bath-tub curve. The life of relays also follows an identical curve. The shape can be easily understood by dividing it into three distinct periods.I.

Bath-Tub Curve



(1) Early failure period
$(0 < t < t_1)$
(2) Random failure period
$(t_1 < t < t_2)$
(3) Wear-out period
$(t > t_2)$

Part (1) is known as the early failure period.

The failure rate improves as the number of operations increases, so that it may appear that poor items are improving. What really happens is that items with defects likely to cause failure fail early on, so that the better items remain. This process is not unlike natural selection. All items should be past this debugging stage before they are sent to the user.

To ensure that the early failure rate of relays is near to zero, the manufacturer inspects the basic characteristics of all relays before shipment, by measuring the must-operate voltage, reset voltage, contact resistance, dielectric strength, time characteristics, and carrying out coil impulse testing. In other words, if this inspection has been carried out, it is apparent that any subsequent failure is either a random failure, wear-out failure, or a failure due to using the relay is some particular way.

Part (2) of the curve is known as the random failure period.

In this period, the failure rate is approximately constant, and independent of the number of operations. The product can be used effectively within this period. Both the manufacturer and user would like to reduce the failure rate to zero in this period, but unfortunately this cannot yet be achieved in practice. However, efforts are made to keep it as small as possible.

The actual failure rate level of each particular type of relay depends on a large number of conditions. Therefore, the failure rate of the final product is also affected to a large degree by the types of relay selected and the conditions under which they are used.

Part (3) of the curve is known as the wear-out period.

In this period, the failure rate increases with the number of operations, so that eventually all items will wear out and break down. It is important to consider the life-expectancy of mechanisms with moving mechanical parts, such as relays, as they inevitably suffer from wear, deformation, and fatigue.

For relays, failure and life-expectancy are normally classified as follows.

1) Failure

Relay failure consists of function changes which can be monitored, random malfunctions, or intermittent deterioration of functions.

2) Life-expectancy

Defective relay functions due to abrasion, wear, deposition, or accumulation. This may be predicted and avoided by preventative maintenance.

5–3–2 Weibull Distribution

The bath-tub curve can also be expressed in terms of the Weibull distribution function.

The Weibull distribution is named after the Swede, W. Weibull, who first applied it to the life-expectancy of steel balls.

This distribution successfully explains how the failure of the weakest point is connected to the failure of all functions. In principle, it can be thought of as an extension of the exponential distribution. From the practical point of view, the Weibull chart offers a convenient method of analyzing data.

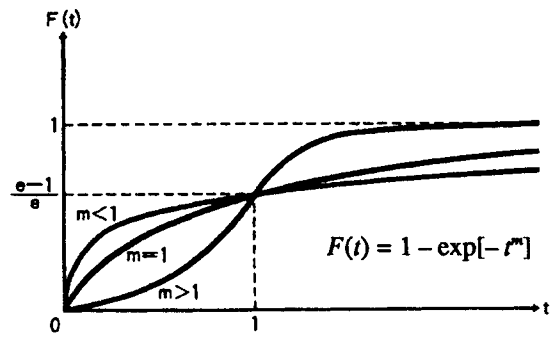
If $m<1$, the distribution resembles the early failure period; if $m=1$, it resembles the random failure period; and if $m>1$, it resembles the wear-out period.

The Weibull distribution can be represented by the following diagrams and functions.

1) Weibull Distribution Function

$$F(t) = 1 - \exp\left[-\frac{(t-\gamma)^m}{to}\right]$$

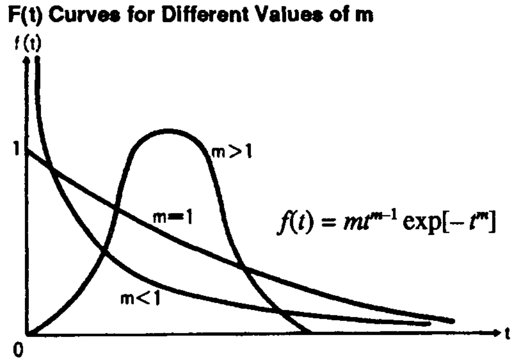
F(t) Curves for Different Values of m



2) Failure Probability Density Function

$$f(t) = \frac{m(t-\gamma)^{m-1}}{to} \exp\left[-\frac{(t-\gamma)^m}{to}\right]$$

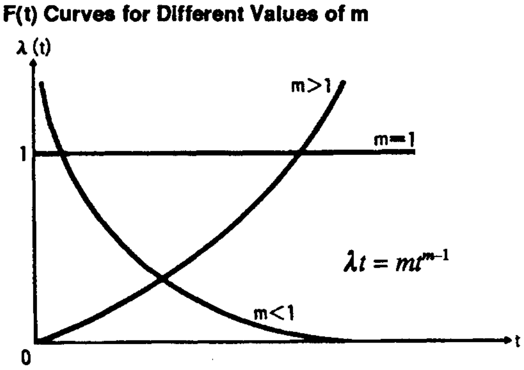
F(t) Curves for Different Values of m



3) Instantaneous Failure Rate

$$\lambda(t) = \frac{f(t)}{1-F(t)} = \frac{m}{to}(t-\gamma)^{m-1}$$

F(t) Curves for Different Values of m



where,

m : shape parameter
to : scale parameter
γ : position parameter

Comparing the shapes of the curves above with the bath-tub curve, it is apparent that m<1 is equivalent to part (1), m=1 is equivalent to part (2), and that m>1 is equivalent to part (3).

A Weibull chart is based on the Weibull distribution function, and is useful for failure analysis.

The vertical axis of the Weibull chart represents F(t) and the horizontal axis represents the time (t). The analysis is carried out by plotting the test results on these axes. For relays, the gradient of the curve plotted from the test data should slope up to the right with a large gradient. This type of curve indicates that the relays reach their life-expectancies together and that the life-expectancies are long. No effort is spared at the relay design and production stages to achieve this type of characteristic, so that all causes of failure cause the relays to simultaneously come to the end of their life-expectancies.

Knowledge of the relay life-expectancy helps the user plan equipment maintenance schedules and predict the useful life longevity.

Refer to "Using Weibull Charts" published by Nihon Kikaku Kyoukai for more details about using Weibull charts.

Refer to the Weibull charts published by Nikka Giren.

5-3-3 Exponential Distribution

The number of trouble-free operations during the random failure period follows an exponential distribution. This distribution is a special case of the Weibull and gamma distributions, and is the most basic life-expectancy distribution used for reliability.

The gamma distribution provides the model for the number of random shocks (k) applied to a relay before the first failure occurs. In the case where a single shock causes failure (that is, k = 1), the gamma distribution is equivalent to the exponential distribution.

Similarly, the Weibull distribution is also equivalent to the exponential distribution when the shape parameter (m) equals 1, as can be seen in the diagram above.

The various exponential distribution functions are described below.

1) Reliability function

$$R(t) = exp[-\lambda t]$$

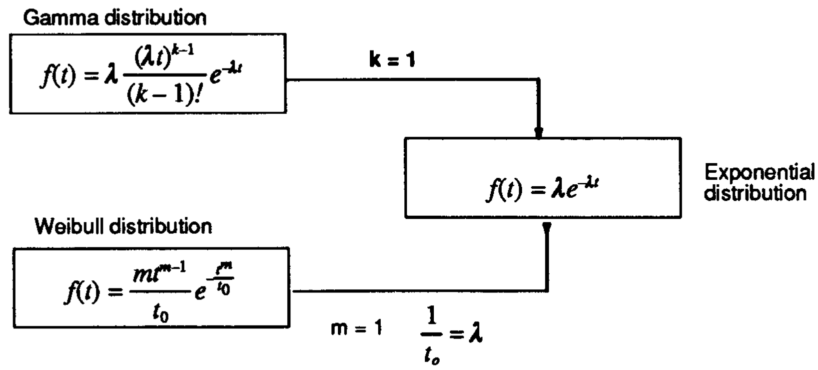
2) Failure probability density function

$$f(t) = \frac{d[1-R(t)]}{dt} = \lambda exp[-\lambda t]$$

3) Instantaneous failure rate

$$\lambda(t) = \frac{f(t)}{R(t)} = \lambda(constant)$$

Functions of Exponential and Other Distributions



5–3–4 Normal Distribution

Failures do not all occur at a single time in the wear-out period, they tend to occur following the distribution shown on page 107.

This can be expressed in terms of the Weibull distribution when m>1 or using the normal distribution if dispersion is considered.

The various normal distribution functions are described below.

1) Reliability function

$$R(t) = \frac{1}{\sigma\sqrt{2\pi}} \int_t^{\infty} e^{-\frac{(t-\mu_1)^2}{2\sigma^2}} dt$$

2) Failure probability density function

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(t-\mu_0)}{2\sigma^2}}$$

3) Instantaneous failure rate

$$\lambda = \frac{f(t)}{R(t)}$$

It is important to know if the life-expectancy is expressed in terms of the number of surviving items or in terms of the average life-expectancy, as shown in the diagram on page 106.

Note that the life-expectancy of relays is normally expressed in terms of 95% surviving items, but some manufacturers quote the life-expectancy of some types of relay in terms of the average life-expectancy.

5–4 Designing Product Reliability

This section describes the philosophy and some of the methods used to design the use reliability of a product (*described in Section 5–2–5*).

5–4–1 Procedures of Reliability Design

1) Determine the Design Specifications

Specify the degree of reliability in the design specifications, from the requirements on the relay, the product functions, operating conditions, and environmental conditions.

2) Assign the Reliability

Consider the requirements on the system and set target reliability values for the system, subsystem, and parts.

Define the meaning of "failure" for each part, a criterion for evaluating failure, the actual method of evaluation, and the time of the evaluation.

The assignment of the reliability highlights the importance of reliability design and is an aid to establishing reliability target figures.

3) Predict the Reliability

Predict the reliability of the product being designed using product field data (also from similar products), failure rate data, and test results.

Predictions for each function block are an aid to assigning the reliability.

5-4-2 Reliability Design

Redundancy

Redundancy involves adding extra elements or stages to the component parts of a system, so that the system can still function if a part fails.

Parallel redundancy, stand-by redundancy, or majority redundancy is used, depending on the system configuration.

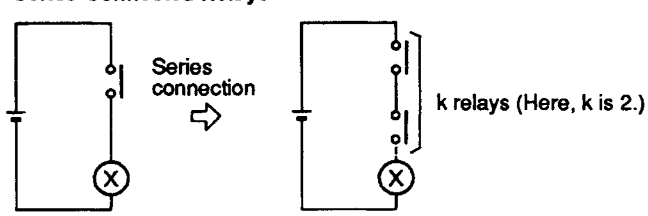
Redundancy in the case of relays is discussed below

In practice, a host of questions must be considered when connecting relays in series or in parallel, such as: How many relay contacts should be connected in series when forming a relay sequence? Do we need a twin contact here? I'd like to use the spare contacts of a multi-pole relay but it seems more trouble than it's worth. And many more.

When relays are connected in series, levels change but the number of operations remains unaffected. However, when they are connected in parallel, it is important to remember that the failure rate is dependent on the number of operations. Therefore, if a relay is to be used for a long period without replacement, use a single contact with high inherent reliability, as failure of the contact cannot be covered by redundancy in the circuit. Conversely, if the relays are to be replaced frequently, several contacts with low inherent reliability can be connected in parallel to limit the overall failure rate.

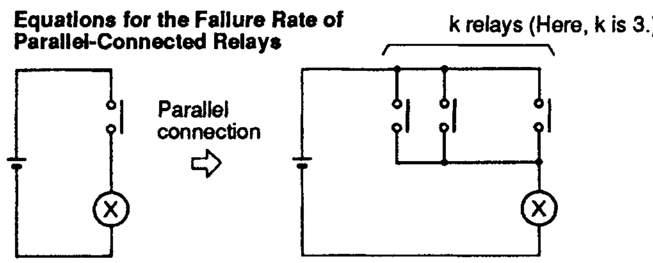
Use the equations shown in the diagram below as a guide to the actual values involved.

Equations for the Failure Rate of Series-Connected Relays



$\lambda(t) = \lambda$ $\qquad$ $\lambda sk(t) = k\lambda$

Equations for the Failure Rate of Parallel-Connected Relays



$\lambda(t) = \lambda$ $\qquad$ $\lambda pk(t) = k\lambda \dfrac{(1-e^{-\lambda t})^{k-1}}{\sum_{r=0}^{k-1}(1-e^{-\lambda t})^{r}}$

Derating

The failure rate of a part can be reduced by lowering the load and environmental stresses acting on the part. This method is known as derating.

The reduction in failure rate for an electronic or electrical part, when a load lower than the rated load is applied, can be determined from the MIL-HBDK-217 standard or other literature. This standard also covers relays.

It is more difficult to predict the failure rate reduction in a mechanical system when the load is reduced. One method is to design the life-expectancy and deterioration using S-N curves (which show the relationship between R, the repetitive stress, and N, the life-expectancy in cycles).

5-4-3 Maintainability Design

Maintenance can be carried out as preventative maintenance (before a problem occurs), after a problem occurs, or when a specific condition is fulfilled.

During maintainability design, it is important to consider various factors, such as the ability of the maintenance personnel, spare parts, maintenance manuals, maintenance policy, test facilities, and ease of maintenance.

5-4-4 Safety Design

The rate of dangerous failures can be used as the criterion to measure safety, but the hazard level used by FMECA and others is also a valuable safety measurement criterion. A hazard is defined as an actual or potential condition which may lead to death or injury to humans or damage to a machine.

The procedures laid down by FMECA and FTA can be used to predict safety levels.

Safety design requires the incorporation of some ergonomic design concepts: fail-safe design to prevent a failure of the machine causing an unsafe situation, and fool-proof design to avoid problems caused by incorrect operation or mistakes by humans.

The following points are important when using relays. Relay contacts can fail in the following modes: an operating defect (poor electrical contact, etc.), or a reset defect (fused contacts, etc.). When carrying out the safety design of relays, it is important to decide what load condition is safer, ON or OFF. For example, it may be preferable for a relay used in a traffic signal to fail in the ON condition. Conversely, it is probably safer for a relay switching a motor load to fail so that the motor does not run.

These questions must be considered along with the redundancy design decision whether to use serial or parallel connections.

5-4-5 Reliability Tests

Reliability tests are carried out to predetermine the reliability of equipment. These tests include environmental tests, life tests, failure rate tests, and accelerated life tests.

Environmental Tests

The contact environment is not determined only by where the relay is installed, but varies infinitely according to the kind of equipment in which the relay is installed and the final configuration of the system in which the equipment is used. If relays are used in a traffic system, the effects of automobile exhaust gases cannot be ignored. Similarly, in a chemical plant, the effects of the chemicals on the relays must be considered.

The main factors causing defective contact in relays are listed below.

1) Temperature and humidity

2) Sulfidizing gas

3) Organic gases

4) Dust

5) Mildew

6) Vibrations and shocks

The adverse effects of dust on electrical contact increase as the temperature rises.

Defective contact due to sandy dust particles cannot be improved by increasing the contact pressure.

When noble-metal contacts are used in an organic-gas atmosphere, friction forms polymers which can cause defective contact.

Accelerated Life Tests

The accelerated life test methods described below permit evaluation of life-expectancy and failure rate in the shortest possible time.

1) Acceleration using time

The method reduces the test time for an intermittent operation by increasing the operation frequency so that the operation is continuous.

This method is used for relays to evaluate the repetitive stress in the spring. Relay springs are designed to have sufficient tolerance, but in some cases the actual performance may differ from the design value due to the manufacturing process or the way in which the relay is used. Mechanical life testing is important to evaluate relay springs.

Both design and testing are carried out according to a minor law (such as the metal fatigue S-N curve).

2) Acceleration using stress

The method reduces the test time by increasing the stress levels, to force deterioration to occur in a shorter time. It is used to evaluate the deterioration of relay coil insulation. Unconditionally defining the coil life-expectancy is difficult because of the large fluctuations due to heating caused by currents flowing in the coil and output circuits, the effects of the external temperature, and differences due to the manufacturing process and material quality. Therefore, the coil temperature rise quoted in the product guide is used to evaluate the coil life-expectancy.

The life-expectancy is used as a guideline for the maintenance timing. Refer to *Section 9-2 Maintenance Philosophy* for details.

The design and evaluation using this method are based on Arrhenius' equation.

Reference : Predicting Life-Expectancy using Arrhenius' Equation

Chemical reactions and the deterioration of insulators can be theoretically modelled using the equation below.

$$K = Ae^{\left(-\frac{\Delta E}{kT}\right)}$$

$$K = \frac{df(\phi)}{dt}$$

where,

K : reaction rate
ϕ : characteristic value
f : function representing condition affected by characteristic value
A : experimental constant
k: Boltzmann constant
ΔE : activation energy
T : absolute temperature

In the case where the characteristic value (Ø) = a, the condition is represented by f(a), and if the life-expectancy t is denoted by L, we get:

$$lnL = C + \frac{\Delta E}{RT}$$ where C is a constant

The equation gives a relationship between life-expectancy and temperature. It can be used to predict the life-expectancy from accelerated life tests where the thermal stress is increased.

3) Other methods

Predicting the life-expectancy of relays from accelerated life tests is difficult because the environmental and other conditions under which a relay is used are not constant. Therefore, attempts are being made to develop accelerated testing techniques for this purpose.

Example of tests which compare functions and determine the degree of fluctuation are given below.

- Testing the repetitive stress relaxation and drop in strength of plastics by measuring the changes in operating and reset times when the relay is stored or carrying current continuously at high temperature.
- Testing the electrical life-expectancy at high temperature. In this test, characteristics of the relay are varied to determine if the chemical products created when the arc breaks down organic gases from the plastic materials used in the relay cause a deterioration in relay reliability.
- Thermal shock testing is used to investigate the effects of the differences in coefficients of thermal expansion between metals and plastics.
- Testing to determine the effects of various gases on relays,. The relays are evaluated after being exposed to various concentrations and mixtures of gas for a specified time.

Failure Rate Tests

A uniform method of testing is required to quantitatively determine the life-expectancy of a relay and to compare the life-expectancies of different types of relay.

After deciding to use a particular type of relay, the ideal method of confirming the reliability of this relay is to carry out actual loading tests. However, in practice, a simulation is carried out under the same conditions as the actual loading tests to estimate if the reliability is suitable or not.

The types of failure rate testing methods available are as follows:

1) Actual loading tests

2) Allen Bradley circuit

3) Transformed Allen Bradley circuit

The failure rate is calculated from the results of the failure rate tests. The reliability of different relays can be compared by assuming that all relays have the same failure rate, and comparing the actual value to the assumed value. The test results described above can be more widely applied if the failure rate is also taken into consideration.

JIS C 5003 (General Test Procedure of Failure Rate for Electric Components) specifies the following equations for the calculation of the failure rate.

If n relays are operated a number of cycles t in an Allen Bradley circuit, and the accumulated number of failures is r, then:

1) the number of component hours is given by: T = nt (cycles)

2) the point estimation of failure rate is given by: $\hat{\lambda} = \frac{r}{T}$ (cycles)

3) the failure rate for a 60% reliability level is given by: $\lambda 60 = K(r)\hat{\lambda}$ (cycles)

Coefficient K(r) Required for the Interval Estimation Value (from JIS C 5003)

Number of failures (r)	Reliability level	
	60%	90%
1	2.02	3.89
2	1.55	2.66
3	1.39	2.23
4	1.31	2.00
5	1.26	1.85
6	1.22	1.76
7	1.20	1.68
8	1.18	1.62
9	1.16	1.58
10	1.15	1.54

Actual examples for relays are given below.

1) Test results from Allen Bradley circuit

a) Difference according to circuit voltage (Table 1)
b) Difference according to contact type (Table 2)
c) Difference according to relay type and atmosphere (Table 3)

Table 1 Difference According to Circuit Voltage (A : single contact)

Type	Circuit voltage	$\lambda 60$ (x 10^{-6} / cycle)	Comment
A	6 VDC	0.0764	n = 20
	24 VDC	0.0114	

Table 2 Difference According to Contact Type (A : single contact, B : twin contact)

Type	Circuit voltage	$\lambda 60$ (x 10^{-6} / cycle)	Comment
A	100 VAC	0.0123	n = 20
B		0.00317	

Table 3 Difference According to Relay Type and Atmosphere (B : encapsulated, C : plastic-sealed)

Type	Atmosphere	Circuit voltage	$\lambda 60$ (x 10^{-6} / cycle)	Comment
B	Sandy dust, 6 hours	100 VAC	12.5	n = 10
C			0.0368	

2) Test results from Transformed Allen Bradley circuit

a) Difference according to contact material and type (Table 4)
b) Difference according to contact type and switching current (Table 5)

Table 4 Difference According to Contact Material and Type

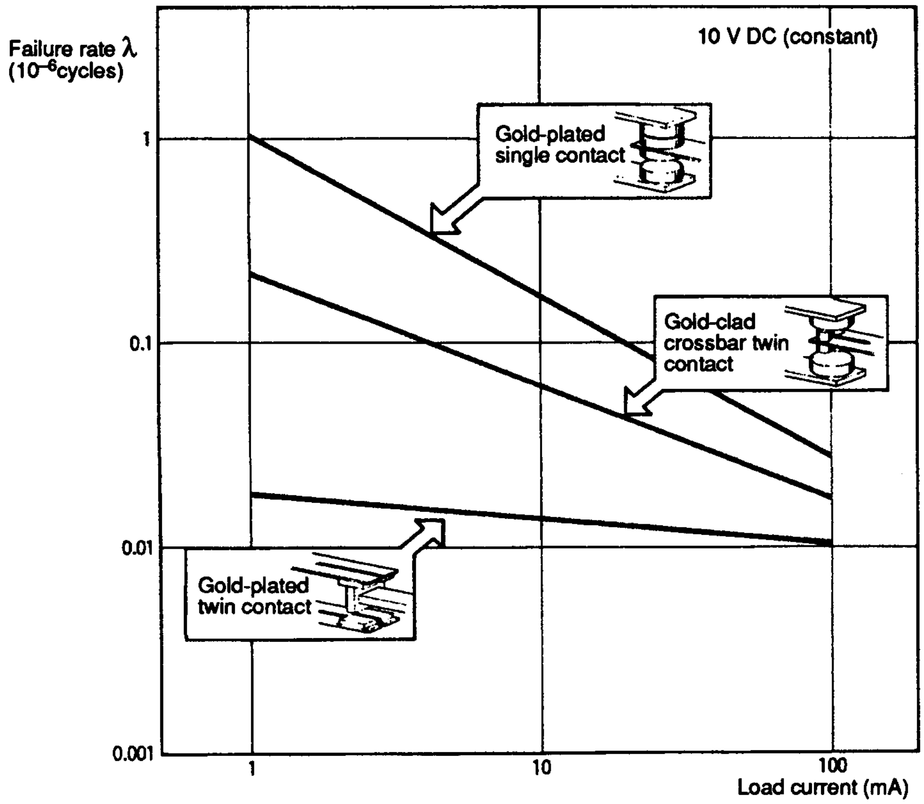
Type	Contact		λ60 (x 10 $^{-6}$ / cycle)	Comment
	Moveable	Fixed		
D	Au-P	Au-P	(μ=710,000 operations)	n = 10 10 V DC, 1 mA 100 Ω detector
E	Au-P	Au-P	(μ=3.600,000 operations)	
F	Au	Au	0.104	
G	Au	Ag	0.0092	
H	Au	AgPd60	0.00368	
I	AgPd60	AgPd60	(μ=650,000 operations)	

Note 1. μ: Average life-expectancy (in the mechanical abrasion failure region)
2. Au-P : gold plating, Au : gold cladding
3. D : single contact, E : twin contact

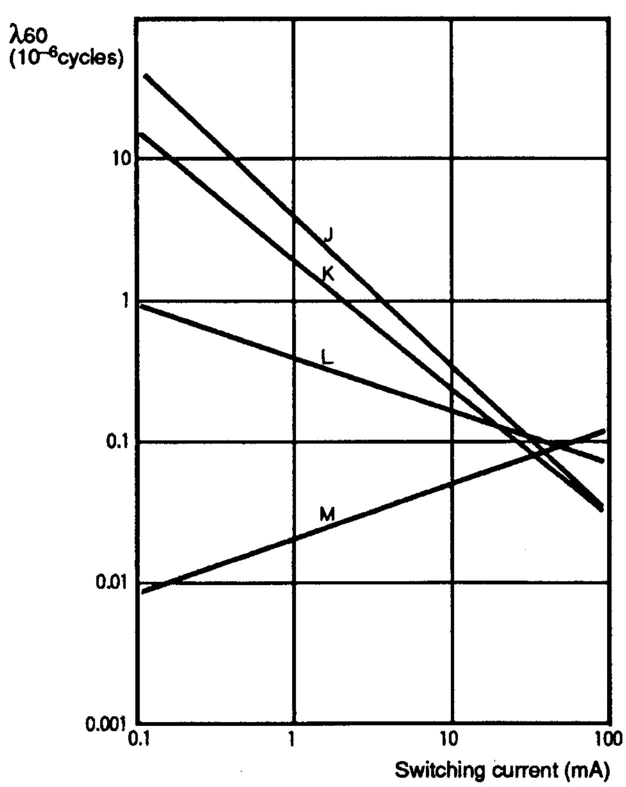
Table 5 Difference According to Contact Type and Switching Current

Type	Contact		λ60 (x 10 $^{-6}$ / cycle)				Comment	
	Moveable	Fixed	0.1 (mA)	1	10	100		
J	Ag	Ag	87.1	3.37	0.26	0.028	—	n = 10 10 V DC, 1 mA 100 detector
K	Au-P	Au-P	11.9	1.30	0.804	0.028	—	
L	Au-P	Au-P	0.804	0.498	0.387	0.038	Twin contacts	
M	Ag	Ag	0.0084	0.018	0.057	0.095	Hermetically sealed construction	

Relationship of Contact Shape to Failure Rate



Relationship of Switching Current to Failure Rate



SECTION 6
Increasing Relay Reliability

6–1 Operation and Wiring

6–1–1 Operation

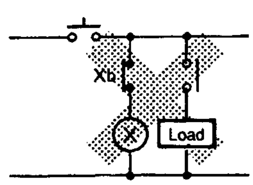
Applying Voltage for a Long Period

A DC-operated relay is most appropriate for a circuit where the voltage is continuously applied to a relay coil for long periods. If an AC-operated relay is used, the losses in the copper parts are compounded by losses in the iron parts (hysteresis losses in the magnetic materials, for example), causing a large temperature rise. Therefore, a DC-operated relay is preferable as it reduces the temperature and buzzing in the control panel.

Latching Relays

Consider the following important points when using a latching relay:

- Do not apply a voltage simultaneously to the set coil and reset coil.
- Do not use latching relays with a power supply which is subject to frequent surges.
- Relays are delivered in the reset condition, but we recommend that the reset voltage be applied before starting operation.
- When a diode is connected in the circuit, external noise and surges must be taken into account for the negative peak reverse voltage and the DC reverse voltage. The average rectification current of the diode must exceed the coil current.
- Excitation with contacts in the latching relay itself may not latch the relay normally. Avoid using a latching relay in a circuit such as the one shown in the diagram below.

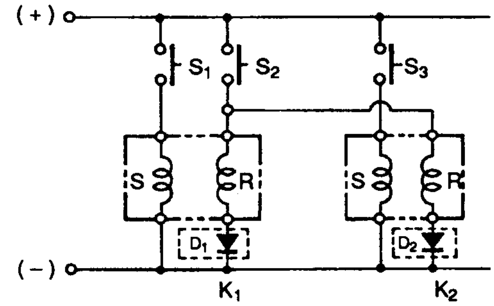


(X) Latching relay
Xb NC contact of relay

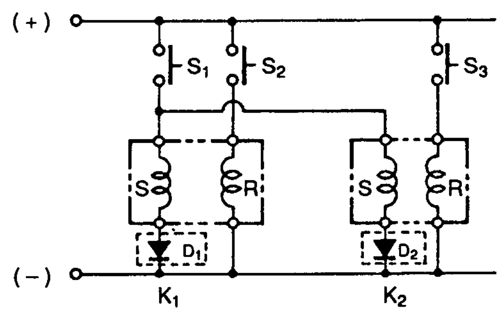
- The latching operation may be lost when the types of circuits shown below are used for DC operation. To overcome this problem, connect a diode (at position D in the following circuit diagrams), modify the circuits, or use a latching relay with a built in diode.

Circuit Diagrams

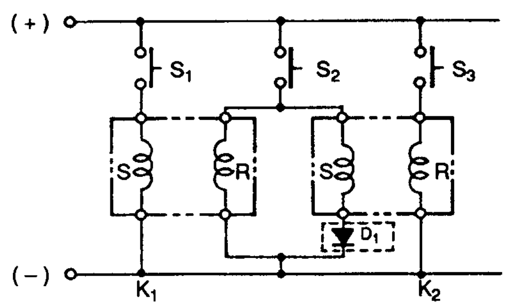
Circuit connecting two reset coils in parallel



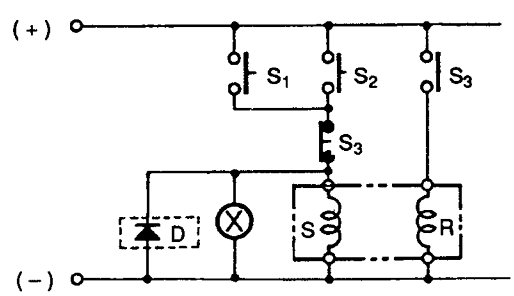
Circuit connecting two set coils in parallel



Circuit connecting set coil to reset coil



Circuit connecting set coil in parallel with the coil of another relay

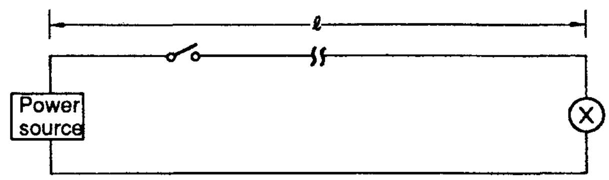


6–1–2 Wiring

Take care of the points outlined below when operating the relay through long cables:

- Even if the rated voltage is applied to the cables, the rated voltage may not be applied to the relay coil terminals because of losses due to the wiring impedance (with AC operation) or the wiring resistance (with DC operation). This voltage drop may result in non-operation of the relay, increased contact bounce, and drop in the relay performance

This problem can be overcome simply by increasing the supply voltage. However, in cases where it is not possible to increase the supply voltage, a limit length of the cables must be set in advance.



Guide for Cable Length Limits

Item		Coil relay	
		DC	AC
Precondition		Operating voltage permitted up to 90% of the rated voltage.	
Calculating cable length	Symbols	Rr: coil resistance R: resistance per unit length of cable ℓ: limit of cable length	Zr: coil impedance R: resistance per unit length of cable ℓ: limit of cable length
	Formula	$\ell = \frac{Rr}{9R}$	$\ell = \frac{Zr}{9R}$ Formula for cable lengths up to about 3 km.
Example: Type MY4 relay		DC 24 V operation of MY4 with CVV cable $\ell = \frac{650}{9 \times 0.017} = 4.248m$ Solution: Keep cable length within approximately 4.2 km.	AC 100 V, 60 Hz operation of MY4 with CVV cable $\ell = \frac{\frac{100}{0.012}}{9 \times 0.017} = 54,466m$ Solution: Value over 3,000 m, so operation possible up to 3 km.

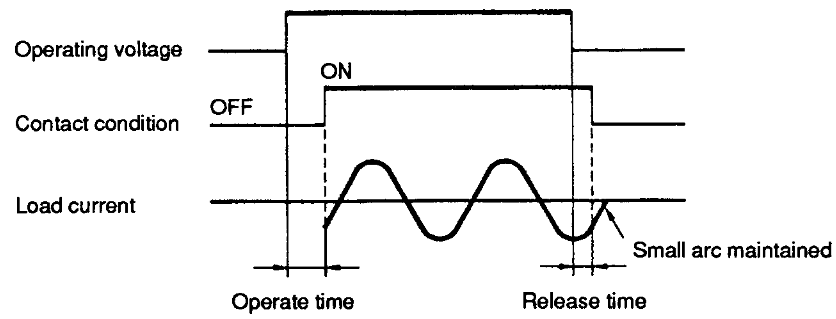
- Because of effects due to induced voltages, in some cases the relay will not reset correctly if the relay operation cables run parallel to AC power cables. If the AC power cables drive a large motor, the voltage induced in the operation cables may be sufficient to operate the relay.

6–2 Precautions about Load Switching

Switching AC Loads

If an AC load is switched in synchronization with the current phase, metal deposition of the contacts occurs, as when switching a DC load.

On the other hand, a method of switching exists to force the contacts to switch the load near the phase zero point, as shown in the following diagram. However, with this method it is necessary to ensure stable relay operation over a long period and to carry out switching at random positive and negative phases.



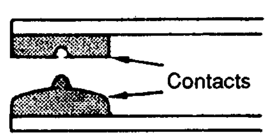
Switching DC Loads

When switching a DC load, the arcing can be reduced compared to a single contact by connecting the contacts in series, which forms the equivalent of a larger contact gap.

When the relay is used to break a DC inductive load, the inductance of the load generates a high voltage. The use of an absorber is recommended to prevent this high voltage causing malfunction of nearby electronic circuits.

A bluish-green residue may be formed inside the relay case when a relay is used to break a DC load. This residue is formed by arcing, which combines nitrogen from the air with hydrogen from water vapor, to produce nitric acid. Relay types MMX and G7X, which are intended for DC operation only, have a hole in the case to allow harmful gas to escape to the atmosphere.

Metal deposition caused by DC switching operation can cause unevenness of the contact surfaces. These uneven surfaces may lock together so that the relay cannot reset.



Metal deposition is the indentation of one contact surface and build-up of metal on the other due to localized melting, evaporation, and chemical changes at the contact surface, resulting from heat generated at the contacts.

This problem can even occur when switching loads less than the rated current of the relay contacts. Practical testing is required to check the relay under actual load conditions.

Serial and Parallel Connection of Contacts

Serial Connection

Normally, the contact clearance has to be increased as the voltage and current switched by a relay increases. The dual benefits of increasing the contact clearance and effectively increasing the break speed can be obtained by connecting the contacts in series. This reduces the arc duration time and reduces wear and fusing of the contacts. This reduction is especially significant when switching DC loads.

However, the actual conditions should be determined by practical testing because of possible effects due to load conditions, discrepancies in contact operation, contact bounce, etc.

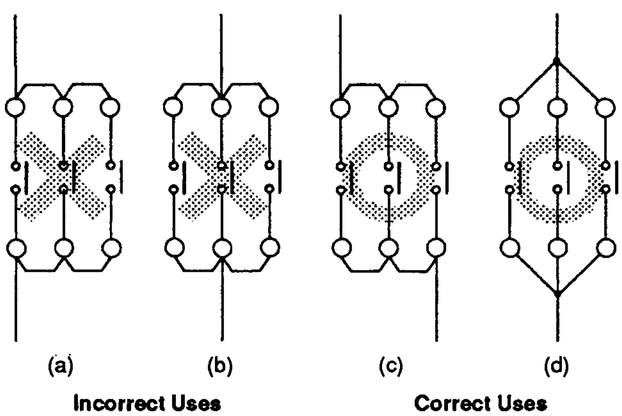
Parallel Connection

Under ideal conditions, it would appear that connecting relays in parallel should increase the switching capacity, make capacity, and break capacity by the number of relays connected. However, in practice, this system is easily affected by a number of factors, including contact resistance and resistance unbalance in the contacts, discrepancies in contact operation, and contact bounce. Practical testing is required to check the actual performance of relays connected in parallel.

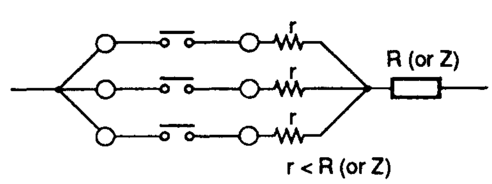
In particular, the make and break capacities should be considered as equal to the capacities of a single relay because the parallel-connected contacts do not open and close in precise synchronization. Therefore, the circuit is made by the first contacts to close, and broken by the last contacts to open.

The method of connection (c) or (d) in the diagram below should be used, to distribute the load equally between all connected relays.

Parallel Connection of Contacts



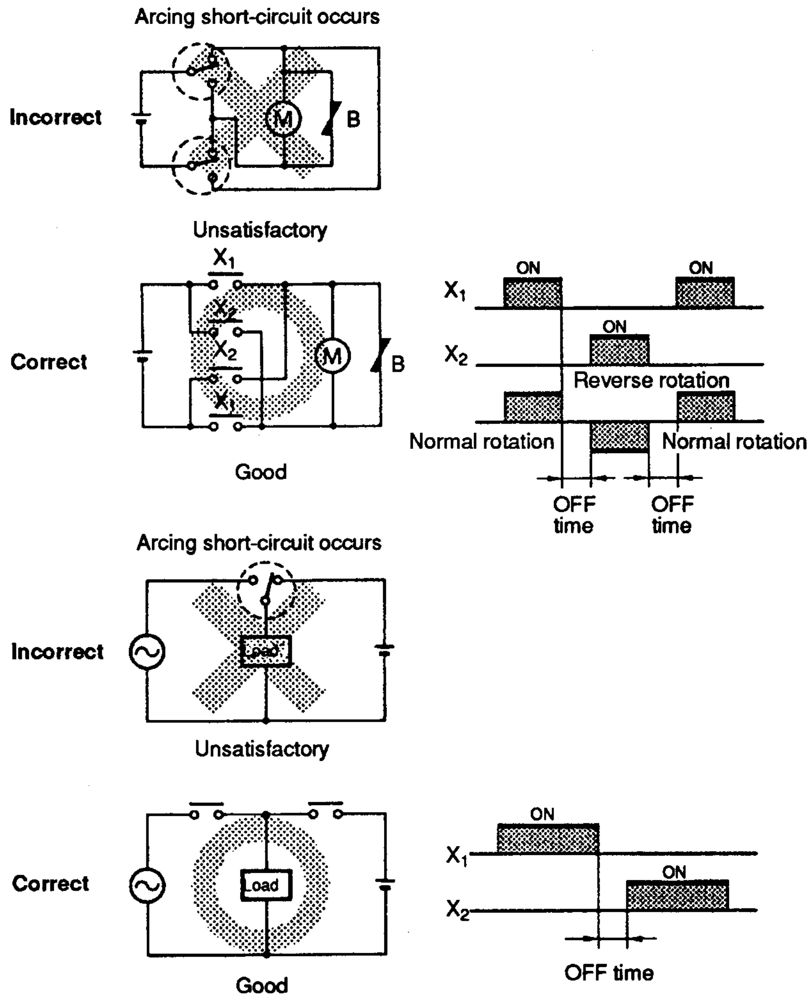
Method to Equalize Load Distribution



However, to minimize effects arising because the contact resistances of the relays are not equal and fluctuate during use, connect the largest possible resistance that does not interfere with the load conditions in series with the contacts of each relay, as shown in the lower diagram. This equalizes the load distribution between the relays and increases the switching capacity.

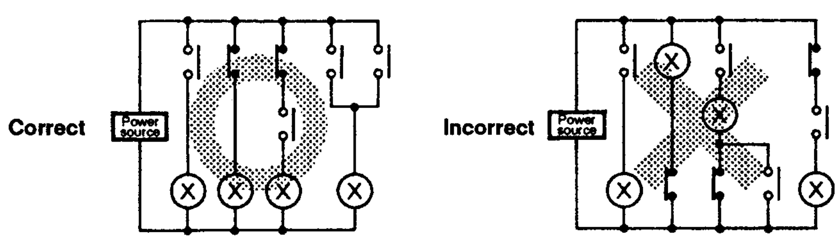
Power Supply Switching

When switching a number of different power supplies or switching power supply polarity, use more than one relay with sufficient time lag to prevent short circuiting of the power supply.



Connecting Loads

When connecting a load to relays, connect the load to the same side of all relays (as shown in diagram (a)), not to both sides (as in diagram (b)). Adjacent contacts are all at the same potential, which eliminates the danger of short circuiting. However, if a short-circuit does occur between adjacent contacts, the power supply is protected, and not shorted out.



(a) (b)

6–3 Caution Regarding the Operating Environment

Environmental Damage to Contacts

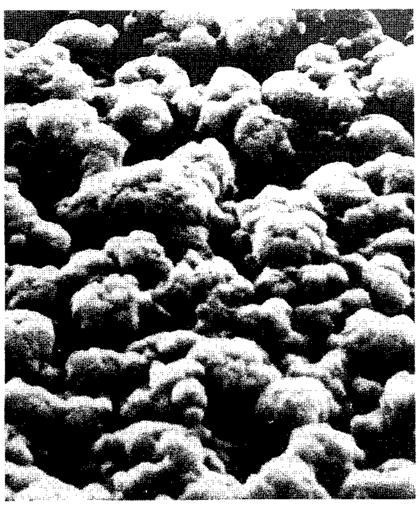
Under some conditions, the relay contacts deteriorate if the relay is simply stored without being used. For example, the contacts may be affected by sulfur or chlorine in the atmosphere, as shown in the table below.

If relays are to be stored for several years before use, choose relays with gold-plated or gold-clad contacts, or measure the switching capacity of the relays before they are dispatched.

The following table and photographs show the deterioration of silver contacts after storage for 12 months at three different locations.

Location	Detected elements	Result
Chemical plant	Ag, S	Fine corrosion product evenly distributed over entire surface of contacts. Revealed as Ag_2S by analysis.
Iron mill	Ag, S	Irregular film over the entire surface of the contacts with occasional pillar-shaped crystals. Revealed as Ag_2S by analysis. The thickness of the film was about 100 Angstroms.
Highway	Ag, S, Cl	Minute spherical crystals scattered on surface. Occasional extremely thin (20 Angstroms) film of Ag_2S.

Chemical Plant



Highway

Iron Mill

Operating Temperature, Voltage

In addition to the normal changes in operating characteristics when the relay is used at high temperatures, other problems may also occur, such as loosening of tightened parts due to the deterioration and thermal deformation of materials in the relay, or defects caused by organic gases or oxidation of the contacts. Malfunction may also result from permanent deformation of the contact spring.

At very low temperatures, the lead loses flexibility, the operating characteristics change due to reduced coil resistance, and ice crystals on moving surfaces can cause malfunction.

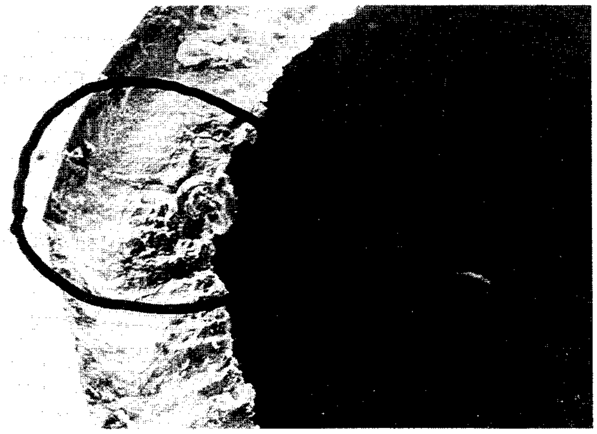
Operation in a high-humidity environment can lead to deterioration of the insulating materials due to water absorption by hygroscopic materials used in the relay, discontinuities in the coil caused by electrolytic corrosion, or rusting of metal parts.

Dust and Harmful Gases

Defective electrical contact can result from dust sticking to the contact surface, or non-conducting oxide and sulfide films on the contact surface caused by reactions with harmful gases.

The harmful gases in the atmosphere can also induce stress corrosion cracks and rusting.

Stress Corrosion Cracks



Iron particles in the atmosphere can cause the relay to malfunction by sticking to the attraction face of the core.

Mounting Direction

The operating characteristics of a relay depend on the orientation in which the relay is mounted. This effect is not significant if the mass of the moving parts is small, but becomes extremely large for relays with heavy moving parts, such as a plunger relay or a heavy-duty relay.

Deterioration of the insulation or defective electrical contact can occur more easily if the relay is mounted in certain orientations, so that the relay may not operate for its specified life expectancy.

If a mounting direction is specified for a relay, always mount the relay as specified.

Mounting Density

If relays are high-density mounted over a surface, the relays nearest the center will tend to become hot because of the heat generated in the relays themselves and in nearby relays, which can cause relay malfunction or burning of the coil. In this situation, cool the relays by improving ventilation or force-cooling them with a fan.

Vibrations and Shocks

The vibrations and shocks produced by heavy-duty switches or solenoids mounted on the same panel as relays can cause relays to malfunction. In this case, move relays further from the offending switch or solenoid, mount the relays on a separate panel, or attach a vibration-damping material. Alternatively, mount the relays such that the direction of operation is perpendicular to the direction of the vibrations and shocks.

6–4 Cautions during Relay Handling and Use

6–4–1 General-Purpose Relays (all Types)

General Handling

To maintain the initial performance, be careful not to drop the relay or apply a shock to it.

The case is constructed not to come off during normal handling. To maintain the initial relay performance, do not remove the case.

Use the relay in a dry atmosphere with low levels of dust and organic gases, such as SO_2 or H_2S.

Do not continuously apply a voltage larger than the maximum permissible voltage.

Be sure to correctly connect the polarity of a relay with specified + and – terminals, such as a DC-operation relay with a built-in diode or indicator lamp. The polarity can be connected either way if it is not specified.

Do not operate the relay with a voltage or current greater than the specified value.

Do not use the relay in temperatures exceeding the ambient temperature specified in the catalog.

If a general-purpose relay is used or stored for a long period of time in conditions of high temperature and humidity or in an atmosphere containing hydrogen sulfide gas, an oxide film and sulfide film will form on the surfaces of the contacts. As the contact force in a miniature relay is too low to mechanically destroy the films, and because the arc when switching very low loads is too weak to break them down electrically, these films can lead to a unstable electrical contact and deterioration of performance and functions of the relay. For these reasons, plastic-sealed or hermetically sealed relays should be used in atmospheres of harmful gases (H_2S, SO_2, NH_3, Cl_2, etc.) or in dusty conditions.

The contact ratings recognized in the various industrial standards may differ from the general ratings. It is important to check the ratings of the relay and socket when combining relays with various types of sockets.

Operating Coils

AC-Operated Relays

The power supply used to operate a relay is almost always at the commercial frequency (50 or 60 Hz). Standard voltages are 6, 12, 24, 48, 100, and 200 V AC. Relays for voltages other than the standard voltages must be custom made, with resulting higher costs and longer delivery period. Therefore, it is advisable to select standard-voltage relays if possible.

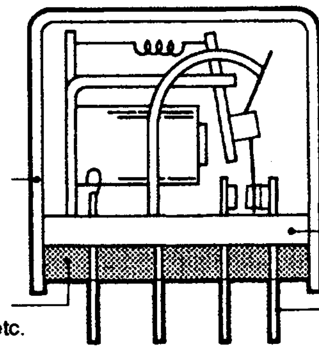
When a relay is operated with an AC voltage, losses occur due to the resistance of the shading coil, eddy-current losses in the magnetic circuit, and hysteresis losses. These losses, combined with a higher input voltage, normally cause a larger temperature rise than with DC operation. In addition, operating voltages below the minimum operating voltage (must-operate voltage) cause the relay to buzz. For these reasons, attention must be paid to fluctuations in the power supply voltage.

For example, if the power supply voltage drops when a motor is started, the self-holding function may cancel, or the relay may buzz and reset, causing burning or fusing of the contacts. With AC operation, an inrush current may flow when the relay is operated. The impedance is low when the armature is separated from the coil, so that a current higher than the rated current flows; the impedance is high when the armature is in contact with the coil, and the rated current flows. This factor must be taken into account with the power consumption when a number of relays are connected in parallel.

DC-Operated Relays

DC-operated relays may operate either with reference to the power supply voltage or to the power supply current. Rated coil voltages for voltage operation are 5, 6, 12, 24, 48, and 100 V DC. The rated current of relay for current operation is listed in the catalog as a certain number of milliamperes (mA).

6-4-2 Plastic-Sealed Relays



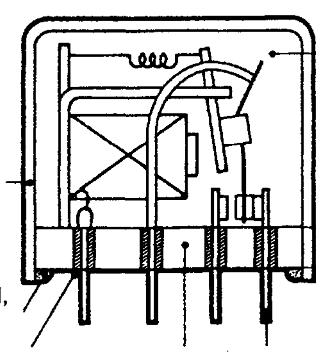
The plastic-sealed relay is of simple construction. The relay is contained in a plastic case and all air passageways between the case and terminal block and between the terminals and terminal block (base) are sealed with epoxy resin.

The following points are important to ensure that the sealing is maintained:

- Normal use at low altitude presents no problems, but avoid use in atmospheric pressures outside the range 1,013 mb ±20%.
- The relays can be immersion-cleaned using Freon TE or Freon TF as the cleaning agent. However, try to avoid this cleaning method as Freon gas is known to be harmful to the Earth's ozone layer.
- The sealing of the plastic case or resin-sealed parts may be destroyed by heat from soldering or overheating of the terminals.

The sealing methods used for plastic-sealed relays are very simple, therefore this type of relay is not suitable for use in environments and locations demanding a high level of sealing. Hermetically sealed relays must be used in a flammable or explosive atmosphere.

6-4-3 Hermetically Sealed Relay



The relay is contained in a sealed metal case which is filled with an inert gas, such as nitrogen. The air passageways between the metal case and terminal block are sealed with solder, and the gaps between the terminals and terminal block are sealed with glass, to provide a high level of sealing, durability, and insulation.

However, if the relay is subject to steam, water droplets, or condensation after freezing, the insulation resistance of the glass which insulates the terminals can drop to the point where the terminals short-circuit and the relay malfunctions.

Take particular care not to drop a hermetically sealed relay as the relay mechanism and metal terminals inside the case cannot be visually inspected. The relay will not operate correctly if it is used with the internal mechanism deformed or moveable parts displaced.

If a hermetically sealed relay is to be mounted on a printed-circuit board, design the printed circuit such that no short-circuiting occurs between it and the metal case of the relay.

6–5 Important Points about Circuit Design

6–5–1 Coil Operating Voltage

Both long-term and instantaneous fluctuations in the power supply voltage can cause a relay to malfunction.

If the power supply capacity is insufficient when a large solenoid, relay, motor, or heater is connected to the same power supply as a relay, or a large number of relays are used from the same power supply, the relay may not operate due to the voltage drop, when several items switch simultaneously. Conversely, if the supply voltage is increased to accommodate the anticipated voltage drop, this high voltage can cause overheating of the relay coil if no voltage drop occurs.

Therefore, the power supply must have sufficient capacity to drive all items connected to it, but the supply voltage must lie within the operating voltage range of the relay.

Lower Limit of the Must-Operate Voltage

With a DC-operated relay in particular, when the relay is used in a high-temperature environment, or the coil temperature rises due to a continuously applied voltage, the coil resistance rises, causing an increase in the must-operate voltage. Therefore, a minimum value of the power supply voltage must be set to avoid problems.

Refer to the example below when designing a relay power supply.

If the coil temperature rises by 10°C, it causes a 4% increase in coil resistance and a related increase in the must-operate voltage.

The rated values from the catalog for an MY4 relay are as follows:

Rated voltage: 24 V DC

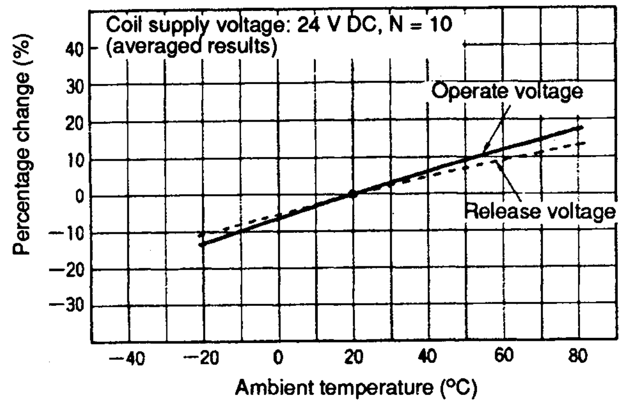
Coil resistance: 650Ω

Must-operate voltage: 80%, or less at a coil temperature of +23°C

The rated current of this relay is 39.6 mA (24 V/ 650 Ω), giving a must-operate current value of 29.5 mA (39.6 mA x 0.80), or less.

If the coil temperature now rises 10%, the coil resistance becomes 676 Ω (650 Ω x 1.04). To cause a current of 29.5 mA to flow through the coil now requires an applied voltage of 19.9 V (29.5 mA x 676 Ω). Therefore, the must-operate voltage at a temperature of 33°C (23°C + 10°C) is 83.1% (19.9 V/24 V) of the rated voltage, which is a higher proportion than at a coil temperature of +23°C.

Relationship of Coil Temperature to Must-Operate and Reset Voltage



Equation to determine the lower limit of the must-operate voltage.

$$E_T > E \times \frac{Epv + 5}{100} \times \left(\frac{T - Ta}{234.5 + Ta} + 1 \right) \quad [V]$$

where,

E: coil rated voltage (V)
Epv: must-operate voltage
Ta: temperature at which Epv was determined. +23°C unless otherwise specified.
T: operating ambient temperature (°C)
E_T: lower limit of the must-operate voltage

Note The equation above is valid if the coil temperature equals the ambient temperature. If the coil temperature is higher due to the switching current, the T = coil temperature.

Upper Limit of the Must-Operate Voltage

Ensure that the upper limit of the relay must-operate voltage does not exceed the maximum permitted voltage value given in the catalog. The maximum permitted voltage is determined by the coil temperature rise, thermal resistance of the coil insulating materials, electrical and mechanical life expectancies, and the general characteristics of the relay. Deterioration of the insulating materials and burning of the coil may result if the applied voltage exceeds the maximum permitted voltage, and the relay may no longer operate with its original characteristics.

In practice, it is possible that the applied voltage may exceed the maximum permitted voltage because of fluctuations in the supply voltage. This is permitted provided that the following conditions are met:

- The coil temperature must not exceed the thermal resistance of the spool and the windings, which provide the coil insulation. The coil temperature upper limits of the most common winding insulation materials are shown in the table below.

Winding insulation material	Coil temperature upper limit
Polyurethane (UEW)	120°C
Polyester (PEW)	130°C

The values in the table were determined from the equation shown below.

Equation to calculate the coil temperature rise:

$$t = \frac{R_2 - R_1}{R_1}(234.5 + T_1) + T_1 \qquad [°C]$$

where,

R_1: DC resistance of coil at before current flow (Ω)
R_2: DC resistance of coil after current flow (Ω)
T_1: Coil temperature (ambient temperature) before current flow (°C)
t: Coil temperature (ambient temperature) after current flow (°C)

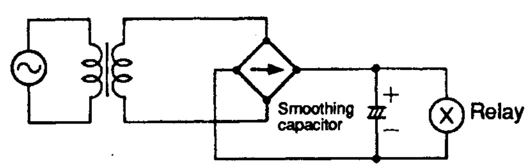
- No problems occur in the machine or equipment in which the relay is used.

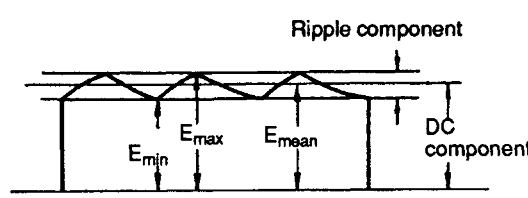
Percentage Ripple (DC-operated relays)

All rated values listed in catalogs are measured using a DC power supply with a percentage ripple of 1%, or less. Using the relay with a power supply having a higher percentage ripple can cause the rated values to differ, a vibrating sound from the relay, incomplete operation, large discrepancies in reset time, and reduced life expectancy.

If the power is supplied from a rectifier, do not let the percentage ripple exceed 5%. Provided that the percentage ripple does not exceed 5%, the pulsating current effects can be ignored and the relay characteristics should be virtually unimpaired.

The safest procedure when designing the rectifier circuit is to experimentally measure the capacity of the smoothing capacitor. As a rough guideline, the smoothing capacitor for a single, miniature relay rated at about 1 W, should be at least 5 µF.

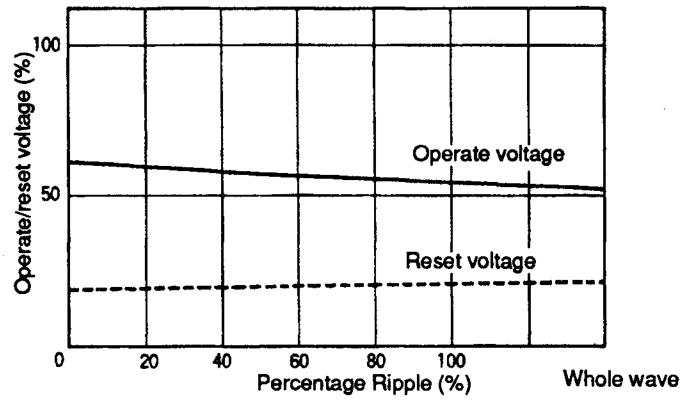




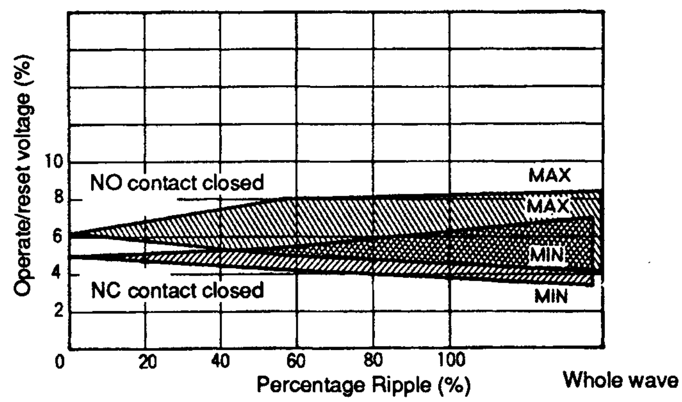
Percentage ripple = $E_{max} - E_{min}/E_{mean}$ x 100%
where,

E_{max}: maximum value of ripple component
E_{min}: minimum value of ripple component
E_{mean}: mean value of DC component

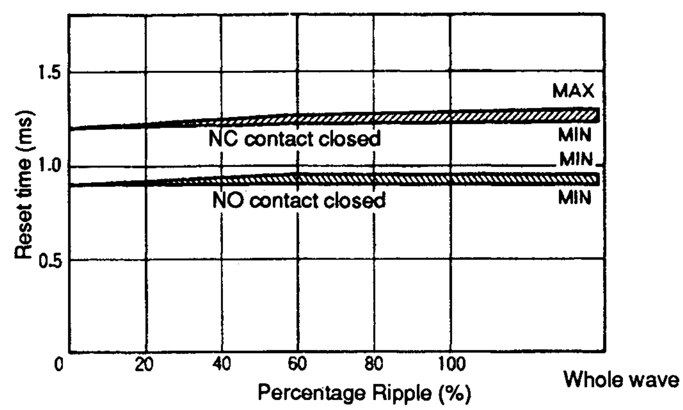
Example of Relationship of Percentage Ripple to Must-Operate and Reset Voltages



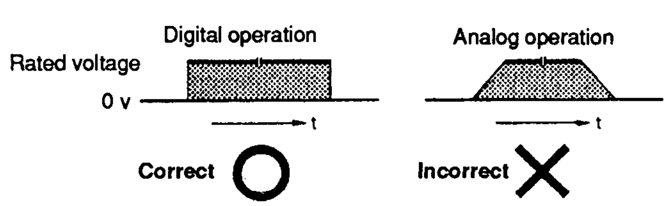
Example of Relationship of Percentage Ripple to Operating Time



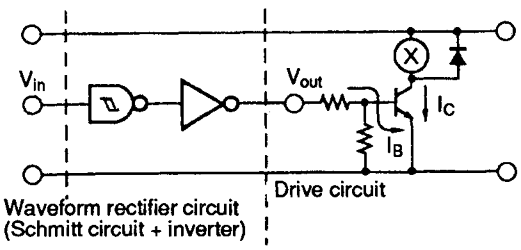
Example of Relationship of Percentage Ripple to Reset Time

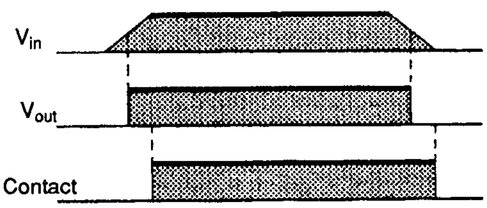


Method of Applying Voltage Apply the operating voltage to the relay as a digital signal. If the voltage is applied as an analog signal, the lower contact switching speed reduces the switching capacity.



If the rise time or breaking time of the relay operation signal is too long, insert a Schmitt circuit before the relay to rectify the signal.





Note A residual voltage remains at the output if the Schmitt circuit is made from a combination of transistors. Therefore, check that the correct rated voltage is applied across the relay coil and that the voltage drops complete to zero when the relay is reset.

Voltage Across the Coil when the Relay Turns ON and OFF

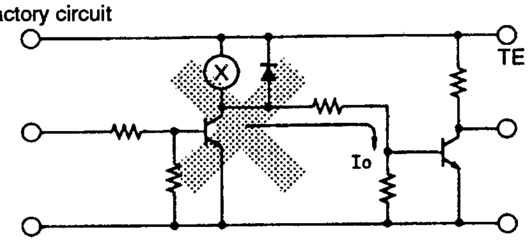
In some cases the relay will not turn OFF because of the semiconductor leak current. The voltage across the coil should be zero when the relay is reset. Make sure that the applied voltage, when the relay is reset, does not exceed 1/2 of the reset voltage listed in the catalog.

Conversely, the voltage drop in the semiconductor (across a transistor C-E junction, for example), when the relay is turned ON may result in insufficient voltage being applied to the coil for the relay to operate. This problem is particularly common for low voltage circuits under 6V.

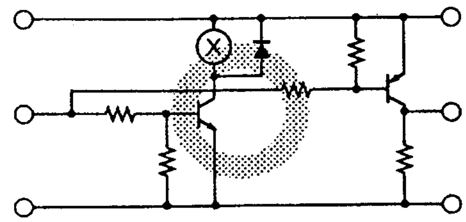
Care is required with the circuit design if another signal is to be output at the same time the relay operates. If the circuit is not well designed, the leak current (I_O) can flow into the relay coil, leading to the relay resetting incorrectly and reduced tolerance to shocks and vibrations. Always use a well designed circuit, such as the lower circuit shown in the following diagram.

Dark Current when Relay Is OFF

Unsatisfactory circuit



Good circuit



Inputting a Pulse to a Relay

The relay may not operate if the signal to operate the relay is input as an extremely short pulse. The input pulse must be maintained for at least the minimum operating time of the relay.

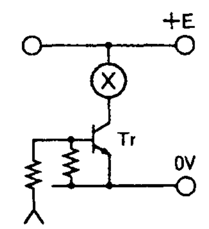
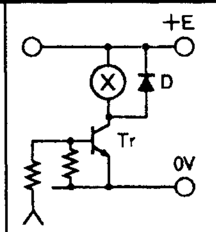
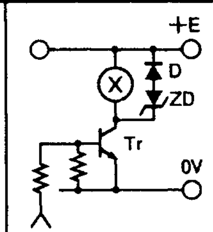
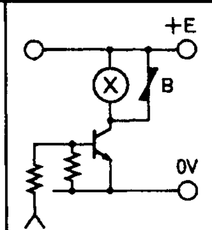
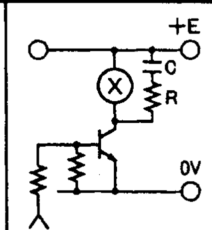
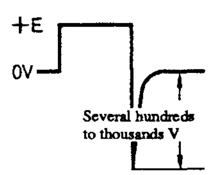
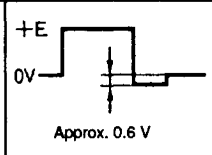
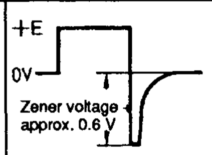
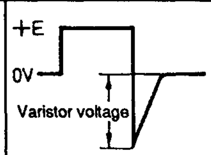
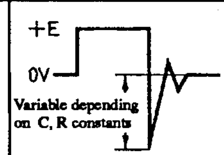
Instantaneous Power Failure

In relay applications where the power is applied for a very short time or intermittently (for example, an input from a moving object through a slip ring and brushes) an instantaneous power failure can cause the relay to malfunction.

6–5–2 Surge Absorber Circuit

A counter electromotive force of several hundred to several thousand volts is generated across the relay coil when the power to the coil is cut off. This voltage is quite sufficient to destroy transistors used in the drive circuit and to produce electromagnetic waves which can cause nearby circuits to malfunction. A surge absorber circuit is required to prevent these problems.

General Surge Absorber Circuits

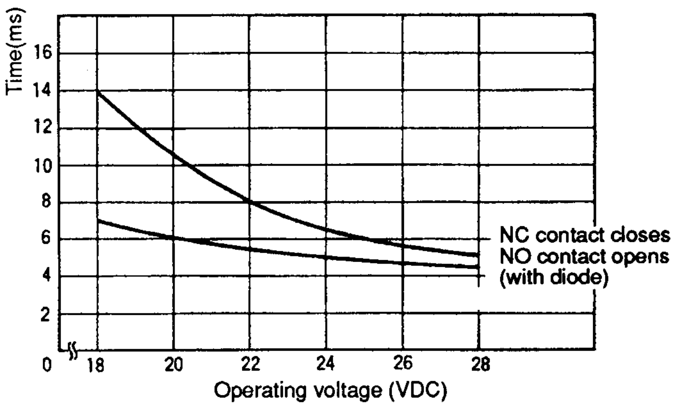
Components	No surge absorber	Diode	Diode + Zener	Varistor	C + R
Connection	 ON/OFF signal	 ON/OFF signal	 ON/OFF signal	 ON/OFF signal	 ON/OFF signal
Switching surge (across coil)					
On relay reset	Standard (catalog value)	2 to 6 times	• Little change if Zener voltage > power supply voltage	• Little change	• Little change if C, R constants suitable
Advantages, disadvantages	• Surge must be reduced by decreasing the transistor cut-off time (> 1 ms).	• Large surge absorption effect • Simple circuit • Long reset time	• Use if reset time too long using circuit with diode only.	• Simple handling, varistor has no polarity • Precautions required against varistor deterioration	• Constants have to be determined according to type of relay.
Rating of surge absorber element	—	• Reverse dielectric strength > Max. supply voltage • Forward current ≥ Relay coil current • Avalanche diode recommended.	• Diode ratings as in column to left. • Zener ratings • Zener voltage = Supply voltage • Forward current ≥ Relay coil current • Permitted losses ≥ Zener voltage x relay coil current	• Varistor voltage > Max. supply voltage	• R ≒ Relay coil resistance ≥ R permitted power Relay power consumption • Determine C value experimentally • C with no polarity recommended
Rating of drive transistor	No suitable transistor available unless switching speed reduced.	V_{CEO} > Max. supply voltage V_{CBO} > Max. supply voltage I_C > Relay coil current P_C - see note below	V_{CEO} > Supply voltage drop + Zener voltage + 0.6 V_{CBO} > Supply voltage drop + Zener voltage + 0.6 I_C > Relay coil current P_C - see note below	V_{CEO} > Max. supply voltage + varistor voltage V_{CBO} > Max. supply voltage + varistor voltage I_C > Relay coil current P_C - see note below	V_{CEO} > Max. supply voltage + varistor voltage V_{CBO} > Max. supply voltage + varistor voltage I_C > Relay coil current P_C (see note below)

Note Minimum values or V_{CEO}, V_{CBO}, and I_C are listed here. In practice, a safety factor should be added to these values.

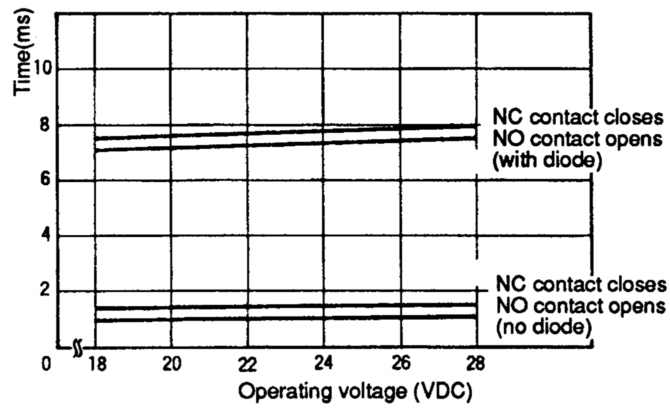
6-5-3 Applications

Drive using a Transistor

Example of Operating Voltage to Operating Time

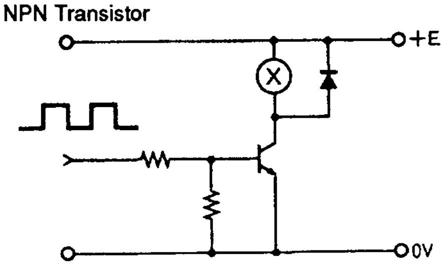


Example of Operating Voltage to Reset Time

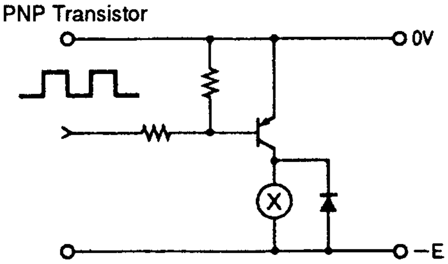


It is recommended that the emitter should be grounded when using a transistor to drive a relay.

NPN Transistor



PNP Transistor



If an emitter-follow configuration is used (collector grounded), check the voltage across the collector and emitter to ensure that the required voltage is applied to the relay coil.

Hints Regarding Selecting a Drive Transistor

When the relay type and ratings have been selected, use the ratings to select the drive transistor.

- Read the following values from the catalog for the type of relay to be used.
  Coil voltage
  Coil rated current
  Coil resistance
- Determine the upper and lower limits of the must-operate voltage, as described in *Section 6-5-1* of this User's Guide.
  Lower limit of must-operate voltage: _V
  Upper limit of must-operate voltage: _V
  (Include the ripple in the upper limit value, if present.)

- Select the type of surge absorber element and then decide the dielectric strength of the drive transistor.

For a diode

(Upper limit of must-operate voltage + 0.6) x 2 (*see Note 1)
$\cong V_{CEO} \cong V_{CBO}$ = _V

For a diode and Zener diode

(Upper limit of must-operate voltage + 0.6 + Zener voltage) x 2 (*see Note 1)
$\cong V_{CEO} \cong V_{CBO}$ = _V

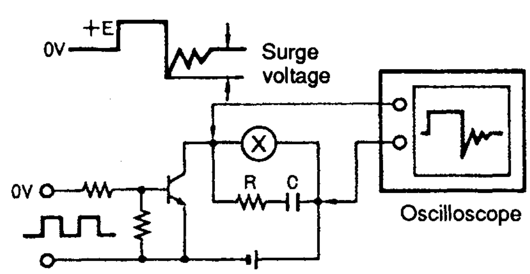
For a varistor

(Upper limit of must-operate voltage + varistor voltage) x 2 (*see Note 1)
$\cong V_{CEO} \cong V_{CBO}$ = _V

For a capacitor and resistor

(Upper limit of must-operate voltage + surge voltage) x 2 (*see Note 1)
$\cong V_{CEO} \cong V_{CBO}$ = _V

Note 1. This number is the safety factor. The user can select a suitable value.
2. The Zener voltage varies from one component to another. Use the maximum quoted operation voltage.
3. The varistor voltage varies from one component to another, and the varistor voltage for a single varistor also fluctuates according to the current flowing.
4. The surge voltage depends on the type and rating of the relay and the C and R constants. Measure the surge voltage experimentally.



Relay power source
R ≅ Relay coil resistance Change and measure C value in range 0.01 µF to 0.2 µF.

- Determine the transistor collector current (I_C).

I_C = (upper limit of must-operate voltage / coil resistance) x 2 (*see Note)

Note This number is the safety factor. The user can select a suitable value.

- Select the transistor according to the values determined the hints given above.

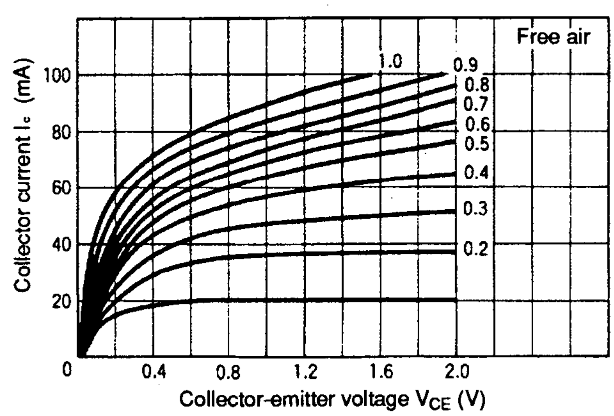
Absolute Maximum Ratings (NPN Transistor Standards Table)

Form	Symbol	Rated voltage	Unit
Collector-base voltage	V_{CBO}	60	V
Collector-emitter voltage	V_{CEO}	50	V
Emitter-base voltage	V_{EBO}	5.5	V
Collector current (DC)	I_C	100	mA
Collector current (pulse)	I_C (pulse)*	200	mA
Base current (DC)	I_B	20	mA
Base current (pulse)	I_B (pulse)*	40	mA
Total losses	P_T	250	mW
Junction temperature	T_J	125	%
Storage temperature	Tstg	–55 - +125	%

PW 10 ms, duty cycle 50%

6) After selecting the transistor, refer to the I_C - V_{CE} characteristics from the standards table.

Example I_C - V_{CE} Characteristics



These curves show the characteristic curves of collector current (I_C) and collector-emitter voltage (V_{CE}) for each base current (I_R).

Determine the collector-emitter voltage for the selected transistor from these curves.

I_C = upper limit of must-operate voltage / coil resistance

I_B = Switching transistor base current, determined by the drive stage

Collector-emitter voltage (V_{CE}) = V

Supply sufficient current flow to the base to ensure that the transistor is used within its switching region (saturated region).

7) Determine the power consumption of the transistor, and make sure that the transistor total losses fall within the permitted range.

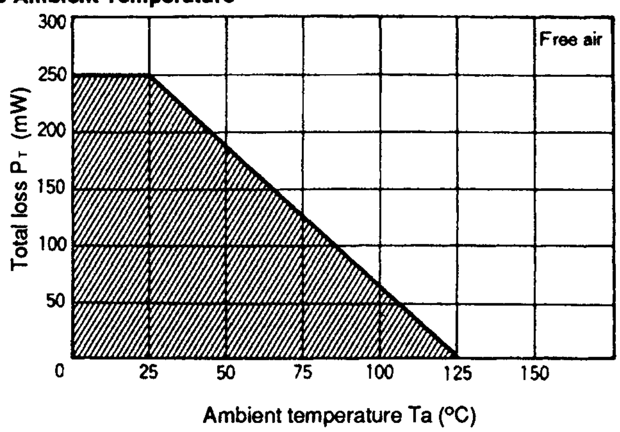
Total losses (P_T) = collector losses (P_C) + base losses (P_B)

P_C = (upper limit of must-operate voltage / coil resistance) x V_{CE} (determined at step 6, above)

P_B = I_B (determined at step 6, above)

Locate the point P_T determined above on the total losses - ambient temperature diagram for the transistor.

Relationship of Total Losses to Ambient Temperature



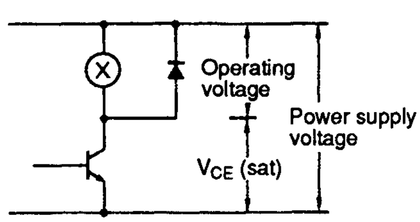
If the total losses lie outside of the permitted range for the transistor, attach a cooling body or use a different type of transistor.

8) Determine the relay supply voltage.

The relay supply voltage is determined from the upper and lower limits of the must-operate voltage and from the value V_{CE} determined at step 6, above).

Upper limit of relay supply voltage = upper limit of must-operate voltage + V_{CE}

Lower limit of relay supply voltage = lower limit of must-operate voltage + V_{CE}



9) Refer to the transistor absolute standards table once more and make sure that the following conditions are satisfied:

V_{CEO} > (upper limit of must-operate voltage + surge voltage) x safety factor*

V_{CBO} > (upper limit of must-operate voltage + surge voltage) x safety factor*

If these conditions are not satisfied, select a transistor with a higher dielectric strength, and repeat the procedure above from step 3.

Caution * Safety factor
Choose the safety factor to protect the transistor from surge voltages from lightening or other machines.

10) Check the following points when the transistor is used in a machine.

At the upper limit of the supply voltage, make sure that the voltage is within the upper limit of the must-operate voltage.

At the lower limit of the supply voltage, make sure that the voltage is above the lower limit of the must-operate voltage.

Make sure that the switching transistor does not overheat.

Make sure that the three conditions above are satisfied across the entire operating temperature range.

Run the machine and check that the circuit operates normally.

Consider the items in the table below when selecting the ratings of the relay coil.

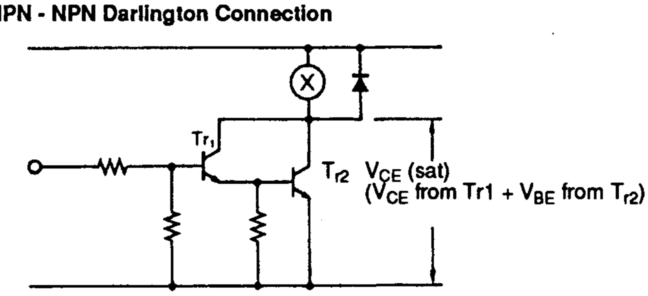
Relay rated voltage	Low	High	Remark
Relay coil current	large	small	inversely proportional to voltage
Switching transistor I_C	large	small	---
Switching transistor V_{ECO}, V_{CEO}	small	V_{CEO} usually in range 35 to 60 V	V_{CEO} usually in range 35 to 60 V
Transistor drive current	large	small	---
Transistor voltage drop (V_{EC})	large	small	---
Transistor total losses (P_T)	large	small	---

Considering the items in this table, the relay coil rating should be 12 V DC or 24 V DC, when it is driven by a transistor.

Drive with Darlington-Connected Transistors

The drive current (base current) can be reduced by using two Darlington-connected transistors to drive the relay. Darlington-connected transistors are also available in a single package.

NPN - NPN Darlington Connection



In this case, care must be taken with the voltage applied to the relay, total losses of transistor Tr_2, and the design voltage of the power supply, because V_{CE} is larger than from a single transistor.

Buffer Circuit

When relay contacts are switched according to signals from an electronic circuit, such as an electronic counter, a buffer circuit must be provided to prevent contact bounce.

In this case, a relay with high contact reliability is required because of the weak level of the input signals.

SECTION 7
Failure Analysis

7–1 Significance of Failure Analysis

Failure analysis determines the modes and mechanisms leading up to failure by carrying out analysis of the electrical, physical and chemical properties of relays which have failed.

Ever increasing levels of reliability are demanded of relays in today's market, particularly of the contacts. OMRON carries out thorough investigations into the causes of problems which occur during manufacture or during use in the marketplace. The results of past failure analyses are incorporated at the design, development, and production stages to increase reliability and prevent failures. Even so, it is impossible to eliminate failures completely.

Whenever a relay does fail, OMRON carries out immediate failure analysis and formulates measures to overcome the problem. Feedback between departments prevents the same problem occurring repeatedly.

Determining the failure mode and failure mechanism of a relay involves a number of technological fields, from material analysis to process and production management.

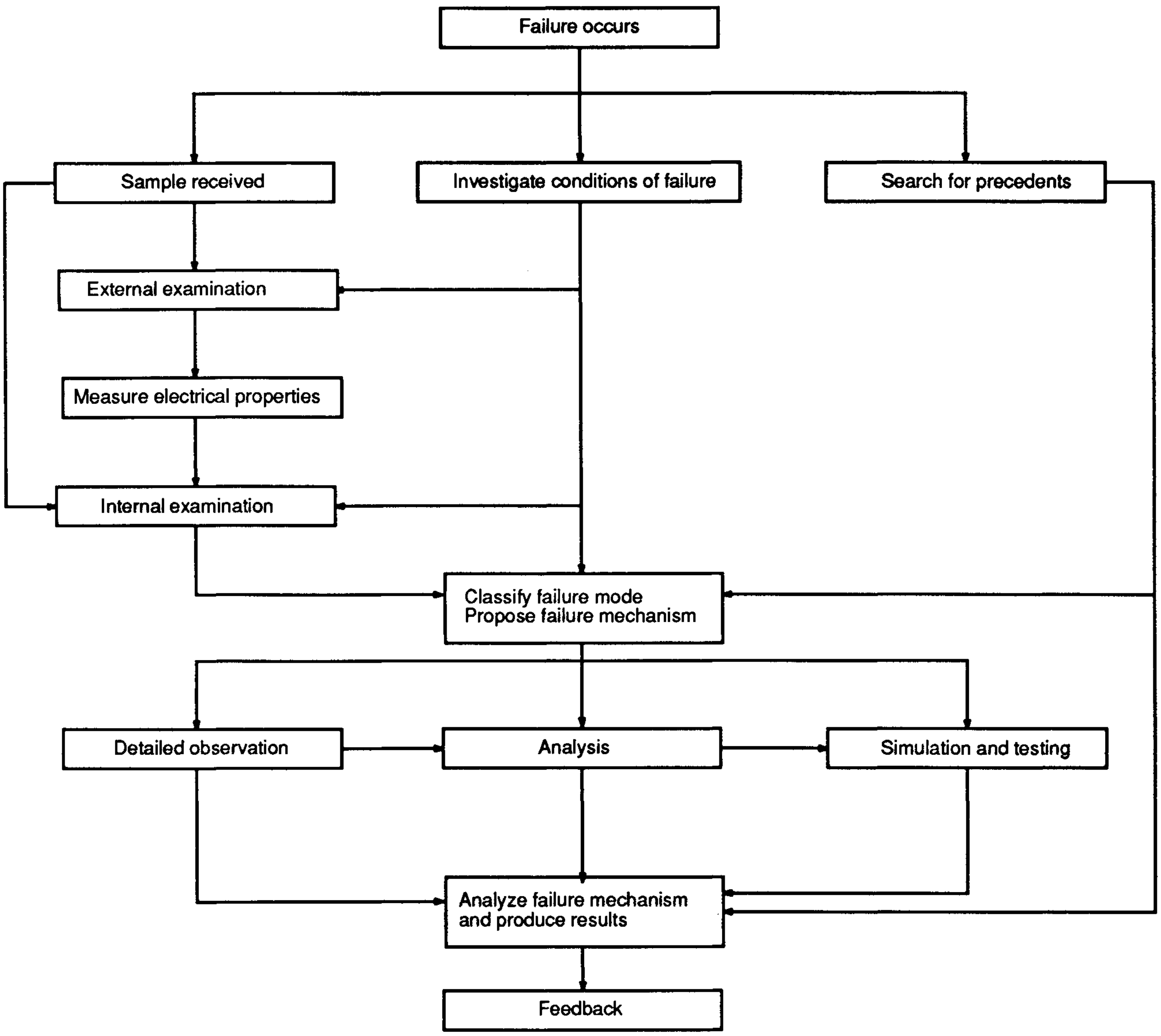
In some cases failure analysis must be carried out on a single sample, so that it is important to investigate the conditions (changes in characteristics, type of malfunction, events leading up the failure, operating environment, how the relay was handled, etc.) and details of the failure as thoroughly as possible before starting on the actual analysis work.

If this investigation is completed correctly, the most suitable analysis procedure can be selected. However, without the important information from the initial investigation, an incorrect analysis procedure may result in destruction of the precious sample without clarifying the cause of the failure.

Consequently, extensive experience in physical and chemical analysis is required to carry out successful failure analysis.

7-2 Failure Analysis Procedure

The processes of failure analysis are shown on the flowchart below. Each processes is described in more detail on the following pages.



7-2-1 Investigating Conditions of Failure

After receiving the failed relay, check the items below to investigate the conditions of failure.

1) Production lot (period of manufacture, length of storage, manufacturer's data).

2) Process, location, and date when the failure occurred.

3) History of the failed part (data of delivery, details of the acceptance inspection, date of mounting).

4) Conditions of mounting (type of equipment, mounting conditions, period of use, circuit conditions, mounting position).

5) Conditions of failure (operating environment and conditions, number of parts failed).

6) Failure mode (complete failure, deterioration failure, intermittent failure, failure rate, failure characteristics of the production lot).

7) Route and time taken to receive the relay since failure.

Checking this information allows a good estimate to be made of the type and mechanism of failure, which is then used to decide on the detailed failure analysis procedure to be carried out subsequently. Take care to store and transport the failed relay correctly if it cannot be analyzed immediately,

It is important to carry out analysis using a standard, non-defective part for comparison.

7–2–2 External Examination

The first step of the analysis is to visually inspect the outside of the relay with your naked eye or using a stereoscopic microscope. Inspect any defects found with a powerful optical microscope or with scanning electron microscope. Analyze any foreign matter found, to determine the substance and its basic elements, using one of the analytical methods described below.

Dust

Any of the following types of dust adhering the relay indicates that the relay was used in severe conditions: organic dust from the atmosphere, fibrous particles, metals or their oxides. In some cases, this type of particles can enter the relay and cause deterioration of the relay properties and defective electrical contact.

Contamination

Solvent, water, oil, soldering flux, and silicone oil residue can also enter the relay and cause deterioration of the relay properties and defective electrical contact, in the same way as dust. Contamination can lead to damage, discoloration, and deterioration of the plastic of the casing and base.

Discoloration of the Terminals

Relay terminals are normally metal plated to make them easier to solder and more resistant to corrosion. Discoloration of the plating is caused by insufficient washing before or after the plating process, defective plating, pinholes, or by corrosion caused by the external environment.

Others

Other problems which may be discovered by the external examination are stress fractures of the terminals, mechanical damage to the terminals, cracking or discoloration of the casing or base, peeling of the seals, or metal migration or whiskers.

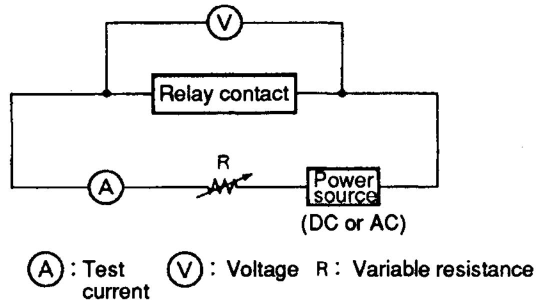
7–2–3 Measuring the Electrical Properties

In general, the electrical properties listed in the catalog are evaluated, with reference to the reported failure condition and operating condition.

Functional testing is carried out to determine whether the relay operates, and parameter measurements to investigate if the properties fall within the rated values.

The important measurement of the contact resistance is carried out using the voltage-drop method with the test current specified in the table below. Use a 4328A milliohmmeter, manufactured by YHP, to obtain reliable test results.

Measuring Circuit for Contact Resistance



Test Current for Measuring the Contact Resistance

Ammeter	Voltmeter
under 0.01	1
0.01 to 0.1	10
0.1 to 1	100
over 1	1000

7-2-4 Internal Examination

Non-Destructive Internal Examination

An X-ray machine can be used to examine the condition inside the relay without damaging it. As the penetration of the X-rays varies according to the type and thickness of material, the X-ray intensity forms a contrast image of the internal structure of the relay. This technique permits observation of the internal condition of a reed switch, a PCB-mounted relay with plastic-sealed casing, the parts inside the resin molding of a solid-state relay, and of the lead inside the relay.

Destructive Internal Examination

The following methods are used to unseal and disassemble the relay for examination and analysis of the internal parts.

1) Mechanical Opening

A relay can normally be opened easily by releasing the clips and removing the base from the casing. However, a cutter or nippers has to be used to open a plastic-sealed or other type of relay sealed in a casing. Take care not to damage the internal parts of the relay when opening the casing.

2) Dissolving Plastic with a Chemical Reagent

Dissolve the plastic with nitric or sulfuric acid or Uresolve Plus, manufactured by Dynalloy Inc. Dissolving plastic with a chemical reagent is a simple method to open a relay, but take care to only melt the required parts.

These chemical reagents give off dangerous poisonous fumes, and must only be used in a well ventilated place. Dispose of waste reagents properly.

Remove the relay from the opened casing and examine it with a stereoscopic microscope or an optical microscope to determine the cause of failure. Carefully examine any part suspected of causing the failure. It is important to carefully examine any hidden parts which cannot be observed directly, by further disassembling or bending parts and illuminating and observing the hidden areas from various angles.

7-2-5 Detailed Observation

Observation with a Scanning Electron Microscope (SEM)

The SEM is frequently used in failure analysis because of the variety of functions it offers in addition to simple observation. The SEM is ideal for detailed observation of a surface because of its magnification ratio of up to 100,000 and the 3-D effect given by the deep depth-of-field.

An SEM is often attached to the other equipment described below to improve the efficiency of gathering information.

Observation of a Sample Cross-Section

Observation of the cross-section of a sample is sometimes required during failure analysis, to examine the metallic structure of a contact or terminal, or the positional relationship of assembled parts, for example.

Large samples can be ground directly, but normal small samples are embedded in resin and then ground down to obtain the required cross-section. Choose the type of resin carefully and take care that no bubbles form while the resin is hardening.

When grinding the sample cross-section, it is important not to allow a temperature rise due to the mechanical grinding stresses.

When grinding, first rough the sample to near the required cross-section, and then decrease the grinding grain size step-by-step. The finished sample cross-section must be free of scratches. If alumina is used at the final grinding stage, make sure that it does not remain on the surface after grinding is complete.

To observe the crystal structure, it is common to cause intergranular corrosion of the metal cross-section with a suitable etching solution.

7–2–6 Instrument Analysis

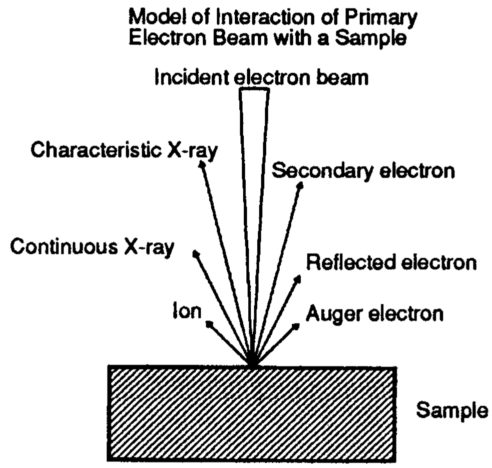
The analysis of the composition of materials used in relays and the qualitative and quantitative analysis of sticking particles and degenerated material are important parts of failure analysis. Analytical instruments have developed remarkably since they were first employed for this aspect of failure analysis. The instruments have become easier to use, and in many cases, advanced computer technology now automatically processes the analysis results.

Although anybody can now use this type of instrument and obtain a printout of of the analysis results, the cause of failure may remain unsolved in many cases because of an inappropriate method of handling, processing or analyzing the sample, or through relying solely on the computerized results.

Extensive knowledge and experience of analytical techniques are required to carry out instrument analysis correctly.

Methods using an Electron Beam

When electrons collide with solid surface, reflected electrons, secondary electrons, Auger electrons, characteristic X-rays, continuous X-rays, etc., are given off by the surface, as shown in the diagram below. Each of these can provide information for analysis. Some of the typical electron-beam analytical techniques are described below.



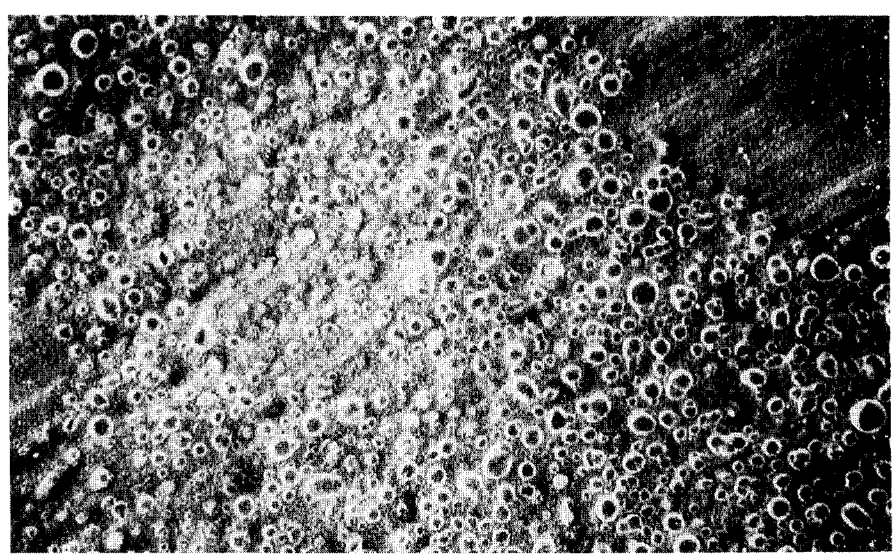
1) Scanning Electron Microscopy (SEM)

SEM offers a deeper depth-of field than an optical microscope and permits high-magnification observation. To examine a large sample with SEM, cut off a 3 mm piece,wash the surface to be observed, and mount the sample on the holder.

Stick the sample to the holder with electrically conductive glue to ensure good electrical contact between the sample and the holder.

If the sample is an insulator (including samples embedded in resin) or a light element which is a poor emitter of secondary electrons, apply a conductive material to the sample surface. The normal method is to apply a 10 nm to 100 nm thick vacuum-evaporation film of gold, silver, gold-platinum alloy, gold-palladium alloy, etc. Apply a thin coating (20 to 30 nm) if the sample is to be examined at high magnification, or a thicker coating if the sample will be examined only at low magnification.

SEM with AU Plating Failure



2) Electron Probe Micro Analysis (EPMA) or X-Ray Microprobe Analysis (XMA)

The characteristic X-rays emitted when an electron beam is incident on the sample are used to analyze the elements of the material. Two methods are used to detect the X-rays: wavelength dispersion (WDX) and energy dispersion (EDX). Each method has its own particular advantages.

The EPMA or XMA analyzer is normally used as a versatile local analyzer in conjunction with SEM. It provides more detailed analysis, such as the qualitative and quantitative analysis of extremely small areas, to suit the condition of the sample surface and the analysis results.

3) Auger Electron Spectroscopy (AES)

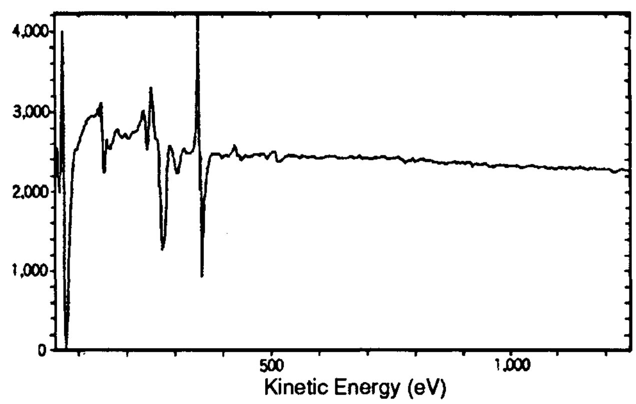
The elements of the material are analyzed by spectral analysis of the Auger electrons emitted when a low-energy electron beam is incident on the sample. As the low-energy Auger electrons are emitted from the layer a few atomic distances from the surface (several 10 Å), this method is used for the analysis of the sample surface. The chemical bonding can also be determined from the energy shift caused by some elements.

This method is normally used with a spatter unit to measure the depth profile of foreign matter or surface films.

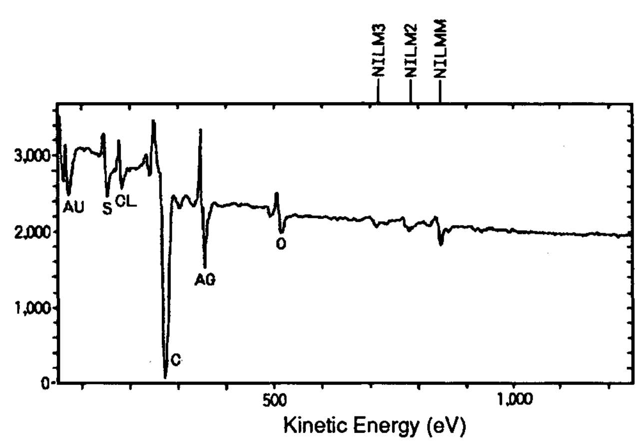
Scanning Auger Microscopy (SAM) has become the most popular system in recent years because of its ability to carry out local analysis of mm-order areas and to produce two-dimensional concentration-distribution analysis of a surface.

An example of AES analysis results is shown in the diagram below.

AES Analysis of AuAg Contacts



(a) Normal Sample



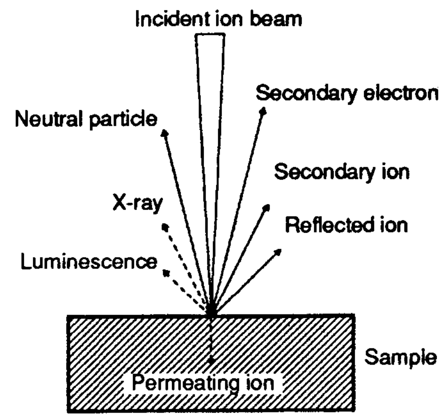
(b) Defective Sample

Methods using an Ion Beam

When ions, with an acceleration voltage in the range 1 to 20 KeV, collide with solid surface, some ions scatter and others continuously collide with lattice structure of the solid and lose energy. Atoms of the solid which receive energy from the ions carry out secondary and tertiary collisions and are discharged into the vacuum as neutral particles or ionized particles.

As shown in the diagram below, the types of discharged particles (visible, UV, and X-ray photons, neutralization electrons, neutral particles, dispersed ions, secondary ions, etc.) are separated to provide information on the substance.

Model of Interaction of Primary Ion Beam with a Sample



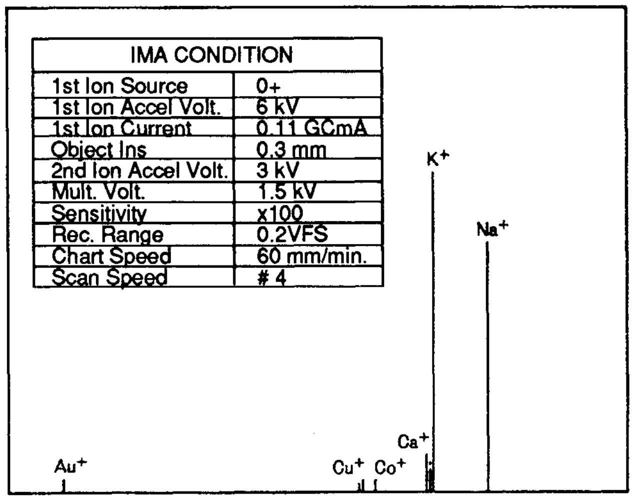
Secondary Ion Mass Spectrometry (SIMS)

Ions of argon (Ar) or oxygen (O) incident on the sample discharge secondary ions from the sample through spattering. SIMS uses quantitative analysis of the discharged secondary ions to identify the elements in the sample.

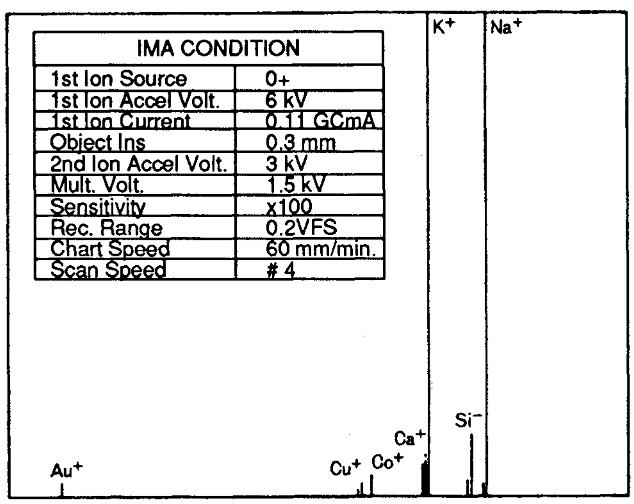
SIMS equipment can be categorized into many types, depending on the irradiation system and detection system. However, it is normal to separate SIMS equipment into static SIMS and dynamic SIMS types.

All elements can be analyzed by using static SIMS for the analysis of organic substances and dynamic SIMS for the analysis of inorganic substances. The method is extremely sensitive, yielding results in the order of ppb or ppm. SIMS is used for identifying foreign matter and measuring diffusion profiles.

Example of a SIMS Analysis



(a) Normal Sample



(b) Defective Sample

Methods using X-Rays

Electron Spectroscopy for Chemical Analysis (ESCA) or X-Ray Photoemission Spectroscopy (XPS)

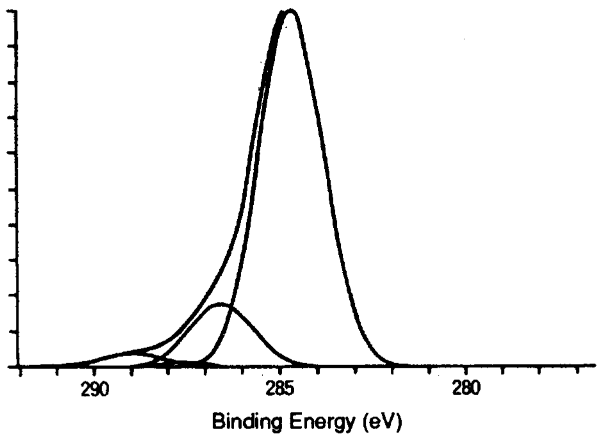
X-rays incident on the surface of the sample discharge electrons from the surface because of the photoelectric effect. ESCA measures the kinetic energy of these electrons in an analyzer which uses an electric or magnetic field.

The ESCA spectra show patterns of the atomic orbitals (inherent in the constituent atoms) and of the molecular orbitals (related to the chemical bonding). The energy levels permit elementary analysis of the sample, and the chemical shifts are used to analyze the chemical bonding.

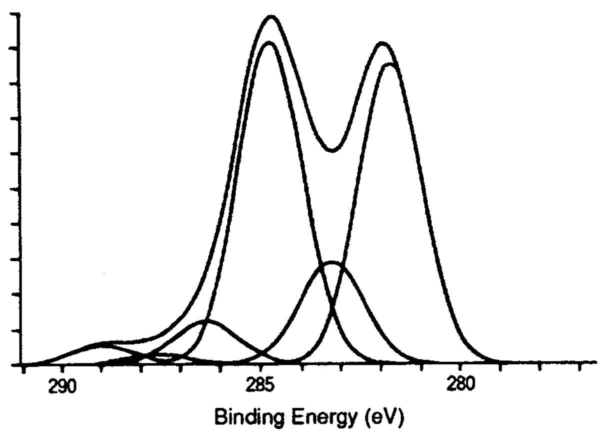
The photoelectrons are emitted from the surface layer of the solid sample with a similar thickness to the layer from which Auger electrons are emitted (several 10 Å). This method is therefore used only for analysis of the sample surface.

The diagram shows the ESCA chemical shift analysis of material formed on a relay contact.

Example of ESCA Composition Analysis using C1S Chemical Shift and Peak Separation



(a) Normal Sample



(b) Defective Sample

Methods using Infrared

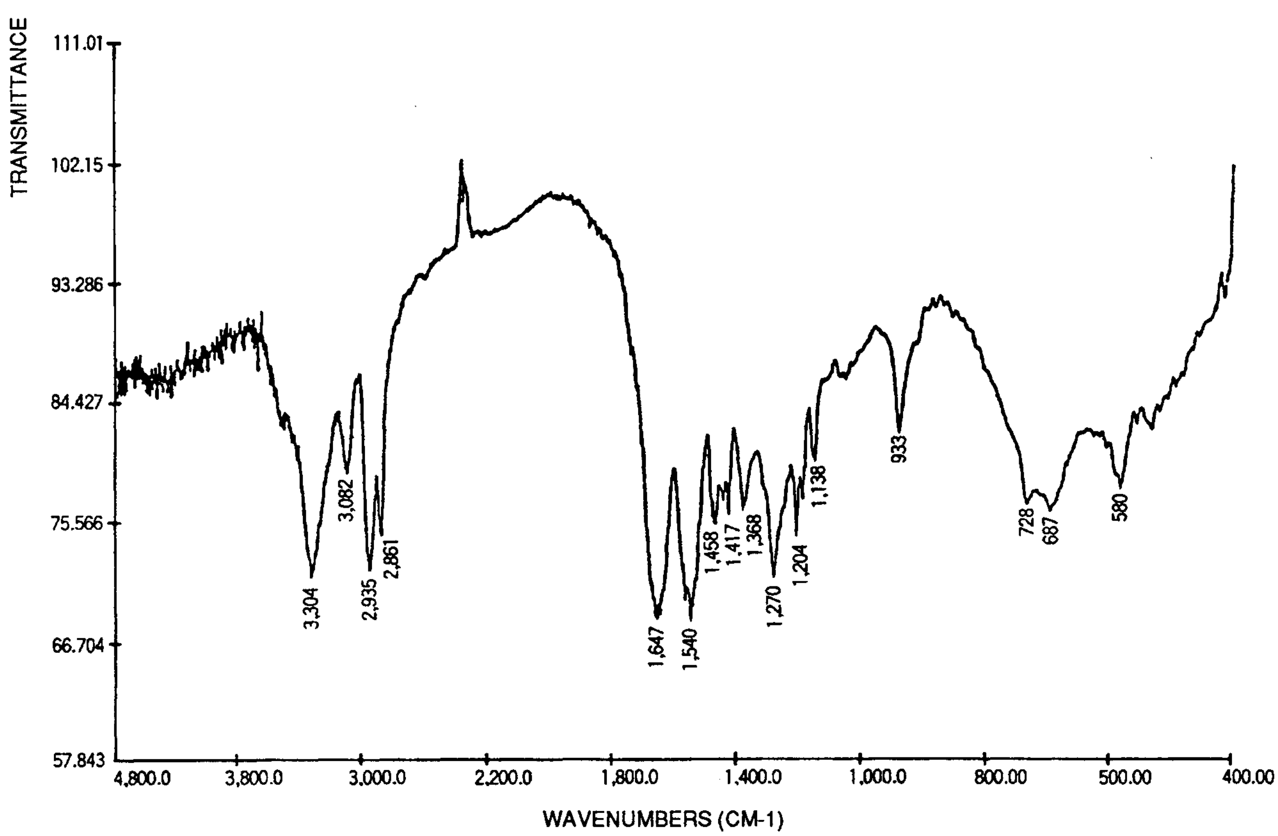
Fourier Transform Infrared Spectroscopy (FT-IR)

Each constituent molecule of a substance has its own inherent oscillation frequency. When IR radiation of continuously changing wavelength is incident on the substance, the IR frequencies corresponding to the molecular oscillation frequencies are absorbed, so that a spectrum corresponding to the molecular composition is obtained. This spectrum can be used to analyze the molecular composition of the substance.

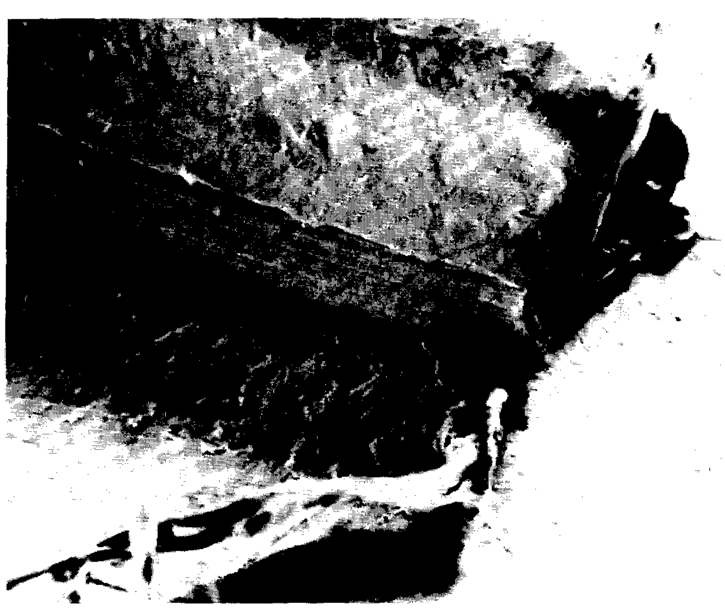
FT-IR analysis is carried out with a single IR beam. At certain intervals, the test sample and comparison sample are measured consecutively. The A/D-converted signals from the optical unit are subjected to Fourier transform to obtain the IR intensities.

Several methods of analysis are available, including the KBr method and the high-sensitivity reflective method. Recently, microscope FT-IR analysis is becoming increasing popular for failure analysis applications because it permits the IR analysis of extremely small areas.

An example of FT-IR analysis results is shown in the diagram below.



Example of Fibrous Foreign Material



The types of analytical techniques used for relay failure analysis are summarized in the table below.

Summary of Analytical Techniques used For Relay Failure Analysis

Abbreviation	Name	Input	Detected	Principle or Method	Information Obtained	Applications	Resolution
AES	Auger Electron Spectroscopy	Electron (0.1 to 5 keV)	Auger electrons	Spectrum (using CMA, etc.) of Auger electron energy is recorded as a differential curve	Elemental analysis of surface (above Li) Depth analysis possible using additional ion gun	Analysis of surface oxides, contamination, and impurities; analysis in depth direction; evaluation of contact cleanliness	Diameter: 0.1 to 1 mm Thickness: 10Å to 20Å
EDX	Energy Dispersive X-ray Spectroscopy	X-ray (up to 30 keV)	Auger electrons	Peak value analysis of energy (wavelength) of incident X-ray beam with an Si (Li) semiconductor detector (SSD)	Analysis of elemental composition using X-ray energy distribution (sensitivity > 0.1%)	Used as an EPMA method	Diameter > 100 Å (using STEM) Thickness: 0.3 to several µm (depending on energy and substance)
EPMA	Electron Probe Micro Analysis	Electron (up to 50 keV)	Characteristic X-rays	Spectral analysis (using EDX or WDX) of characteristic X-rays generated by incident electron beam	Analysis of elemental composition (above Na using EDX, above boron using WDX)	Analysis of elemental composition of metal parts; analysis of contamination, adhering particles, and corrosion products	Diameter > 0.5 µµ Å (using STEM) Thickness: 0.3 to several µm (depending on energy and substance)
ESCA	Electron Spectroscopy for Chemical Analysis			Generic name for XPS and UPS		Analysis of adhering particles and discoloration; analysis of states of organic and inorganic matter; surface analysis	
I(M)MA	Ion Microprobe (Mass) Analysis	Ion (Ar, O, Cs)(up to 30 keV)	Secondary ions	Quantitative analysis of secondary ions emitted due to spattering caused by primary ions on the surface material. Microbeam scanning and phase-conversion types available	One-dimensional elemental analysis of chemical composition; analysis in depth direction (sensitivity: ppb to ppm, depending on elements)	Analysis of residual impurities; composition trace analysis; additive trace analysis	Diameter > 1 to 2 mm (0.1 mm with surface ionization) Thickness: several 10Å to 100Å
IR	Infrared Absorption Spectroscopy	Photon (Infrared ray 2.5 to 16 GCmm)	Photons (transmitted)	Wavelength of incident IR radiation is continuously changed and the spectrum of IR frequencies absorbed due to molecular oscillation is measured.	Identification of material using inherent molecular absorption waveband; analysis of molecular composition	Identification of organic substances; analysis of molecular composition; identification of adhering organic particles	Frequency > 0.1 cm_{-1}
NMR	Nuclear Magnetic Resonance	Electromagnetic waves	Electromagnetic waves	Resonance absorption spectrum produced by the Zeeman effect, which is determined by the quantum spin number in the presence of an external magnetic field.	Identification of atoms from the internal magnetic field and spin relaxation; analysis of atomic sequences	Analysis of molecular composition of organic substances	

Abbreviation	Name	Input	Detected	Principle or Method	Information Obtained	Applications	Resolution
SAM	Scanning Auger Microscopy	Electron (3 to 20 KeV)	Auger electrons	AES using a micro electron-beam (SEM type Å 200 Å, CMA type : ca. 1000 Å)	3-dimensional analysis of the composition of surface films; chemical-shift analysis problematical	Analysis of local surface composition, analysis of surface oxides, contamination, and impurities; analysis in depth direction	Diameter ≥ 500 Å Thickness: Several Å to 20 Å
SAES	Scanning Auger Electron Spectroscopy			Same as SAM method			
SEM	Scanning Electron Microscopy	Electron (5 to 50 KeV)	Secondary electrons, reflected electrons	The intensities of the secondary electrons (SE) and reflected electrons (BE) are recorded in synchronization with the primary micro-electron-beam as it scans the surface.	Analysis of surface roughness; qualitative composition analysis	Observation and measurement of material surface conditions	Diameter > 30 Å
SIMS	Secondary Ion Mass Spectroscopy	Ion (Ar, O)(100 eV to 10 KeV)	Secondary ions	Quantitative analysis of secondary ions emitted due to spattering caused by primary ions on the surface material. Primary ions do not scan.	Elemental analysis of chemical composition (2-D distribution not possible); higher sensitivity than I(M)MA	Same as I(M)MA method	Diameter:100 to 500 mm
WDX	Wavelength Dispersive X-ray Spectroscopy	X-ray (up to 10 keV)	X-rays (diffracted)	Wavelengths of incident X-ray beam are separated into a spectrum by Bragg reflection from a crystal, and the intensity measured using photoelectric conversion.	Elemental analysis of chemical composition using X-ray wavelength distribution. (sensitivity > 0.1%)	Used as an EPMA method	Diameter: Several µm Thickness: 0.3 to several m (depending on energy and substance)
XD	X-ray Diffractometry	X-ray	X-rays (diffracted)	Pattern and intensities of incident X-rays diffracted by Bragg reflection from a crystal lattice surface are recorded.	Analysis of crystalline composition; azimuth detection, photographic methods, chart methods (single crystals, powders, etc.)	Evaluation of crystals; analysis of contamination, adhering particles, and corrosion products	Thickness: 0.1 to several µm
XMA	X-ray Microprobe Analysis			same as ESCA			
XPS	X-ray Photo-emission Spectroscopy	X-ray (up to 10 keV)	Photoelectrons	Energy spectral analysis of photoelectrons due to X-ray excitation (AlK or MgK rays).	Used to detect the chemical shift of light elements, in particular, as the atomic orbital energy shifts due to the chemical bonding.	same as ESCA	Thickness: 10 Å to several 10 Å
XRFS	X-ray Fluorescence Spectroscopy	X-ray, Rl line (10 to 100 keV)	Characteristic X-rays (fluorescent)	Spectral analysis (using EDX or WDX) of secondary (fluorescent) X-rays	Analysis of elemental composition (above N); below Ni problematic with secondary crystal methods	Analysis of particles adhering to surface	Thickness: 0.1 to several µm

The following table evaluates the local analytical techniques, and compares their abilities of analyzing organic elements and halogens.

Evaluation or the Functions of Local Analytical Techniques *

	Basic functions				Appropriate samples		Ion type	Isoto pe	Bondi ng	Surface information			
	Ele-ment	Quali-tative	Quan-titative	Non-analyz-able elements	SP **	CE ***				Sur-face obser-vation	Sur-face distri-bution	Depth distri-bution	Sur-face com-posi-tion
AEM	P	P	PL	H, He, Li	UN	Y	NP	NP	NP	PL	PL	NP	NP
AES	P	P	PL	H, He	N	Y	NP	NP	PL	PL	PL	P	NP
APS	P	P	NP	H, He	N	Y	NP	NP	PL	NP	NP	NP	NP
EPMA	P	P	P	H, He, Li	UN	Y	NP	NP	NP	P	P	PL	NP
GDS	P	P	P		N	Y	PL	NP	NP	NP	NP	NP	NP
ISS	P	PL	PL	H	N	Y	NP	PL	PL	NP	PL	P	NP
LMA	P	PL	PL	Halogens, noble gases	N	Y	PL	NP	NP	NP	PL	NP	NP
PIXE	P	P	P	H, He	N	Y	NP	NP	NP	NP	PL	PL	NP
RBS	P	P	P	H, elements with mass approaching He heavy isotopes [Q:]	N	Y	NP	PL	PL	NP	PL	P	NP
RHEED	NP	NP	NP	All the elements	N	Y	NP	NP	PL	NP	PL	PL	P
SAM	P	P	PL	H, He	N	Y	NP	NP	PL	P	P	P	NP
SCA-NIIR	P	P	PLL	Elements emitting UV in vacuum (not impossible)	N	Y	NP	NP	NP	PL	PL	P	NP
SEM (+SSD)	P	P	P	H, He, Li	UN	Y	NP	NP	NP	P	P	PL	NP
SIMS	P	P	PL	Probe atom	N	Y	P	P	PL	P	P	P	NP
XPS	P	P	PL	H	N	Y	NP	NP	P	NP	NP	PL	NP

*P: good; PL: possible; NP: not possible
**Sample preparation: NP: required; PL: not required
***Contamination effects: NP: affected; PL: not affected

Capacity of Local Analytical Techniques for Analyzing C, N, O, P, S, and Halogens *

	Qualitative analysis						Quantitative analysis					
	C	N	O	P	S	Halogen	C	N	O	P	S	Halogen
AEM	P	P	P	P	P	P	P	P	P	P	P	P
AES	P	P	P	P	P	P	TP	TP	TP	TP	TP	TP
APS	P	P	P	P	P	P	I	I	I	I	I	I
EPMA	P	P	P	P	P	P	P	P	P	P	P	P
GDS	P	TP	TP	P	P	I	P	TP	TP	P	P	I
ISS	P	P	P	P	P	P	TP	TP	TP	TP	TP	TP
LAMMA	P	P	P	P	P	P	TP	TP	TP	TP	TP	TP
LMA	I	I	I	I	I	I	I	I	I	I	I	I
PIXE	P	P	P	P	P	P	TP	TP	TP	P	P	TP
RBS	P	P	P	P	P	P	TP	TP	TP	TP	TP	P
RHEED	I	I	I	I	I	I	I	I	I	I	I	I
SAM	P	P	P	P	P	P	TP	TP	TP	TP	TP	TP
SCA-NIIR	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP	TP
SEM (+SSD)	P	P	P	P	P	P	P	P	P	P	P	P
SIMS	P	P	P	P	P	P	TP	TP	TP	TP	TP	TP
XPS	P	P	P	P	P	P	TP	TP	TP	TP	TP	TP

* P : possible, TP : possible in theory, I : not possible

Other Methods

Other techniques used for failure analysis of relays include gas chromatography (GC), gas chromatography mass spectrometry (GC-MS), X-ray diffractrometry (/D), X-ray fluorescence spectroscopy (XRFS), and nuclear magnetic resonance (NMR).

Gas chromatography (GC) and gas chromatography mass spectrometry (GC-MS) are used for the analysis of gases in the relay and gases from organic constituent materials and for the quantitative and qualitative analysis of organic foreign matter.

7–2–7 Determining the Failure Mechanism from Results

The results produced by the various failure-analysis techniques have to be carefully examined to determine the actual cause of failure. However, in many cases the results of failure analysis must be produced in a very short time. Whatever conditions the failure analysis results are produced under, they must give a noncontradictory explanation of the failure and its cause.

Abnormalities which are discovered are not necessarily related to the failure. Similarly in some cases, different causes of failure can produce the same analysis results. If the cause is misunderstood, incorrect measures will be taken which will not prevent the failure occurring again.

The types of failure occurring in relays are becoming more varied as the environments in which relays are used become more complicated due to the appearance of new materials, application of relays under a wider range of operating conditions, and increased system complexity. To determine the exact mechanism of failure under these conditions, failure analysis has to adopt increasingly sophisticated analysis procedures and technology, and comprehensive simulation testing.

SECTION 8
Safety Standards

8–1 Relationship of Safety Standards to Other Standards

The safety requirements on equipment and apparatus have become extremely strict in recent years. Stringent safety requirements also apply to relays. National safety standards have been laid down throughout the world: in the Electrical Appliance and Material Control Law in Japan, in UL Standards in the U.S.A, in CSA Standards in Canada, and in the VDE Standards in Germany, for example.

These safety standards cover the construction and materials used in equipment and products to prevent loss of life or property from fire, electric shocks, and other accidents.

As Europe approaches unification in 1992, attempts are being made to adapt the European CENELEC Standards to conform to the IEC standards. Similarly, in North America the U.S. UL Standards and Canadian CSA Standards are being upgraded to incorporate the central ideas of the IEC Standards.

Numerous safety standards lay down requirements for relays. Representative safety standards have been categorized by region in the table below.

Safety Standards

Type and purpose		International	North America	Europe	Japan
Safety standards (to eliminate danger) (Vary according to region. In N. America, protection of human life and property. In Europe, prevention of death from electric shock and fires from electrical leakage.)		IEC	UL (United States)CSA (Canada)	VDE (West Germany) SEV (Switzerland) SEMKO (Sweden) NEMKO (Norway) DEMKO (Denmark) KEMA (Holland) BS (England) USE (France) CEI (Italy) CEBEC (Belgium) CEE (Europe)	In accordance with the law
Industrial standards (interchangeable)		ISO	ANSI (United States)	DIN (West germany)	JIS
Marine standards (covering ships and machinery)		—	ABS (United States)	LR (England) GL (West germany) BV (France)	NK
Others	Electromagnetic interference	CISPR	FCC (United States) DOC (Canada)	FTZ (West Germany)	VCCI
	Laws and regulations	—	CFR (United States)	—	Electrical Appliance and Material Control Law
	Trade organizations	—	NEMA (United States) ASTM (United States)	—	JEM JEC NECA

The standards listed in the table below apply to relays and relay-related equipment.

Application		UL	CSA	VDE	IEC
Functional parts	Relay	UL 508 : Industrial Control Equipment UL 840 : Insulation Coordination including Clearances and Creepage Distances for Electrical Equipment.	CSA C22.2 No. 14 : Industrial Control Equipment CSA C22.2 No. 0 : General Requirements	VDE 0435 : Electrical Relays VDE 0110 : Insulation co-ordination within low-voltage systems including clearances and creepage distances for equipment.	IEC 255 : Electrical Relays IEC 664, IEC 664A : Insulation co-ordination within low-voltage systems including clearances and creepage distances for equipment.
Products	Radio, audio equipment	UL 1270 : Radio Receivers, Audio Systems, and Accessories	CSA C22.2 No. 1 : Radios, Televisions, and Electronic Apparatus	VDE 0860 : Safety requirements for mains operated electric and related apparatus for household and similar general use. EN 60335 : Safety of household and similar electrical appliances.	IEC 65 : Safety requirements for mains operated electric and related apparatus for household and similar general use. IEC 335 : Safety of household and similar electrical appliances.
	Video, television	UL 1409 : Low-Voltage Video Products Without Cathode-Ray-Tube Displays UL 1410 : Television Receivers and High-Voltage Video Products.			
	Microwave oven	UL 923 : Microwave Cooking Appliances	CSA C22.2 No.150 : Microwave Ovens	VDE 0700 Teil 25 : Particular requirements for microwave ovens.	IEC 335–2–25 : Particular requirements for microwave ovens.
	Information processing equipment	UL 114 : Office Equipment UL 478 : Information-Processing and Business Equipment UL 1950 *1 : Information Technology Equipment Including Electrical Business Equipment	CSA C22.2 No. 220 : Information Processing and Business Equipment CSA C22.2 No. 950 *1 : Safety of Information Technology Equipment, Including Electrical Business Equipment	EN 60950 : Safety of information technology equipment including electrical business equipment.	IEC 950 *1 : Safety of information technology equipment including electrical business equipment.
	Vending machine	UL 751 : Vending Machines	CSA C22.2 No.128 : Vending Machines	—	—
	Vacuum cleaner	UL 1017 : Vacuum Cleaning Machines and Blower Cleaners	CSA C22.2 No. 67 : Vacuum Cleaners and Floor Polishers	EN 60335–2–2 : Particular requirements for vacuum cleaners and water suction cleaning appliances.	IEC 335–2–2 : Particular requirements for vacuum cleaners and water suction cleaning appliances.
	Refrigerator	UL 250 : Household Refrigerators and Freezers	CSA C22.2 No.63 : Household Refrigerators and Freezers	EN 60335–2–24 : Particular requirements for refrigerators and food freezers.	IEC 335–2–24 : Particular requirements for refrigerators and food freezers.
	Air conditioner	UL484 : Room Air Conditioners	CSA C22.2 No.117 : Room Air Conditioners	VDE 0772 : Safety requirements for the electrical equipment of room air-conditioners.	IEC378 : Safety requirements for the electrical equipment of room air-conditioners.
	Humidifiers	UL998 : Humidifiers	CSA C22.2 No.104 : Humidifiers and Evaporative Coolers	VDE 0704 Teil225 : Humidifiers	—
	Amusement equipment	UL22 : Amusement and Gaming Machines	CSA C22.2 No.149 Electrically Operated Toys	—	IEC 335–22 : Particular requirements for electric toys (mains-operated).
	Portable electric tools	UL45 : Portable Electric Tools	CSA C22.2 No.71.1 : Portable Electric Tools	VDE 0740 Teil1 : Safety of hand-held motor-operated electric tools.	IEC 745 : Safety of hand-held motor-operated electric tools.

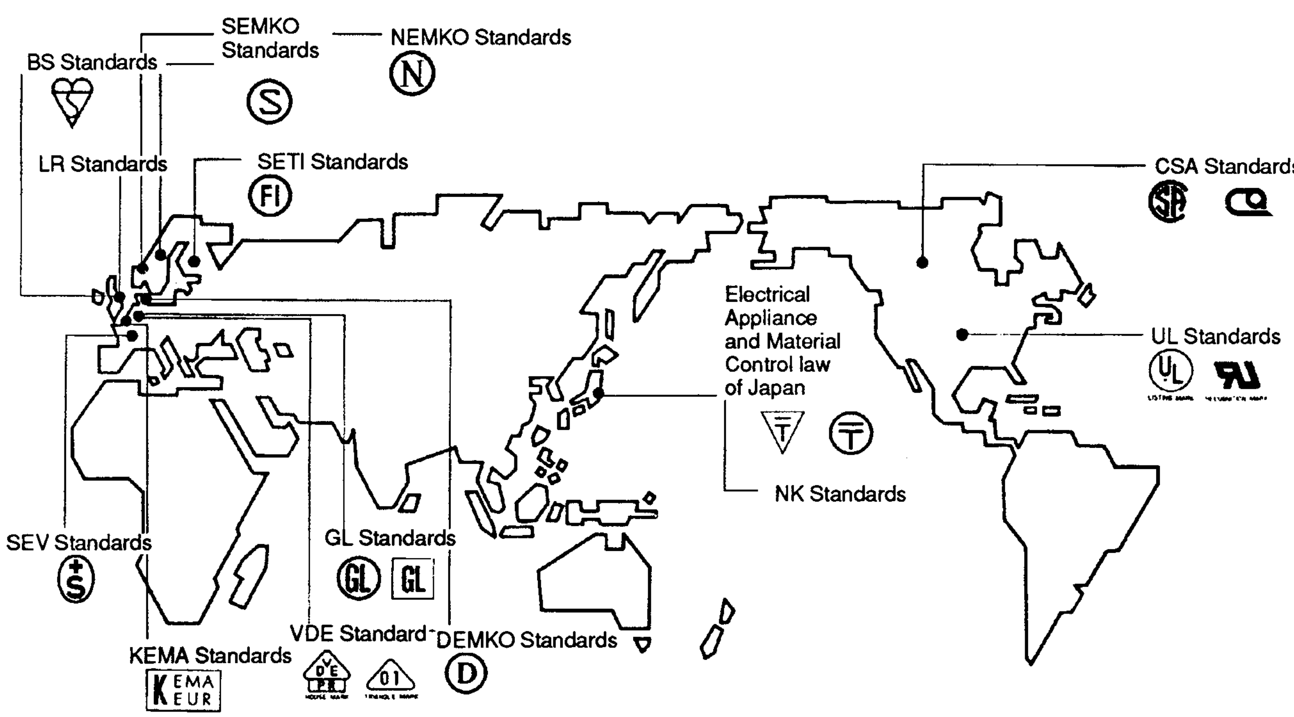
Application		UL	CSA	VDE	IEC
	Telecommunications equipment	UL1459 : Telephone Equipment	CSA C22.2 No.225 : Telecommunication Equipment	—	—

Note 1. The contents of the standards covering information technology equipment including electrical business equipment are almost identical to the IEC 950 Standard. The CENELEC, UL, and CSA standards are being modified to go into force in 1992, to coincide with EC unification.

2. The following standards covering relay spacings are being changed to unify with IEC standards:
VDE 0110 will be almost identical to IEC 664 and 664A (except for a few required values).
UL 508 will adopt the majority of basic ideas of IEC 664 and 664A (CTI value over 175, pollution degree from 1 to 3).

8-2 Summary of National Standards

8-2-1 Major Standards



IEC Standards (International Electrotechnical Commission)

A standardization organization established in 1906 to promote unification and cooperation in international standards related to electricity. Headquarters in Geneva, Switzerland.

At present, a total of 43 countries are affiliated to IEC, including Japan. Changes to IEC standards are proceeding rapidly in all member countries.

UL Standards (Underwriters Laboratories Inc.)

A nonprofit organization established in 1894 by the American association of the fire insurance industry.

Underwriters Laboratories (abbreviated to UL hereafter) conducts approval testing on all kinds of electrical products. In many U.S. cities and states, UL approval is legally required on all electrical items sold.

In order to obtain UL approval on an electrical product, all major internal components also require UL approval.

UL offers two classifications of approvals, the listing mark and the recognition mark.

A Listing Mark constitutes a entirely approval of a product. Products display the Listing Mark shown below.

LISTING MARK

The Recognition Mark applies to the components used in a product, and therefore constitutes a more conditional approval of a product. Products display the Recognition Mark shown below.

RECOGNITION MARK

CSA Standards (Canadian Standard Association)

This association descended from a nonprofit, non-government standardization organization established in 1919. In addition to industrial standardization work, the association now carries out safety testing on electrical products.

Has closer ties to government agencies than UL, so that electrical products not approved by CSA cannot be sold in Canada. Non-approved goods being sold illegally may have to be withdrawn.

CSA approval is known as "certification," and consequently, CSA-approved equipment is referred to as "certified equipment." Products display the mark shown. For a conditional certification, products display component acceptance mark.

CERTIFICATION MARK   COMPONENT ACCEPTANCE MARK

CENELEC Standards (Comite Europeen de Normalisation Electrotechnique)

A European electrical standardization organization established in 1973 jointly by the EC (European Community) and EFTA (European Free Trade Association). Head office is located in Brussels, Belgium. 18 countries affiliated at present.

By actively working toward the creation of new, unified European standards for 1992, CENELEC is playing an extremely important role in EC unification.

Documents published by CENELEC include formal EN (European Norm) standards and provisional HD (Harmonization Documents) and ENV (European Prestandards).

VDE Standards (Verband Deutscher Electrotechniker e.V.)

The VDE (German electrical technician's association), established in 1893, is mainly responsible for carrying out safety testing and approval administration of electrical products.

Compliance with VDE standards is not proscribed under German law, however, the extremely heavy penalties imposed on the manufacturer of an unapproved product which causes an electric-shock or fire mean that compliance is effectively compulsory in practice.

The VDE offers two classifications of approval: unconditional and conditional. Products with unconditional approval bear the upper mark shown below, while products with conditional approval bear the lower mark.

HOUSE MARK TRIANGLE MARK

The House Mark indicates that the product completely complies with all VDE standards. The Triangle Mark shows that the product does not satisfy all standards, but if it is correctly installed into another assembled product, the assembled product will meet appropriate VDE standards.

SEV Standards (Schweizerischer Electrotechnischer Verein)

A private organization founded in 1903 for the testing of electrical products and components. Since these standards received Swiss Government approval in 1954, it has been illegal to market electrical products and components not approved by SEV in Switzerland.

SEV-approved products may bear the approval mark shown.

SEMKO Standards (Svenska Elektriska Materielkontroll Anstalten)

Founded in 1925 by the Swedish electrical suppliers' association and the fire-insurance association. Received Swedish Government approval in 1935.

All domestic electrical appliances, lamps, power tools, cords, cables, plugs, etc., sold in Sweden must be SEMKO approved.

SEMKO-approved products may bear the approval mark shown.

DEMKO Standards (Danmarks Elektriske Materielkontrol)

A private organization founded in Denmark in 1924. Became a government organization in 1930, and remains so today.

DEMKO approval is compulsory for all equipment with a supply voltage from 24 V to 250 V, and for equipment with a supply voltage below 24 V which could be dangerous to humans.

Products which pass the testing bear the approval mark shown.

NEMKO Standards (Norges Elektriske Materiellkontroll)

A semi-government testing organization founded in 1924 under sponsorship of the Norwegian electrical suppliers' association.

All electrical products sold and imported in Norway must be NEMKO approved.

NEMKO-approved products may bear the approval mark shown.

SETI Standards (Sahtotarkastuskeskus Elinspektionscentralen)

Successor organization to the electrical equipment testing center (EI) founded in Finland in 1928.

In practice, testing and SETI approval is compulsory for all types of domestic appliances, office equipment, electronic instruments, and electrical apparatus in Finland.

SETI-approved products bear the approval mark shown.

BS Standards (British Standards)

The British domestic industrial standards organization, the British Standards Institution, issues industrial standards covering standardization and safety.

The British Standards Institution was founded in 1901 as an industrial standards committee on recommendation of the British Civil Engineering Society.

BS testing and approval in Britain is voluntary.

Products which pass the testing may bear the approval mark shown.

KEMA (N.V. tot Keuring van Electrotechnische Materialen)

A testing organization founded in 1927 under sponsorship of the Dutch electrical suppliers' association.

In the Netherlands, KEMA approval is compulsory for some wiring equipment, such as plugs and sockets, but approval is voluntary for other electrical equipment.

KEMA-approved products may bear the approval mark shown.

LR Standards (Lloyd's Register of Shipping)

These standards are issued by the Lloyd's Register of Shipping in London. All LR-approved OMRON control equipment is rated for UMS ship use. (UMS is Lloyd's classification for ships with an unmanned engine room.)

Unlike the UL and other safety standards, the LR standards check the marine equipment in the actual operating environment found on the ship.

No mark is applied to LR-approved products. However, Lloyd's Register of Shipping publishes an annual list of approved products.

GL Standards (Germanischer Lloyd)

These standards are issued by Lloyd's of Hamburg, W. Germany, which is a shipping register unrelated to Lloyd's Register of Shipping in London.

GL offers two classifications of approval: unconditional and conditional. Products with an unconditional approval bear the leftmost mark shown below, while products with conditional approval bear the mark to the right.

NK Standards (Japanese Marine Association)

Automation instruments and equipment obtain formal NK approval after passing testing laid down under the steel-ship regulations.

Part or all of the testing of automation instruments and equipment with formal NK approval can be omitted at the time of installation into the ship at the shipyard.

The manufacturer of NK-approved products usually indicates that the products are approved (for example, by attaching a label where required).

Electrical Appliance and Material Control Law of Japan

The Electrical Appliance and Material Control Law of Japan covers all domestic and office appliances, and industrial electrical equipment.

Approvals for under this law classifies electrical equipment into Type A and Type B equipment, according to the level of safety and how widespread the equipment is.

Type A equipment is tested for formal approval before manufacturing commences. If the product passes the testing, the upper mark shown in the diagram below is attached to permit manufacture and marketing.

Type B equipment receives the lower of the marks shown in the diagram after the manufacturer reports that the product is to be manufactured. This mark permits the manufacture and marketing of the product.

For Reference

1. TÜV (Technischer Überwachungsverein)

An independent, nonprofit organization founded in 1875 by the German boilermaker's federation for the purpose of preventing boiler accidents. Currently operates independent test facilities in each of W. Germany's 11 states.

The TÜV carries out the testing of a wide range of industrial plant and equipment, and also tests and approves electrical products according to VDE standards, normally at government request.

TÜV approval is valid nationwide, regardless of which state it was obtained in, and carries the same authority as VDE approval.

Approvals for OMRON products are obtained from TÜV Rhineland. Two types of TÜV approval mark are used: the first mark shown below is for equipment, and the other one is for component parts of equipment. These are the new marks introduced from January 1, 1990.

Displaying the TÜV approval-marks is discretional.

2. BEAB (British Electrochemical Approvals Board)

Nonprofit organization founded in 1960. Mainly involved with the testing and approval of domestic electrical appliances according to BS standards.

Two types of BEAB approval mark are used: the left one in the diagram below is for equipment, and the mark to the right for component parts of equipment.

Displaying the BEAB approval-marks is discretional.

3. TV-rated Switches and Relays (UL, CSA)

TV-rating testing is carried out on 1 sample/UL and 6 samples/CSA with normal tungsten lamp loads. The tungsten lamp load has an inrush current of approximately 10 times the normal current. Testing is carried out for 25,000 switching operations on each sample.

The TV-rating and test current are marked on the product. For example, if the testing was carried out with a steady-state current of 2 A (at 120 V), the product is marked TV-2.

4. Types of Load

Note that the conditions for using a load other than a resistive load for the switching test differ between the N. American standards (UL, CSA) and the European standards (VDE, SEMKO, etc.).

When testing using a load other than a resistive load under the N. American standards, the load is referred to as a "general-purpose load," and normally has a power factor of 0.75 to 0.8. In Europe, however, testing is carried out using an inductive load with a power-factor of 0.4.

8–2–2 Main Standards Applying to General-Purpose Relays

Country	Approval mark	Standards	Agency	Country	Approval Mark	Standards	Agency
United States		UL	UL (Underwriters Laboratories Inc)	Holland		KEMA	KEMA (N.V.Tot Keuring Van Electrotechnische Materialen)
				Australia		AS	SAA (Standards Association of Australia)
Canada		CSA	CSA (Canadian Standard Association)	Austria		OVE	ÖVE (Österreichischer Verband Für Elektrotechnik)
Japan		Electrical Appliance and Material Control Law of Japan	Japan Electrical Testing Laboratory	Norway		NEMKO	NEMKO (Norges Elektriske Materiellkontroll)
				United States	—	FCC	FCC (Federal Communication Commission)
Switzerland		SEV	SEV (Schweizerischer Electrotechnischer Verein)	Finland		EI	SETI (Sahkotarkastuskeskus Elinspektionscentralen)
West Germany		VDE	VDE (Verband Deutscher Electrotechnischer e.v.)	Denmark		DEMKO	DEMKO (Danmarks Elektriske Materielkontrol)
				France		USE	UTE (Union Technique de Lelectricite)
West Germany		VDE	TUV (Technischer uberwachungs-Verein)	Italy		CEI	IMQ
England	—	LR	LR (Lloyd's Register of Shipping)	Belguim		CEBEC	CEB (Comité Electrotechnique Belge)

Country	Approval mark	Standards	Agency	Country	Approval Mark	Standards	Agency
Japan	—	NK	NKK (Nippon Kaiji Kyokai)	West Germany	GL GL	GL	GL (Germanischer Lloyd)
Japan	—	RCJ	RCJS	Saudi Arabian		SSA	SASO (Saudi Arabian Standards Oganization)
Sweden		SEMKO	SEMKO (Svenska Electriska Materielkontroll Anstalten)	United States	—	AAMVA	AAMVA
England	BEAB	BS	BEAB (British Electrotechnical Approvals Board)	West Germany	DIN	DIN	DIN (Deutsches Institut for Normung)
			BSI (British Standards Insitution)	France	—	BV	BV (Bureau Veritas)
Japan		JIS	Japanese Industrial Standards	International	—	IEC	IEC (International Electrotechnical Commission)

8–3 Terminology Relating to Safety Standards

8–3–1 Terminology Relating to Approval Marks and Ratings

UL RECOGNITION and LISTING

The differences between the RECOGNITION and LISTING markings on a relay are explained in the table below.

UL approval mark	Type of approval	Type of product	Comments
UL LISTING	Unconditional approval	Some limit switches and proximity switches (used in field wiring)	White card issued
RECOGNITION	Conditional approval	Relays, microswitches, timers (used inside equipment)	Yellow card issued

VDE HOUSE MARK and TRIANGLE MARK

The TRIANGLE MARK is appropriate for a relay. The differences with the HOUSE MARK are explained in the table below.

UL approval mark	Type of approval	Type of product
VDE PR HOUSE MARK	Unconditional approval	Product meets all VDE standards
01 TRIANGLE MARK	Conditional approval	Product does not satisfy all standards, but if it is correctly installed into another assembled product, the assembled product will meet appropriate VDE standards.

TÜV and VDE

Both the TÜV and VDE carry out product testing and approval according the German VDE standards.

The Electrical Appliance and Material Control Law of Japan : Type A and Type B

The actual types of equipment covered by each type is laid down in the Electrical Appliance and Material Control Law Statutes.

Relays are not covered by this law, but as they are internal component parts of equipment, testing can be carried out by an electrical appliance testing center, which issues a test-result certification.

TV-rating

As a result of fires resulting from TV appliances in the U.S.A., in 1970 UL made new requirements on switches used for televisions. CSA implemented almost identical requirements as UL from 1971.

TV-rated switches must have an aperture area below a certain specified limit and an external casing of the self-extinguishing material 94V–0, which has an arcing resistance of at least 180 seconds. The switch contacts must be able to withstand tungsten lamp loads, which include a high inrush current.

TV switches are required to meet the standards laid down in UL 1270 (Radio Receivers, Audio, Systems and Accessories), and UL 1410 (Television Receivers and High Voltage Video Products) when the switches are used to switch the power circuit inside receiving equipment.

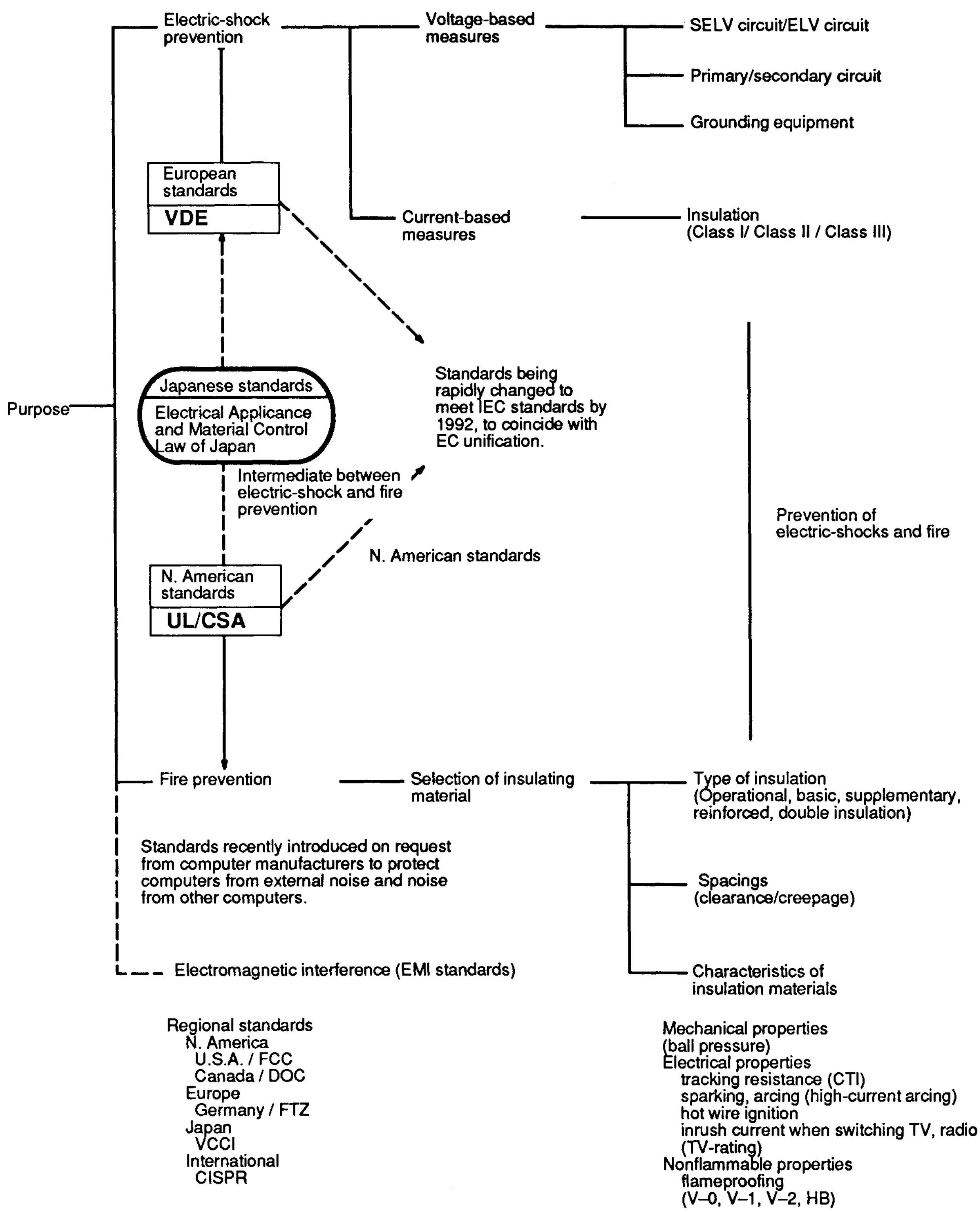
The CSA lays down similar standards in CSA C22,2 No. 1 (Radio, Television and Electronic Apparatus).

It is compulsory to use TV-rated relays for switching the power circuit is television, VTR, and audio equipment.

8–3–2 Terminology Used in Reports on Standards

A schematic layout of the terminology often seen in approved reports on relays is shown in the diagram below.

In addition to electric-shock prevention (the aim of European standards) and fire prevention (the aim of N. American standards), prevention of electromagnetic interference has now been included in the standards, reflecting the wishes of computer manufacturers.



Primary Circuit

An internal circuit which is directly connected to the external supply mains or other equivalent source (such as a motor-generator set) which supplies the electric power. It includes the primary windings of transformers, motors, other loading devices and the means of connection to the supply mains. (IEC 950 1.2.8.1)

Secondary Circuit

A circuit which has no direct connection to primary power and derives its power from a transformer, convertor or equivalent isolation device situated within the equipment.
Some solid state devices may provide equivalent isolation. (IEC 950 1.2.8.2)

Extra-low Voltage (ELV)

A voltage between conductors or between a conductor and earth not exceeding 42.4 V peak, or 60 V d.c., existing in a secondary circuit which is separated from hazardous voltage by at least basic insulation, but which does not meet the requirements for a SELV circuit nor those for a limited current circuit. (IEC 950 1.2.8.4)

Safety Extra-low Voltage (SELV)

A secondary circuit which is so designed and protected that under normal and single fault conditions the voltage between any two accessible parts, or between one accessible part and the equipment protective earthing terminal for class I equipment, does not exceed a safe value.

Under normal conditions this limit is either 42.4 V peak, or 60 V d.c. Under fault conditions higher limits are specified in this standard for transient deviation.
This definition of SELV circuit differs from the term SELV as used in IEC Publication 364: Electrical Installations of Buildings. (IEC 950 1.2.8.5)

Operational Insulation

Insulation needed for the correct operation of the equipment.
Operational insulation by definition does not protect against electric shock. It may however serve to minimize exposure to ignition and fire. (IEC 950 1.2.9.1)

Basic Insulation

Insulation to provide basic protection against electric shock . (IEC 950 1.2.9.2)

Supplementary Insulation

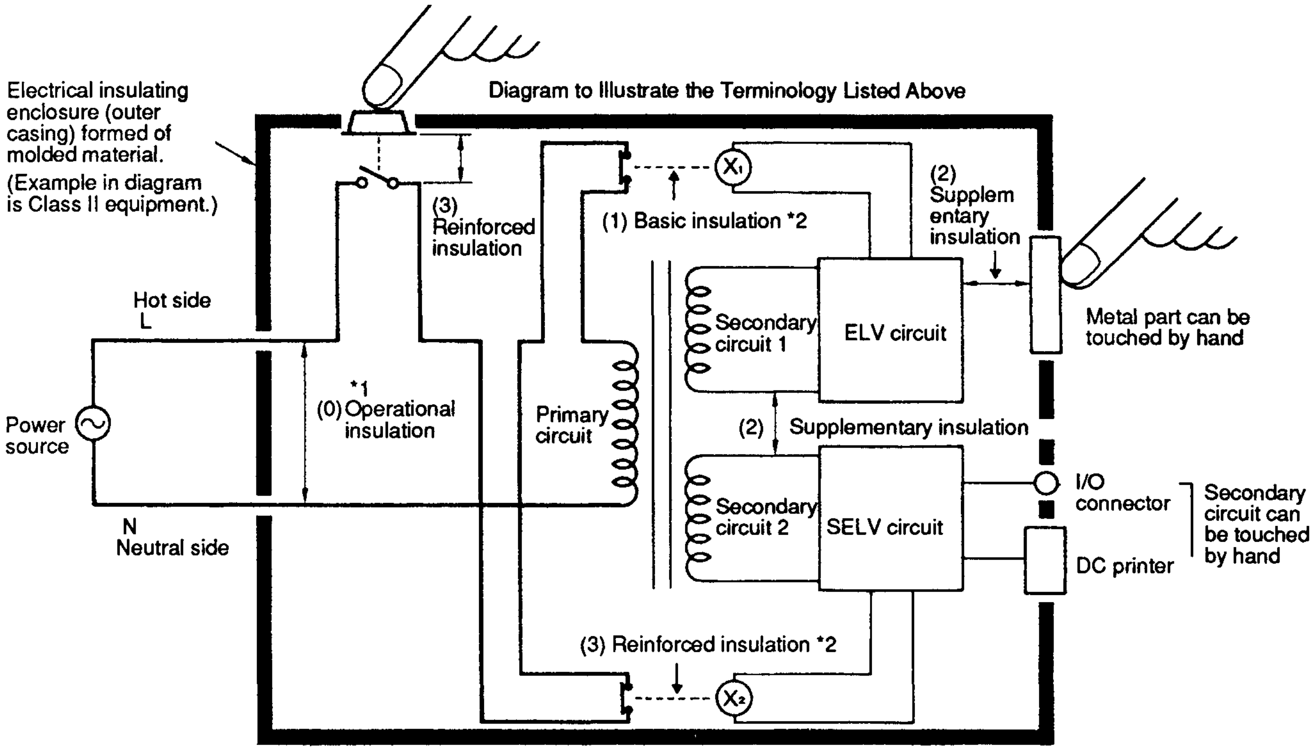
Independent insulation applied in addition to basic insulation in order to ensure protection against electric shock in the event of a failure of the basic insulation. (IEC 950 1.2.9.3)

Double Insulation

Insulation comprising both insulation and supplementary insulation. (IEC 950 1.2.9.4)

Reinforced Insulation

A single insulation system which provides a degree of protection against electric shock equivalent to double insulation under the conditions specified in this standard.
The term "insulation system" does not imply that the insulation has to be in one homogeneous piece. It may comprise several layers which cannot be tested as supplementary or basic insulation. (IEC 950 1.2.9.5)



Basic insulation (1) + Supplementary insulation (2) = Double insulation (the equivalent of reinforced insulation (3) with 2 x insulation distance of basic insulation)

*1 Operational insulation across transformer primary terminals (0).

*2 In some cases a relay can be used with the basic insulation (1), in other cases, the same relay requires double insulation or reinforced insulation (known as a Class II relay).

Classes of Equipment for Protection against Electric-Shock

Class I Equipment
(IEC 950 1.2.4.1)

Equipment where protection against electric shock is achieved by:

(a) using basic insulation, and also

(b) providing a means of connecting to the protective earthing conductor in the building wiring those conductive parts that are otherwise capable of assuming hazardous voltages if the basic insulation fails.

Class I equipment may have parts with double insulation or reinforced insulation, or parts operating in safety extra-low voltage circuits.

For equipment intended for use a power supply cord, this provision includes a protective earthing conductor as part of the cord.

Class II Equipment
(IEC 950 1.2.4.2)

Equipment in which protection against electric shock does not rely on basic insulation only, but which additional safety precautions, such as double insulation or reinforced insulation, are provided, there being no provision for protective earthing or reliance upon installation conditions.

Such equipment may be of one of the following types:

1) equipment having a durable and substantially continuous electrical enclosure of insulating material which envelops all conductive parts, with the exception of small parts, such as nameplates, screws and rivets, which are isolated from parts at hazardous voltage by insulation at least equivalent to reinforced insulation; such equipment is called insulation-encased Class II equipment.

2) equipment having a substantially continuous metallic electrical enclosure, in which double or reinforced insulation is used throughout; such equipment is called metal-encased Class II equipment.

3) equipment which is a combination of the above two types.

Class III Equipment
(IEC 950 1.2.4.3)

Equipment in which protection against electric shock relies upon supply from SELV circuits and in which hazardous voltages are not generated.

Creepage Distance and Clearance (IEC 950 1.2.10)

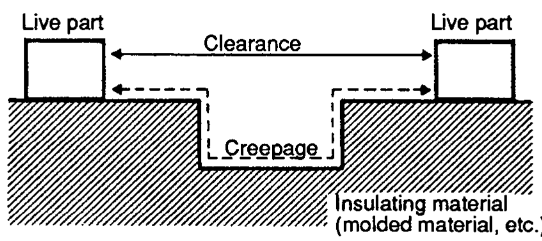
Creepage Distance

The shortest path between two conductive parts, or between a conductive part and the bounding surface of the equipment, measured along the surface of the insulation. (IEC 950 1.2.10.1)

Clearance

The shortest path between two conductive parts, or between a conductive part and the bounding surface of the equipment, measured through air. (IEC 950 1.2.10.2)

Creepage distance and clearance are illustrated on the diagram below.



According to IEC 950 2.9.3, the required values of the creepage distance depends on pollution degree and the CTI value of the insulating material between the charged parts.

Pollution Degree 1

No pollution or only dry, non-conductive pollution occurs. The pollution has no influence. The clearance has to be determined only according to the voltage as described in Sub-clauses 6.1 and 6.2. (IEC 664 6.3.1a)

Pollution Degree 2

Normally, only non-conductive pollution occurs.Occasionally, however, a temporary conductivity caused by condensation must be expected. The clearance has to be determined only according to the voltage as described in Sub-clauses 6.1 and 6.2. However, *the minimum clearance is 0.2 mm.* (IEC 664 6.3.1b)

Pollution Degree 3

Conductive pollution occurs, or dry, non-conductive pollution occurs which becomes conductive due to condensation which is expected. The clearance has to be determined only according to the voltage as described in Sub-clauses 6.1 and 6.2. However, *the minimum clearance is 0.8 mm.* (IEC 664 6.3.1c)

Pollution Degree 4

The pollution generates persistent conductive caused, for instance, by conductive dust or by rain or snow. The clearance has to be determined only according to the voltage as described in Sub-clauses 6.1 and 6.2. However, *the minimum clearance is 1.6 mm.* (IEC 664 6.3.1d)

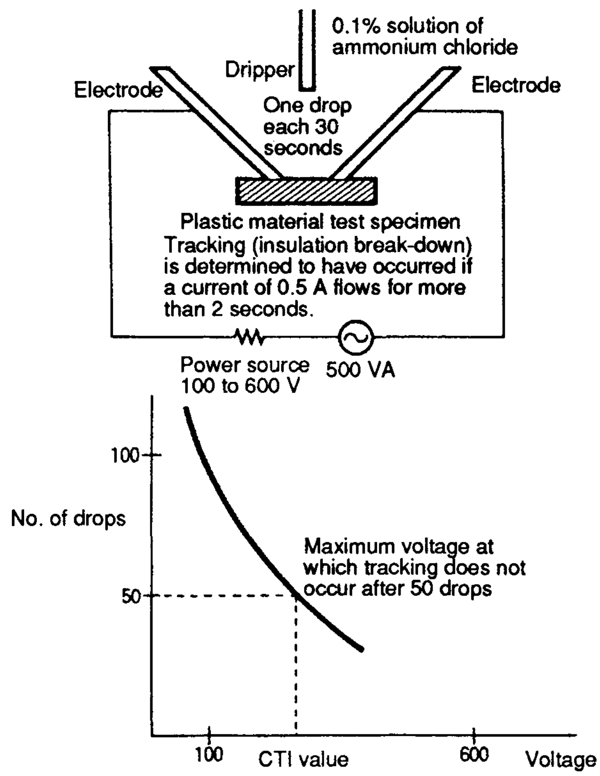
Note The minimum clearances given for pollution degrees 2, 3 and 4 are based on experience rather than on fundamental data.

CTI (Comparative Tracking Index)

CTI Measurement

The CTI is measured according to CTI and PTI measurement method A laid down in IEC 112.

A 0.1% solution of ammonium chloride is dripped at a rate of one drop per 30 seconds. The maximum voltage at which tracking does not occur after 50 drops is taken as the CTI value.



Classification of Plastic Materials According to CTI Value

Material group I : CTI value 600, or over
Material group II : CTI value from 400 up to 600
Material group IIIa : CTI value from 175 up to 400
Material group IIIb : CTI value from 100 up to 175

PLC Level Classifications (0 to 5) from UL Yellow Book

PLC level 0 : CTI value 600, or over
PLC level 1 : CTI value from 400 up to 600
PLC level 2 : CTI value from 250 up to 400
PLC level 3 : CTI value from 175 up to 250
PLC level 4 : CTI value from 100 up to 175
PLC level 5 : Less than 100

PTI (Proof Tracking Index)

The materials which have one of the five specified CTI values, 175, 250, 300, 375, and 500, are denoted as PT-175, PT-250, PT-300, PT-375, and PT-500, respectively.

IEC 335 (home appliances) and IEC 65 (television, videos, VTR's, etc.) specify PTI-175 or PTI-250 materials.

Dielectric Strength of each Type of Insulation

Type of insulation	Dielectric strength from IEC 950 (250 V circuit)
Operational insulation	1,500 V
Basic insulation	1,500 V
Supplementary insulation	1,500 V
Double insulation	3,000 V
Reinforced insulation	3,000 V

Spacings [(Pollution Degree 2(*1)) in a 250 V Circuit]

Spacings from IEC 950			
Basic insulation	Clearance		2.0 mm
	Creepage distance	Material group I	1.3 mm
		Material group II	1.8 mm
		Material group IIIa, IIIb	2.5 mm
Reinforced insulation *2	Clearance		4.0 mm
	Creepage distance	Material group I	2.6 mm
		Material group II	3.6 mm
		Material group IIIa, IIIb	5.0 mm

*1 : Pollution degree 2 is the environmental condition specified for a relay used indoors or inside a control box.

*2 : Reinforced insulation has twice the value of basic insulation. These creepage distances and clearances are required for Class II relays. Note that a small creepage distance is permitted for a material group with a high CTI value.

8–4 Power Supplies Worldwide

Relationship of Power Supply Voltage to Safety Standards in each Country

It was explained previously in section 8–1 that the purpose of safety standards differs somewhat between Europe and N. America. This difference arose from the differences in the power supply voltages: the voltage in Europe is approximately double the voltage in N. America or Japan.

As a result, the N. American standards (UL and CSA) make extremely strict flameproofing requirements on plastic materials in order to prevent fires. On the other hand, the European standards (VDE, etc.) are more concerned with insulating distances and insulating materials, to prevent electric-shock accidents due to the high voltages.

In Japan, where the supply voltage is approximately the same as the U.S.A., the Electrical Appliance and Material Control Law adopts an intermediate stance between N. America and Europe regarding plastic materials.

Although safety standards vary slightly from country to country, these standards are being changed to provide a single worldwide safety standard based on the IEC standards to coincide with EC unification in 1992.

Power Supply Voltage and Distribution System in each Country Proscribing Standards Related to General-Purpose Relays.

No.	Country	Frequency and error (Hz and %)	Domestic power supply voltage (V)	Commercial power supply voltage (V)	Industrial power supply voltage (V)	Voltage error (%)
1	United States of America Charlotte	60±0.06	240/120 (K) 208/120 (A)	460/265 (A) 240/120 (K) 208/120 (A)	14.4 KV 7.2 KV 2.4 KV 575 (F) 460 (F) 240 (F) 460/265 (A) 240/120 (K) 208/120 (A)	+5–2.5
	Detroit	60±0.2	240/120 (K) 208/120 (A)	480 (F) 240/120 (H) 208/120 (A)	13.2 KV 4.8 KV 4.16 KV 480 (F) 240/120 (H) 208/120 (K)	+4–6.6

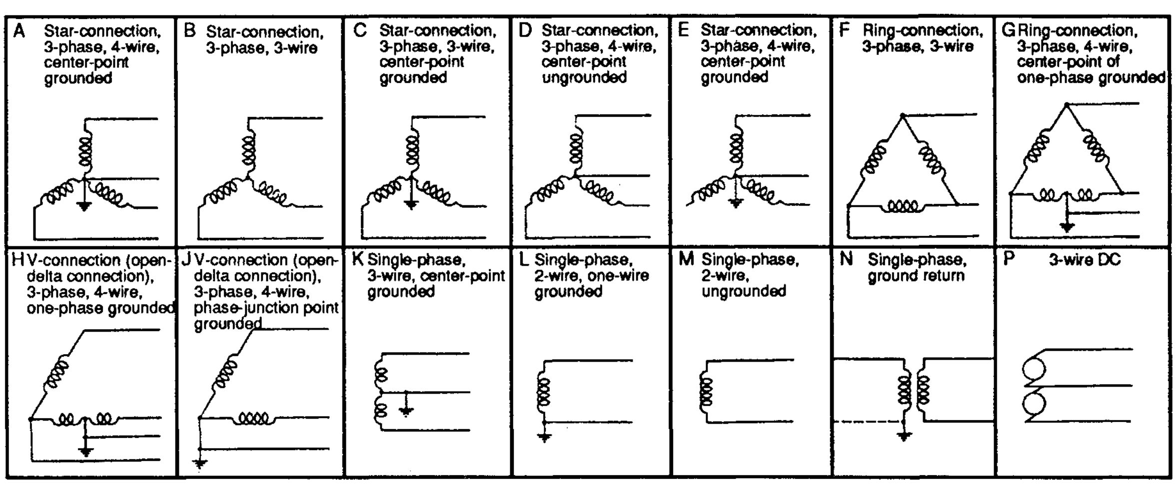
No.	Country	Frequency and error (Hz and %)	Domestic power supply voltage (V)	Commercial power supply voltage (V)	Industrial power supply voltage (V)	Voltage error (%)
	Los Angels	60±0.2	240/120 (K)	4.8 KV 240/120 (G)	4.8KV 240/120 (K)	±5
	Miami	60±0.3	240/120 (K) 208/120 (A)	240/120 (K) 240/120 (H) 208/120 (A)	13.2 KV 2.4 KV 480/277 (A) 240/120 (H)	±5
	New York	60	240/120 (K) 208/120 (A)	240/120 (K) 208/120 (A) 240 (F)	12.47 KV 4.16 KV 480/277 (A) 480 (F)	
	Pettsburgh	60±0.03	240/120 (K)	460/265 (A) 240/120 (K) 208/120 (A) 460 (F) 230 (F)	13.2 KV 11.5 KV 2.4 KV 460/265 (A) 208/120 (A) 460 (F) 230 (F)	±5 (light) ±10 (power)
	Portland	60	240/120 (K)	480/277 (A) 240/120 (K) 208/120 (A) 480 (F) 240 (F)	19.9 KV 12 KV 7.2 KV 2.4 KV 480/277 (A) 208/120 (A) 480 (F) 240.(F)	
	San Fransisco	60±0.08	240/120 (K)	480/277 (A) 240/120 (K)	20.8 KV 12 KV 4.16 KV 480/277 (A) 240/120 (G)	±5
	Toledo	60±0.08	240/120 (K) 208/120 (A)	480/277 (C) 240/120 (H) 208/120 (K)	12.47 KV 7.2 KV 4.8 KV 4.16 KV 480 480/277 (A) 208/120 (A)	±5
2	Italy	50±0.4	380/220 (A) 220/127 (E) 220 (L)	380/220 (A) 220/127 (E)	20 KV 15 KV 10 KV 380/220 (A) 220 (C)	±5 (city) ±10 (local)
3	Australia	50±0.1	415/240 (A)(E) 240 (L)	440/250 (A) 415/240 (A) 440 (N)(B)	22 KV 11 KV 6.6 KV 440/250 (A) 415/240 (A)	±6
4	Austlia	50±0.1	380/220 (A)(B) 220 (L)	380/220 (A)(B)	20 KV 10 KV 5 KV 380/220 (A)	±5
5	Holland	50±0.4	380/220 (A) 220 (E)(L)	380/220 (A)	10 KV 3KV 380/220 (A)	±6
6	Canada	60±0.02	240/120 (K)	600/347 (A) 480 (F) 240 (F) 240/120 (K) 208/120 (A)	12.5/7.2 600/347 (A) 208/120 (A) 600 (F) 480 (F) 240 (F)	+4 –8.3
7	Saudi Arabian	60±0.5 50±0.5	220/127 (A) 127 (L)	380/220 (A) 220/127 (A) 127 (L)	380/220 (A)(B) 220.127 (A)	±5
8	Spain	50±3	380/220 (A)(E) 220 (L) 220/127 (A)(E) 127(L)	380/220 (A) 220/127 (A)	15 KV 11 KV 380/220 (A)	±7

No.	Country	Frequency and error (Hz and %)	Domestic power supply voltage (V)	Commercial power supply voltage (V)	Industrial power supply voltage (V)	Voltage error (%)
9	Denmark	50±0.4	380/220 (A) 220 (L)	380/220 (A) 220 (L)	30 KV 10 KV 380/220 (A)	±10
10	The Federal Republic of Germany (West Germany)	50±0.3	380/220 (A) 220 (L)	380/220 (A) 220 (L)	20 KV 10 KV 380/220 (A)	±10
11	Japan (East)	50±0.2	200/100 (K) 100(L)	200/100 (H)(K)	6 KV 200/100 (H) 200 (G)(J)	±10
	Japan (west)	60±0.1(5)	210/105 (K) 200/100 (K) 100 (L)	210/105 (H)(K) 200/100 (K) 100 (L)	22 KV 6 KV 210/105 (H) 200/100 (H)	±10
12	Norway	50±0.2	230 (B)	380/220 (A) 230 (B)	20 KV 10 KV 5 KV 380/220 (A) 230 (B)	±10
13	Finland	50±0.1	220 (L)	380/220 (A)	660/380 (A) 500 (B) 380/220 (A)(D)	±10
14	France	50±1	380/220 (A) 220 (L) 220/127 (E) 127 (L)	380/220 (A)(D) 380 (B)	20 KV 15 KV 380/220 (A)(D) 380 (B)	±10
15	Belgium	50±3	380/220 (A) 220/127 (A) 220 (F)	380/220 (A) 220/127 (A) 220 (F)	15 KV 6 KV 380/220 (A) 220/127 (A) 220 (F)	±5 (daytime) ±10 (nighttime)

Note
1. Domestic distribution is normally carried out with a single-phase voltage and A or G type (neutral) ground.
2. Varies according to region.
3. The line dividing the 50 Hz supply in east Japan and the 60 Hz supply in west Japan is a vertical line running through the city of Shizuoka.
4. Remote regions are supplied by a single-wire ground return system.

Worldwide Distribution Systems

The letters A to P were used to denote distribution systems in the table above. The key to these letters is given below.



SECTION 9
Troubleshooting and Maintenance

9–1 Troubleshooting

A variety of relay-related problems may occur in equipment in which relays are mounted. When a relay becomes defective, the problem has to be traced using the FTA (fault-tree analysis) approach.

The problems which may occur with a relay are listed with the probable causes in the table below.

9–1–1 Problems Visible Externally

Problem	Check	Probable cause
Relay does not operate	No input voltage applied to relay	• Circuit breaker or fuse blown • Wiring incorrect or short-circuited • Screw terminals loose
	Relay not suitable for the input voltage	• 200 to 240 VAC relay used on 100 to 120 VAC voltage line
	Relay input voltage too low	• Power supply capacity too low • Wiring too long
	Defective relay	• Discontinuity in coil • Mechanism damaged due to being dropped or shock
	Abnormal output circuit	• Output power supply • Defective load • Incorrect wiring • Defective connection
	Defective contact	• Defective relay contacts • Contacts worn through long use • Mechanical damage
Relay does not reset	Input voltage not completely cut off	• Leak current in protective circuit (surge absorber) • Voltage applied from bypass circuit • Residual voltage from semiconductor control circuit
	Defective relay	• Fused contacts • Deteriorated insulation • Damaged mechanism • Inductive load (wiring too long)
Relay malfunctions (operation indicator lamp lights incorrectly)	Abnormal voltage applied to relay input terminal	• Inductive load (wiring too long) • Bypass circuit due to inductive load (latching relay does not latch)
	Vibrations or shocks too strong	• Poor operating environment
Burning	Burning caused by coil	• Incorrect coil specification • Voltage exceeds rated voltage applied • Incomplete electromagnet operation with AC specification (armature not attracted correctly to coil)
	Burning caused by contacts	• Current exceeds rated coil current • Inrush current exceeds permitted limit • Short-circuit current • Defective external contact (heating due to defective contact in the socket, etc.)

9–1–2 Problems Visible Internally

Problem	Check	Probable cause
Burned contact	Current too large	• Rush current from lamp, etc. • Short-circuit current from resistive load
	Abnormal vibration of contacts	• External shocks or vibrations • Buzzing of AC relay • Chattering because of incomplete operation due to low voltage (possibly an instantaneous voltage drop when a motor is started)
	Switching frequency too high	—
	Relay use exceeds the life-expectancy	
Defective contact	Foreign matter stuck to contact surface	Silicon or carbon particle sticking to contact
	Corrosion of contact surface	Sulfurization of contact due to SO^2 or H^2S
	Contact defect caused by mechanism	Misplaced terminal or contact, contact follow
	Worn contacts	Life-expectancy exceeded
Buzzing	Applied voltage too low	• Incorrect coil specification • Ripple in power supply • Gradual increase in supply voltage
	Incorrect type of relay	DC-specification relay used in AC line
	Incomplete electromagnet operation	Foreign matter between armature and coil
Abnormal contact wear	Incorrect type of relay	Incorrect rated voltage, current, or inrush current
	Problem caused by load	Inrush current from motor, solenoid, or lamp load

9–2 Maintenance Philosophy

Two basic types of relay maintenance are carried out: replacing and inspecting relays after failure, and preventative maintenance carried out before failure occurs.

Deciding when to inspect or replace relays is a very important part of preventative maintenance.

Considering an entire system, the factors affecting the preventative maintenance timing are the importance of the unit in the system and the required degree of reliability. Considering the relays themselves, the factors are the characteristics of the relay and its failure modes.

The failure modes of a relay can be broadly categorized into wear failure caused by wear and abrasion of the contacts, and deterioration failure, such as shorting between the coil layers.

When a particular type of relay is used normally, the time until the relay experiences a wear failure is determined by the number of switching operations, so that it is often possible to predict and prevent such failures. Deterioration failures, on the other hand, are greatly affected by the inherent reliability of the relay itself. For this reason, the timing of this type of failure is determined by operating and environmental conditions affecting the reliability of the relay, in addition to the length of time the relay is used. Consequently, the time of failure varies from relay to relay, so that it is difficult to predict the timing of this type of failure.

Both wear and deterioration proceed together when a relay is used in practice

so that it is important to determine which failure mode will occur first in order to decide when to carry out maintenance. The information in the table below can be used as a reference for deciding on the relay maintenance timing.

		Maintenance timing	**Applicable axis**		**Comments**
Wear	Wear of contacts	The maintenance timing is determined from the appropriate electrical life-expectancy curve for the load voltage, current, and type of load. If no such information is available, the maintenance timing is determined experimentally with the relay installed in the equipment.	No. of operations axis	—	The time axis may be used if the maximum number of switching operations in a certain period is fixed.
	Wear of moving parts	The maintenance timing is determined from the appropriate mechanical life-expectancy curve. Note that the mechanical life-expectancy is measured under standard test conditions. If the actual operating conditions differ from the standard conditions, the maintenance timing is determined experimentally under the actual conditions.		—	
Deterioration	Deterioration of coil or coil winding insulation	The life of the insulation can be predicted if the actual operating temperature of the coil is known. For polyurethane-coated copper wire at a temperature of 1205C, the insulation life is normally taken as 40,000 hours.	—	Time axis	—
	Contact stability	Basically determined by the inherent reliability of the material, but greatly affected by the operating conditions and environment. The maintenance timing is determined by sampling after determining the operating conditions and environment.	—	Time axis	It is important to determine concentrations of gases harmful to the contact materials in the operating environment
	Characteristics of metal parts				
	Characteristics of plastic parts				

Appendix A
Markings Used on Relays

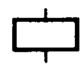
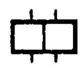
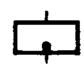
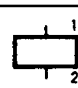
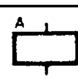
Two similar sets of markings are prescribed for use on relays as follows:

JIS specifications within Japan
IEC specifications overseas.

The symbols are used to show connections on electrical circuit drawings.

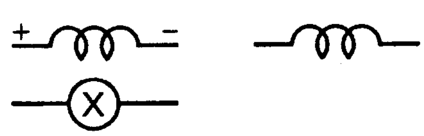
Coil Symbols (JIS C 0301)

The symbols used for coils are shown in the table below

Symbol	Meaning
	Single winding
	Compound windings
	Single winding with winding start-mark
	Single winding with resistance display
	Single winding with terminal number display
	Name display

Coil Symbols

The following symbols are marked on the relays themselves and in catalogs.



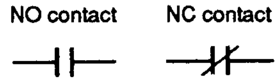
Contact Symbols

The symbols for the main types of contact are shown in the table below.

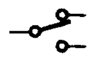
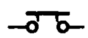
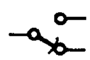
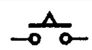
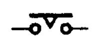
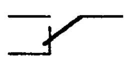
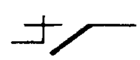
NO contact	NC contact	Switching contact	MBB contact
			

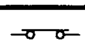
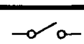
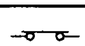
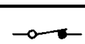
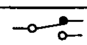
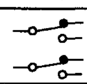
The following symbols are used to create ladder diagrams for relay sequence circuits.

NO contact NC contact



Contact Symbols (JISC0301)

Symbol	Meaning
	NO contact
	NC contact
	Switching contact
	Time limit contact
	Time limit contact
	Make contact
	Time Limit NO contact
	Time Limit NC contact
	Switcing contact
	Make-before-break contact (or Overlap contact)
	NO contact
	NC contact
	NO contact
	NC contact

Symbol	Contact form	
	American style	European style
 	SPST-NO (Single-Pole, Single-Throw, Normaly-Open)	Form 1 A
 	SPST-NC (Single-Pole, Single-Throw, Normaly-Close)	Form 1 B
	SPDT (Single-Pole, Double-Throw)	Form 1 C
	DPDT (Double-Pole, Double-Throw)	Form 2 C

Glossary

General Terms

Hinged type relay	The armature rotates about a pivot point to directly or indirectly open and close the contacts.
Plunger type relay	The armature is in the center of the coil, and moves along the coil axis.
Rated coil voltage	The standard voltage value applied to the coil for normal relay operation. This voltage is the standard voltage required to guarantee all relay functions.
Rated current	The standard current value input to the coil for normal relay operation. Rated power consumption The amount of power consumed by the relay coil when the rated voltage is applied to it.
Maximum permitted voltage	The maximum permitted voltage within the range of fluctuation of the relay control power supply. The maximum permitted voltage is determined from estimated fluctuations of the control power supply. The coil may burn out or the coil insulation deteriorate if the relay is used continuously at this voltage.
Operating voltage (current)	The relay operates at this voltage (current) when the input is increased with the relay in the reset condition. Also known as the must-operate voltage.
Reset voltage (current)	The relay resets at this voltage (current) when the input is decreased with the relay in the operated condition.
Rated insulation voltage	The standard voltage used for insulation design. Determined from the insulation distances across gaps and along surfaces.
Contact resistance	The resistance across the relay contacts, including the resistances of the conductors, such as the contacts themselves.
Reset time	The time required for the contacts to reset after the input to the coil is cut off. In a relay with more than one contact, this is the time for the slowest contact to reset. This time does not include the bounce time.
Insulation resistance	The electrical resistance between insulated conductors and between charged and non-charged parts. For a relay with a rated insulation resistance up to 60 V, the insulation resistance is measured at 250 V; for a relay with a rated insulation resistance over 60 V, it is measured at 500 V.
Dielectric strength	Indicates the dielectric strength of the insulation.
Impulse withstand voltage	The instantaneous abnormal voltage, due to lightning or switching an inductive load, that the relay can withstand.
Vibration resistance	The amount of vibration that the relay can withstand during transportation and operation. Indicates the durability of the relay and its tolerance of misuse.

Shock resistance The amount of shock that the relay can withstand during transportation and operation. This value is used to evaluate the durability of the relay and its tolerance of misuse.

Rush current A current larger than the normal current which flows when the contacts open or due to some transient effect.

Mechanical life expectancy The mechanical limit of the number of times the relay contacts can be switched at the rated switching frequency with no load applied. This value is used to evaluate the drop in performance, abrasion, and cyclic stresses after prolonged use of the relay.

Electrical life expectancy The life of the relay operated at the rated switching frequency with the rated load applied to the contacts. This value is used to evaluate the contacts, the insulation near the contacts, and the drop in performance after prolonged use of the relay.

Terms Related to Contacts

Switching section The entire switching mechanism of the relay, comprised of the contacts, movable arm, internal conductors, terminals, insulating materials, etc.

Normally open contact The circuit is open when the relay is reset. The circuit is closed when the relay operates or is in the holding condition. Also referred to as the NO contact or Form A contact (in Europe).

Normally closed contact The circuit is closed when the relay is reset. The circuit is open when the relay operates or is in the holding condition. Also referred to as the NC contact or Form B contact (in Europe).

Switching contact When the relay operates, the NC contact opens and the NO contact closes. Also known as the transfer contact or Form C contact (in Europe).

Make-before-break contact A combination of two contacts. When the relay operates or resets, the contact that closes a circuit operates before the contact that opens a circuit.

Rated load The load that serves as the reference in determining the performance of the switching section.

Contact voltage The voltage that serves as the reference in determining the performance of the switching section.

Contact current The current that serves as the reference in determining the performance of the switching section.

Rated carry current The value of the current that can continuously flow through the relay contacts while the contacts are not switched, which allows the relay to stay within the allowable temperature rise limit. Take care when choosing a relay and socket combination, as in some cases the rated values may differ.

Contact pressure The force that the contacts exert on each other when they are closed.

Moveable contact A contact that can be directly driven by a drive mechanism or part of a drive mechanism.

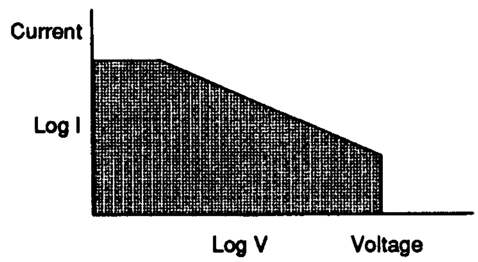
Fixed contact A contact that cannot be directly driven.

Twin contact The end of the arm (fixed or moveable) is divided into two forks, with a contact at the tip of each fork. This configuration increases the contact reliability. Also known as a bifurcated contact.

Conversely, only one contact at the end of the armature is known as a single contact.

Maximum switching capacity The maximum load that can be switched by the relay in practice.

The relay must be used in the shaded area of the curve shown in the diagram.



The life expectancy of the relay depends on the maximum switching capacity, so that the life expectancy must be estimated from the life-expectancy curve.

Minimum permissible load Gives an indication of the lower limit of the switching capacity for minute loads in electronic and other circuits. This value is used to evaluate the failure level of the relay. However, the relay should also be checked under actual load conditions.

Terms Related to the Electromagnet

Coil Windings to convert electrical energy into magnetic energy. Some relays also have special-purpose coils, such as an operating coil, reset coil, or holding coil.

Shading coil When operating a relay with an alternating current, buzzing can occur due to fluctuations in the attractive force caused by the current waveform. To overcome this, the attraction face of the core is divided and a short-circuit ring inserted. By delaying the magnetic flux flowing through it, the short-circuit ring prevents the fluctuations in the attractive force. This arrangement with a short-circuit ring is known as a shading coil.

Reset spring This spring returns the moveable armature to the reset condition. With an NC contact, the reset spring also provides the contact pressure.

Moveable armature The part of the magnetic circuit that converts magnetic energy into mechanical energy.

Core This is inserted inside the coil to effectively exploit the magnetomotive force produced by the coil.

Yoke The part of the magnetic circuit that links the core to the moveable armature.

Card A card-shaped insulator that transmits the drive from the moveable armature to the moveable arm.

Terms Related to the Relay Phenomena

Coherer effect	If the electrical contact is made through a film formed on each surface of the relay contacts, this film breaks down electrically when the contact voltage reaches a certain value, resulting in a rapid decrease in contact resistance.
Migration	A metal moves over the surface of an insulating material with time, causing deterioration of the insulator. This phenomenon occurs readily in a high-temperature, high-humidity environment, particularly when a direct current is applied. A common example of this phenomenon is the migration of silver over phenol resin.
Insulation breakdown	The sudden loss of insulating properties of an insulating material between two electrodes when a voltage is applied.
Flashover	A discharge causing a short-circuit between two opposing conductors. This phenomenon is common between contacts handling medium to large currents.
Chattering	Open contacts repeatedly open and close due to external causes. The duration time of this phenomenon is called the chattering time.
Bounce	An undesirable intermittent bouncing (opening and closing) of the contacts after they make or break the circuit. The duration time of this phenomenon is called the bounce time.
Deposition	Some of the metal from one contact is deposited on the opposing contact due to Joule heat, or to electrical discharge from on, or near, the contact surface.
Adhesion	The contacts become difficult to open due to some cause other than fusing of the contact surfaces or mechanical interlocking.
Fusing	The contacts become difficult to open due to fusing of the contact surfaces or parts near the contact surfaces.
Locking	The contacts become difficult to open due to mechanical interlocking caused by deformation of the contacts from abrasion or deposition.
Sticking	The contacts become difficult to open due to fusing, locking, or adhesion.
Contact abrasion	Removal of part of the contact by mechanical causes, such as friction, during the repeated opening and closing of the contacts.
Contact wear	Removal of part of the contact by electrical, thermal, or chemical causes during the repeated opening and closing of the contacts.

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