

## 5 MAGNETIC SYSTEM - COIL

### 5.1 Magnetic system

The magnetic, coil system or motor unit is also called the energizing or primary side of a relay. It consists of all the parts used to transform the electrical energy in the primary side into mechanical force to actuate the contacts and switch the secondary circuit.

#### Magnetic circuit

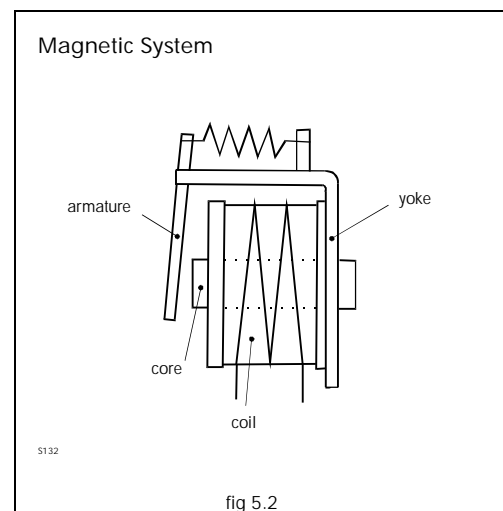
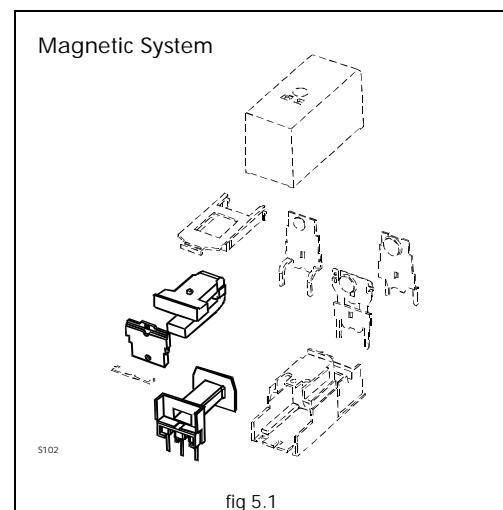
The magnetic circuit consists of non moving metal parts such as the core, yoke and a movable armature, and an air gap between the armature and the pole area of the core.

The armature closes and opens under the influence of a magnetic field, its movement directly or indirectly operating the relay contacts.

The magnetic field is generated by a coil consisting of copper wire wound in layers around the bobbin in which there is an iron core.

If voltage is applied to the coil terminals a current (Ohms law  $I=U/R$ ) flowing through the coil generates a magnetic field and hence magnetic flux. This induced magnetic field/flux is directly proportional to the coil current and the number of turns of the coil ( $H \approx n \cdot I$ ,  $H$ =magnetic field,  $n$ =number of turns,  $I$ =coil current).

Due to the high permeability of the soft magnetic iron core in comparison with air, the magnetic field concentrates within the magnetic circuit (except the stray field). The



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only non iron (low permeability) part of the magnetic circuit is the air gap between the armature and the core. In this air gap an attracting force pulls on the armature. If the magnetic field is strong enough it will pull-in the armature towards the core, closing the magnetic circuit. In turn, the moving armature directly or indirectly operates the relay contacts.

### Classification of magnetic systems

The field/flux necessary to actuate the armature can also be generated by a coil combined with a permanent magnet (see polarized relays).

Sufficient energy to maintain the closed position of the magnetic circuit can be provided either by the coil (neutral monostable relays), by the remanence effect of the iron core (bistable remanence relays) or by permanent magnets (bistable polarized relays).

The magnetic systems of relays are grouped according to their function in monostable and bistable relays, and with respect to the method of generating the magnetic field in neutral and polarized relays.

#### 5.1.1.1 Monostable relays

monostable relays have only one stable position - OFF. To actuate the contacts the coil has to be energized. These relays always assume their defined OFF position in the non energized state.

#### Neutral relays

the necessary magnetic flux is built up entirely by the coil, being designed to work efficiently from either a DC power source or from an AC power supply e.g. the mains supply. Most power relays are monostable relays with a neutral coil system.

### Polarized relays

polarized relays generate the required magnetic field for actuating the armature partly by the coil and partly by a magnet, superimposing the two magnetic fluxes. For the correct superimposition, the coil supply voltage has to be applied in the correct polarity.

Polarized systems can be more sensitive, but in general are more expensive.

### Bistable relays

also called latching relays, retain their switched position after interruption of the energizing current through the coil. To reset the relay a counter-energization of the coil is necessary.

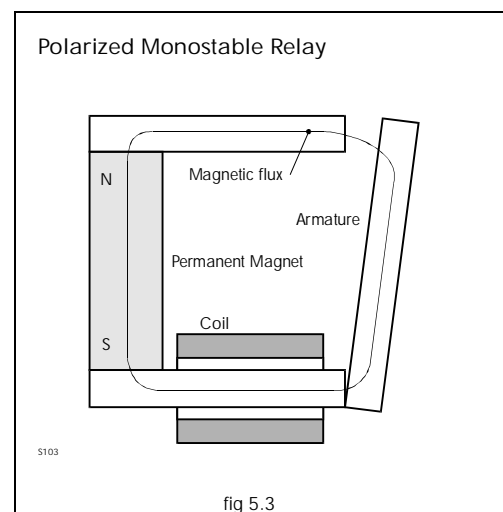
These relays have two stable positions, ON and OFF, and maintain their last actual switching position. To change the switching state, an energy supply is needed.

Bistable relays can be:

### Remanence relays

the remanence effect is where magnetism in the semi-hard magnetic material of selected iron parts of the magnetic circuit retain enough energy to keep the relay in the ON (or pulled-in) position without any other energy supply.

To change the switching state, coil current is required to demagnetize the magnetic circuit and let the armature drop back.



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### Polarized

the switched position is maintained by the effect of a permanent magnet

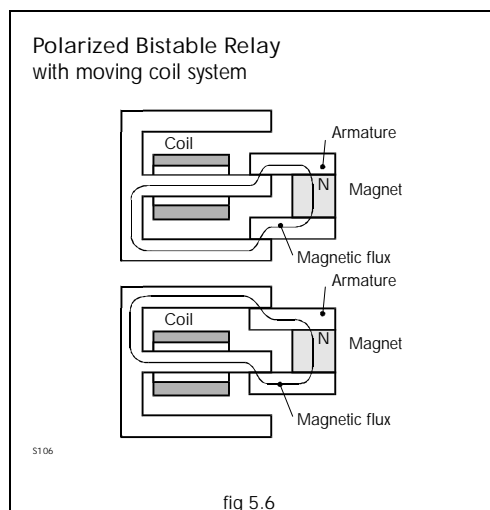
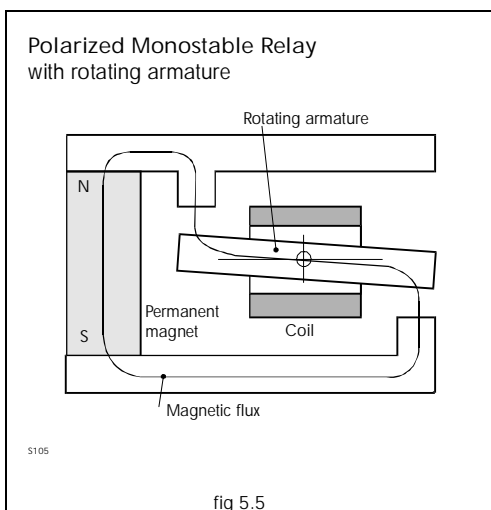
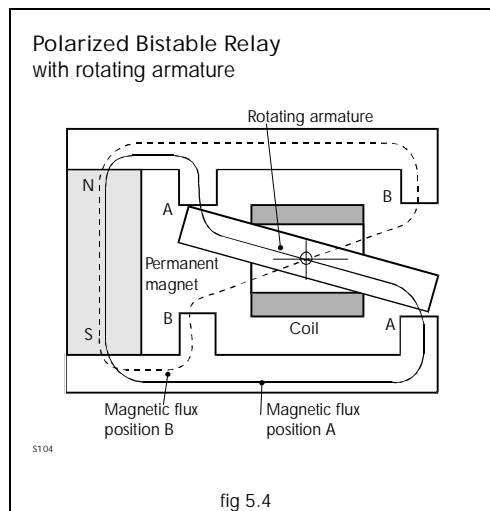
As bistable relays stay in their previous switched position, special care has to be taken to define the relay contact position before use.

If a relay is subjected to mechanical shock or vibration exceeding its specification during shipping, installation, or use, it may change state.

It is advisable to use an electronic circuit to check contact position and set the relay into its required state (set or reset) whenever the power is turned on.

### Mechanical latching

the last switching state is maintained by mechanically locking the armature. These relays are not used so much in modern applications mainly because of their size.



### Classification of component design

Relays may also be classified according to the working principle and design of magnetic circuit and armature:

- flat armature or clapper type is the most common

- pivoting armature (fig 5.5)
- moving coil: The coil and core are designed as an armature and are mounted at their centre of gravity. Relays of this design are highly sensitive, but due to their large mass and armature movement, require long pull-in and drop-out times.

## 5.2 Coil

Current flowing through the coil generates the magnetic field/flux.

The coil must be energized sufficiently by the power source to generate the required magnetic field and force to operate the system at all times and under various conditions. Together with the magnetic system, the coil design has a major effect on various parameters such as sensitivity, operating speed, power consumption, maximum operating temperature, etc.

### Electrical terms

#### Coil voltage

is the voltage applied to the coil terminals that drives the coil current as a function of coil resistance (Ohms law  $U=R*I$ ).

Although the current is the primary factor in generating flux and the pull force in the magnetic system, it is common practice to work with voltages to select and specify the relay coil.

#### Nominal values

are the value to which other characteristics of a relay are specified or referred.

#### Coil current

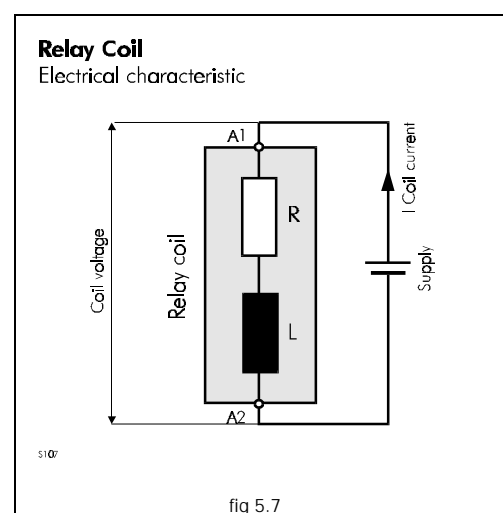
is the current passed through the coil as result of applied voltage, generates a magnetic field and flux which in turn creates the magnetic pull force between the armature and the pole (core).

#### Coil resistance

The principal parameters dictating coil resistance ( $R_{coil}$ ) are the specific resistance of copper ( $R_{copper}$ ), the cross section of the wire ( $A$ ) and the length of the wire ( $l$ ).

The resistance is  $R_{coil} = R_{copper}(T) * l / A$ .

The coil resistance changes as the specific resistance of copper varies with temperature. Generally, the nominal value for coil resistance is given for a coil temperature of



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20°C/68°F. However, in some cases, the resistance may be given for temperatures other than this standard value.

The variation of coil resistance is  $\pm 10\%$  for low nominal coil voltages and up to  $\pm 15\%$  for high nominal coil voltages (e.g. 110VDC) owing to variations in the diameter of the coil wire.

### Coil inductance

As a result of the high number of turns, the soft iron magnetic circuit, and low magnetic resistance, relay coils have a relatively high inductance. The inductance is dependent on the number of turns and of the length of the air gap (which varies according to the position of the armature) between pole and armature.

Open magnetic system, unenergized:

big air gap, resulting in lower inductance

Closed magnetic system, armature pulled in:

zero to very small air gap, high inductance

Effects of inductance on coil voltage and current:

### DC coil

coil current is delayed with respect to the driving supply voltage. The necessary current for actuation of the relay (pull-in current), will only be built up after a certain delay after applying the coil voltage, giving the electrical response time.

When switching off the supply voltage a high voltage peak will be induced in the coil due to the back EMF, making protection circuits necessary (such as flywheel diodes) to protect coil driving transistors and other electronic components.

In the case of a circuit with flywheel diodes the inductance keeps the coil current flowing after the coil voltage has been switched off and the induced coil current is sufficient to keep the relay in the pulled-in state delaying the drop-out.

### AC coil

the AC coil impedance (resistance + reactance) is higher than the resistance and increases with the frequency of the coil supply. Thus, the coil current at 60Hz is lower compared to a 50Hz supply.

### Number of turns, ampere turns

The induced magnetic field/flux is directly proportional to the coil current and the number of turns ( $H \approx \text{number of turns} \times \text{coil current}$ ).

The energization of the magnetic circuit may therefore be expressed in terms of ampere turns. In order to generate the required magnetic field for actuating the relay, the coil has to be energized with sufficient ampere turns. The ampere turns required to operate a relay depend on the design of the magnetic circuit and will be the same for one type of relay design, regardless of the nominal coil voltage.

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### Relationship between basic electrical values

To generate a satisfactory magnetic field a defined value of ampere turns, has to be provided, depending on the relay design.

The coil current is a result of the applied coil voltage and the coil resistance ( $I=U/R$ ). The resistance is dictated by wire diameter and length. The number of turns is dictated by the coil diameter and length of the coil wire.

Coil	U voltage	R resistance	L inductance
$U_2=$		$U_1 \cdot (R_2/R_1)^{1/2}$	$U_1 \cdot (L_2/L_1)^{1/2}$
$R_2=$	$R_1 \cdot (U_2/U_1)^2$		$R_1 \cdot (L_2/L_1)$
$L_2=$	$L_1 \cdot (U_2/U_1)^2$	$L_1 \cdot (R_2/R_1)$	

fig 5.8

Inductivity is a function of the design of the magnetic system and the number of turns on the coil.

As can be seen, the values of voltage, resistance, current and number of turns are directly interrelated and cannot be chosen arbitrarily. The following table gives the calculation formulae to calculate the respective dependent variables.

### Power consumption

The coil, while energized, consumes power. The power for actuating the relay is dependant on relay design. For monostable relays, power has to be continuously supplied to pull-in (operate) the relay. The nominal power rating is the power consumption of the relay coil at nominal voltage, current and coil resistance.

The power consumption for:

- DC coils: is the product of coil voltage and coil current or according to Ohms law  $P=U \cdot I=U^2/R=I^2R$ , given in Watts.
- AC coils: is the product of coil voltage and current and the coil power factor  $\cos \phi$  (due to the coil inductance)  $U \cdot I \cdot \cos \phi$ . The coil power is given in VA, usually for a 50Hz supply. At 60Hz the impedance of the coil is higher than at 50Hz and the coil power consumption is, therefore, lower.
- bistable relays: power will only be consumed for the usually short time the coil is energized, as the contact position will be maintained by remanence effect.
- polarized relays: only consume little coil power, as the actuating force is not only generated by the coil but also by superimposing the induced magnetic field with a field created by a permanent magnet.

Input power for power relays ranges from approximately 1.2W to 1.5VA for industrial power relays and down to 100mW for miniature PCB relays.

The lower the input power the less heat is generated. This can be particularly important in temperature critical applications such as those where relays are densely packed on a pcb.

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Coil power for other than nominal voltages: the power consumption increases or decreases with the square of the coil voltage ( $P=U^2/R$ ).

For a coil energized at the pull-in voltage, or where the relay position is maintained with a holding voltage, the coil power consumption will be drastically reduced compared to nominal power.

Example:

A relay with nominal voltage of 12V, coil current of 16.7mA and coil resistance of 720Ω consumes the nominal power of

$$P=U \cdot I = U^2/R = I^2 \cdot R = 200\text{mW}$$

The pull-in power at the pull-in voltage of 8.4V is only  $P=U^2/R=98\text{mW}$

The hold power for a minimum holding voltage of 4.5V is

$$P=U^2/R=28\text{mW}$$

### Coil sensitivity

The higher the coil resistance the lower the coil current for a defined nominal coil voltage. The lower the power consumption, the higher the sensitivity of the relay.

The advantages of high sensitivity are the possible use of smaller power supplies, lower heat generated by the relay, and the possibility of direct control by transistors. A disadvantage might be higher sensitivity to electrical and magnetic interference.

### Coil heating

A negative effect of power consumption is the heating of the coil and, in turn, the entire relay. The coil temperature is a result of:

#### Ambient temperature

for an unenergized coil under thermally stable conditions, the coil temperature and the ambient temperature are the same.

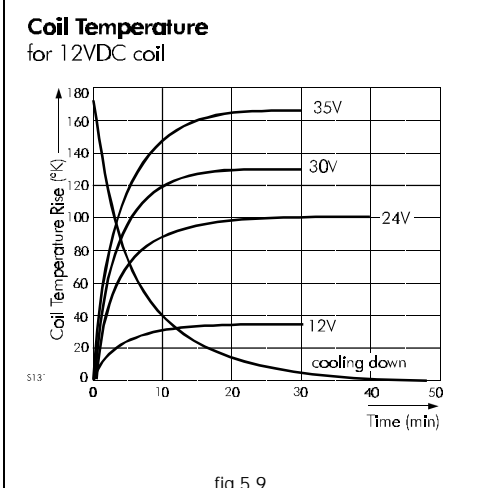
#### Self heating

due to coil power consumption ( $U \cdot I$ ,  $U^2/R$ ,  $I^2 \cdot R$ ), heat is dissipated via the coil and relay surface. Dissipation is directly proportional to the difference between ambient and coil temperature and the size and quality of the dissipation surfaces (relay size, mounting, ventilation, etc.).

The temperature rise per unit of applied coil power is called the thermal resistance of a relay.

The final coil temperature is reached some time after applying the power to the coil. This delay is defined as the thermal time constant of the coil.

Temperature rise for pulsed voltage and low

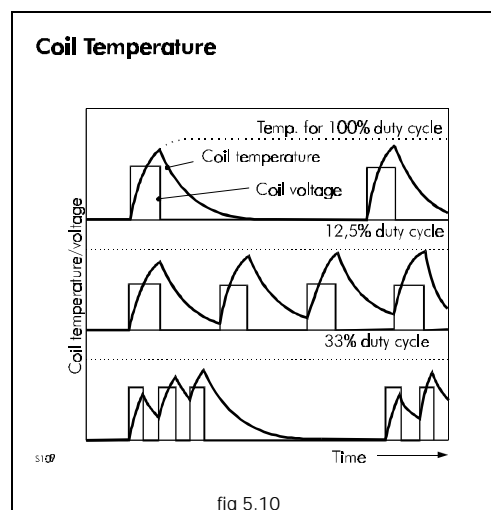




duty cycle rates: when a relay coil is energized for less than two minutes, the coil temperature rise varies with the ratio of ON time to OFF time. Compared to continuous operation, the final coil temperature rise will be less. The shorter the energization time of the relay the lower the self heating effect. Various relay designs are essentially the same in this respect.

COIL TEMPERATURE	
ON/OFF relation	temperature rise approximately
100% ON	100%
3:1	80%
1:1	50%
1:3	35%

The energization time for pulsed coil supply may be expressed in terms of duty cycle. Duty cycle is the ratio of ON time (relay coil energized) to the total cycle time. (Cycle time is the sum of the ON time and OFF time interval of a periodically energized relay.) For low values of duty cycle and short ON time compared to the thermal time constant of the relay, the temperature rise will be low.



#### Induced heating

Coil heating caused by heat generated by the contact system.

The load on the contact system (contact current, contact resistance, resistance of contact springs etc.) generates heat which in turn heats other relay parts such as the coil.

As an estimate, an induced coil heating of approximately 10°C may be used for contacts being used at their rated load.

#### Magnetization losses

Heating, as a result of additional magnetization losses in the magnetic circuit of AC coil systems (eddy currents), depends on the applied frequency and the saturation of the magnetic circuit. For coil voltages well above the nominal voltage these losses are significantly increased.

#### Other sources

Heating from other components in the vicinity of the relay such as other relays. Since the temperature of densely mounted relays are raised by mutual interaction, the temperature

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increase should be checked. Special care should be taken when installing a card in a rack with a high number of relays per PCB.

The total coil heating and final coil temperature is the sum of the temperature rises caused by these effects.

Where coil temperature is critical, bistable relays offer the advantage of needing only a very short coil energizing time. The armature is kept in the pulled-in position without further energy from the supply. The temperature rise, in this case, is only due to induced heating by the contact system.

### Coil resistance as function of coil temperature

practically all relay coils are made of copper wire. The resistance of copper wire increases/decreases by 0.4% per degree C.

Usually the nominal coil resistance is given for an ambient temperature of 20°C. A coil at this temperature is referred to as a "cold" or "cool" coil. A coil heated by the effects listed previously is called a "hot" coil.

For a constant coil supply voltage, a higher coil temperature and the resulting higher resistance leads to reduced coil current ( $I=U/R$ ), and therefore to a reduced magnetic field/flux with lower pulling forces on the armature.

To generate a sufficient magnetic field, the coil voltage has to be increased at higher temperatures. The same applies to other important operating voltages such as holding voltage, drop-out voltage and non operate voltage for monostable relays, as well as reset voltage for bistable relays. There can be a point at high ambient temperatures where coil energization (with a constant voltage) may not take place even with nominal voltage applied.

#### Example:

At  $T_{amb}=20^{\circ}\text{C}$  the coil resistance is  $R_{20}=1200\text{ Ohm}$ .  
The resistance for a warm coil of  $40^{\circ}\text{C}$  is:  
temperature rise  $20^{\circ}\text{C}$  leading to an increase in resistance of  $20 \cdot 0.4\% = 8\%$ ; therefore  
 $R_{40} = R_{20} \cdot (1 + 0.08) = 1296\text{ Ohm}$

#### Example:

At  $T_{amb}=20^{\circ}\text{C}$  the pull-in voltage is  $U_{in20}=8.4\text{V}$ , the coil resistance is  $R_{20}=1200\text{ Ohm}$ . This gives an pull-in current of  $I_{in}=U/R=7\text{mA}$ .  
For a warm coil of  $60^{\circ}\text{C}$  the pull-in voltage is:  
temperature rise  $40^{\circ}\text{C}$  leading to an increase in resistance of  $40 \cdot 0.4\% = 16\%$ . Therefore  
 $R_{60} = R_{20} \cdot (1 + 0.16) = 1392\text{ Ohm}$ ,  
the required pull-in current remains the same  $I=7\text{mA}$ ,  
the pull-in voltage therefore is  $U_{in60} = R_{60} \cdot I_{in} = 9.74\text{V}$   
which can also be calculated by  
 $U_{in60} = U_{in20} \cdot (1 + 0.16)$

### 5.2.2 Monostable relays

#### Operating voltages for monostable relays

Operating voltages (voltage indirectly producing "current"): Although the current is the primary factor in generating the pull force in the magnetic system, it is normal practice to work with voltages to select the relay coil when designing a circuit.

Coil voltage specifications are given either in volts or more commonly as a percentage of the nominal coil voltage e.g. 70% of  $U_{nom}$  with a nominal coil voltage of 24V indicates an operating voltage of 16.8V.

#### Nominal Voltage (rated coil voltage)

is the voltage applied to the coil designed to energize a relay according to recognized standards or the manufacturers specification.

Relay characteristics such as bounce time, electrical life etc. are all specified for a coil energized with  $U_{nom}$ .

#### Non operate voltage

is the voltage at which a relay will not operate under specified conditions, i.e. no relay will switch to the ON state. This voltage is important where there may be leakage currents in electronic circuits.

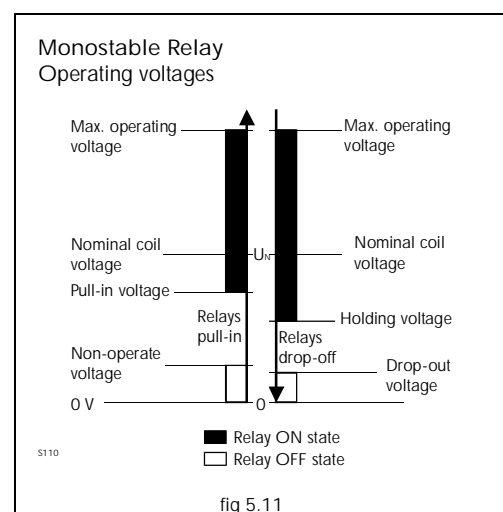
#### Pull-in voltage (operate voltage, pick-up voltage)

is the voltage at, or below which, the relay must have operated and all contacts transferred to the operated position.

The standard level of pull-in voltage is 60-80% of the nominal voltage. This means that relays supplied with the nominal voltage are able to perform their function at higher ambient temperatures and with fluctuations of supply voltage.

#### Holding voltage (non release voltage)

is the voltage sufficient to keep a monostable relay in its actuated position and at which the armature must not drop out. Due to the smaller air gap between the pole and the armature, the relay needs less power to be kept in the pulled-in state than to pull-in, therefore the holding voltage is always lower than the pull-in voltage.



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This value is important in power saving circuits, rectifying circuits and for high ambient temperature applications.

### Drop-out voltage (release voltage)

is the voltage applied to the coil at which all contacts must revert to their unoperated position, and a monostable relay must have dropped out.

The standard drop-out voltage for power relays is in the range of 5-15% of the nominal coil voltage.

### Maximum thermal voltage (maximum continuous voltage)

is the maximum voltage which can be applied continuously to the coil without exceeding the maximum temperature limit of the individual components within the relay. If the voltage is higher than the maximum thermal voltage, the heat generated cannot be dissipated causing the coil to overheat.

### Maximum voltage

is the maximum voltage including supply fluctuations and spikes that can be applied to the relay coil without causing damage to the insulation.

### Permissible coil operating range

The operating temperature range of a relay is defined by the following two factors:

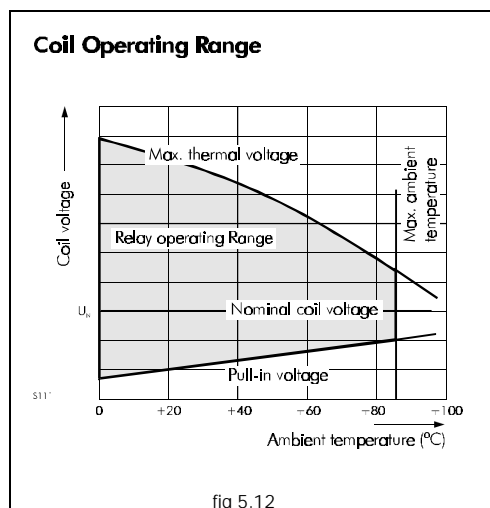
- the coil temperature rise due to self heating and contact load must not exceed the defined maximum temperature for plastic and insulation materials used for the coil, bobbin, etc.
- the ambient temperature, beyond which the relay will not operate reliably due to the increase in coil resistance (pull-in voltage).

The electrical and thermal limits for coil supply voltage are:

### Maximum thermal coil voltage

When the coil supply exceeds the maximum thermal voltage (with 100% duty cycle), the heat generated cannot be dissipated and the coil will overheat causing damage to plastic parts such as coil insulation, bobbin, case etc. For most insulation and plastic materials the maximum permissible temperature is 120°C.

Higher temperatures cause degradation in insulation and mechanical properties. Special relays are available for use in extremely high temperature applications.



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In high ambient temperatures, heat is more difficult to dissipate due to reduced temperature differential.

$W = a \cdot \Delta T \cdot A$  (W=dissipated heat, a=dissipation coefficient,  $\Delta T$ =temperature difference, A=dissipation area)

In any application the continuous coil voltage (100% duty cycle) has to be below the maximum voltage curve.

### Maximum ambient temperature

is the maximum temperature at which a relay with continuously energized magnetic system and contacts carrying the full rated load on all contact poles can operate without damage to the mechanical and electrical subcomponents (plastic parts, insulation, bobbin, case, etc.).

### Pull-in voltage range

Energization of the magnetic system and subsequent coil heating will increase the pull-in voltage of a relay. This effect should be taken into account if a relay is actuated after only short period of de-energization (cooling).

A coil that has been energized as described above and reached a steady thermal state is known as a "hot coil" whereas a coil at ambient temperature is known as a "cold coil".

Although the pull-in current is a constant value over temperature the pull-in voltage for a relay will rise with temperature.

$$U_{in}(f(T)) = I_{in}(\text{const}) / R(f(T))$$

### Coil operating range

For a relay to operate reliably, the coil supply voltage has to be within the shaded segment of the graph. See fig 5.12.

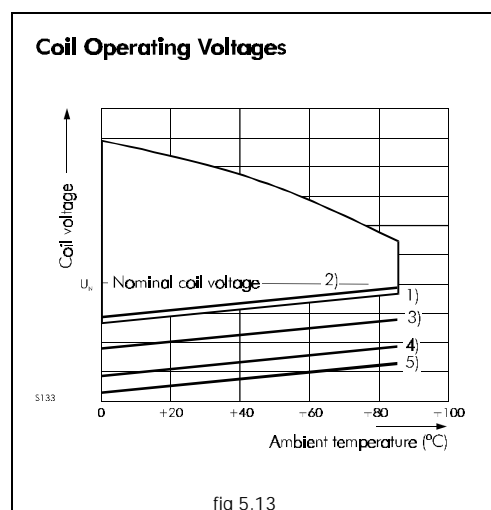
Additional information for relay operating range

### Complete coil operating range

Apart from pull-in voltage the graphs for coil operating range may show additional information such as pull-in voltage for:

- pull-in voltage "cold" coil - curve 1
- pull-in voltage "hot" coil - curve 2
- hold voltage (hot coil) - curve 3
- drop-out voltage (cold coil) - curve 4
- non-operate voltage (cold coil) - curve 5

All these operating voltages show the same



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temperature characteristics as explained for pull-in voltage.

For higher coil temperatures (ambient temperature, self heating and induced heating by contact load) these voltages will increase by 0.4% per °C.

During circuit design, care has to be taken that calculations are made under the respective "worst case" conditions, such as the highest possible coil temperature (ambient temperature, self heating of coil and induced heating with applied contact load) for pull-in, maximum thermal and holding voltage.

For the non operating and drop-out voltage the "worst case" is represented by a "cold" relay coil (no prior coil heating, no induced heating by the contact load at the lowest expected ambient temperature).

Equipment generating strong magnetic fields such as transformers and loudspeakers, situated near a highly sensitive or polarized relay, can cause variations in operating voltages. Often these problems can be solved by careful location/orientation of the relay or by providing shielding.

### DC coils

#### Coil supply

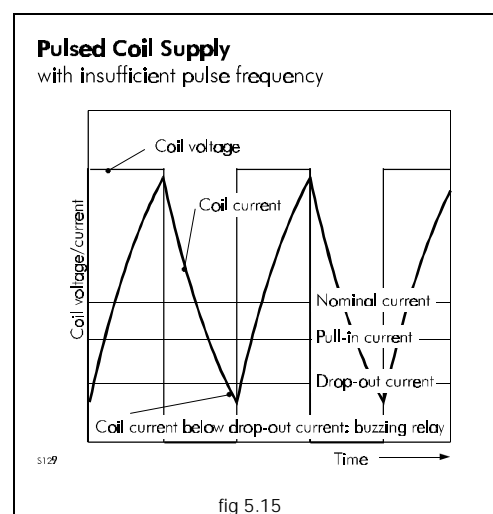
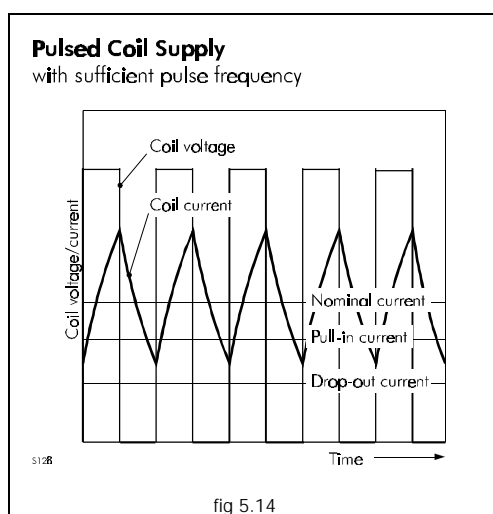
The power source for DC operated relays should in principle be either a battery or a DC power supply with a maximum ripple of 5%.

In the case where power is supplied by a rectification circuit, the operate, holding and drop-out voltage may be higher and vary with the ripple percentage.

Standard nominal voltages for DC relays are 5, 6, 12, 24, 48 Volts.

#### Pulsed coil supply

With a pulsed coil supply the coil current has to be above the holding current at all times (see fig 5.14). If the current drops below this level, the armature will start to open and sufficient pull-in force will only be re-established after reaching a value higher than the pull-in current (see fig 5.15). Buzzing of the relay and increased contact wear will result.



For high switching frequencies (in the kHz range) the ripple current will be very low and the mean current should be equal to the nominal coil current.

Excessively large fluctuations of the applied voltage can cause the relay not to operate at the lower limit of supply voltage and burning or degradation of coil at the upper limit. It is therefore important to check the fluctuation of the supply voltage and to select a relay capable of operating safely within these limits at the required ambient temperature.

Care is required where power source voltage fluctuations are caused by load switching. If the power source for the relay coil circuit is connected to the same supply line as lamps, capacitors, motors or other heavy loads, the line voltage might drop when these loads are switched. In such cases the voltage may drop below the holding voltage of the relay causing burning and premature failure of the contacts.

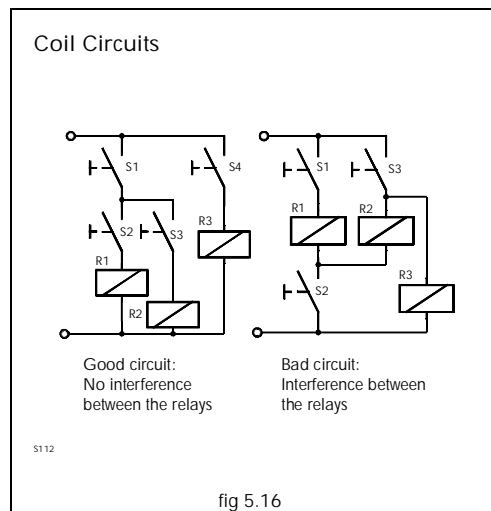
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### Coil circuits

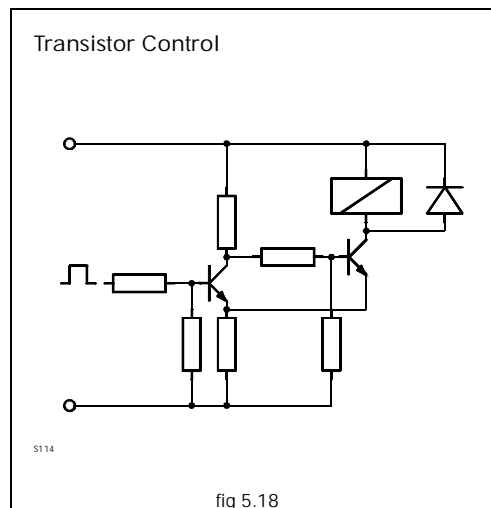
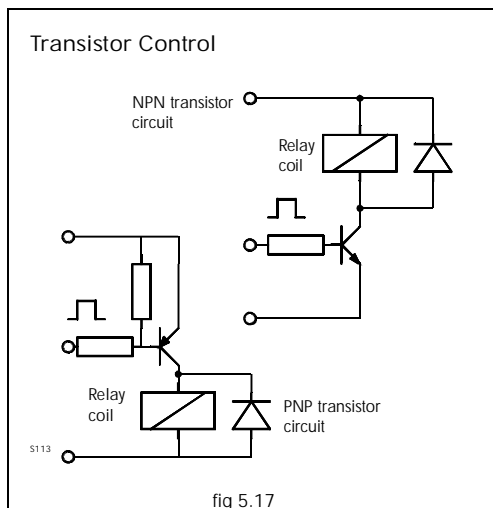
The coil control circuit should be kept as simple as possible and leakage currents prevented where possible. Leakage currents could cause false operation of one or more relays (fig 5.16).

### Coil protection - flywheel diodes

Due to the inductance of the coil, high voltage peaks are induced when the coil supply is switched off. To protect the relay control transistors or contacts of other control relays against this surge voltage, protection in the form of flywheel diodes or other more elaborate circuits have to be used. This could also be necessary in order to comply with EU EMC regulations.



### Transistor control

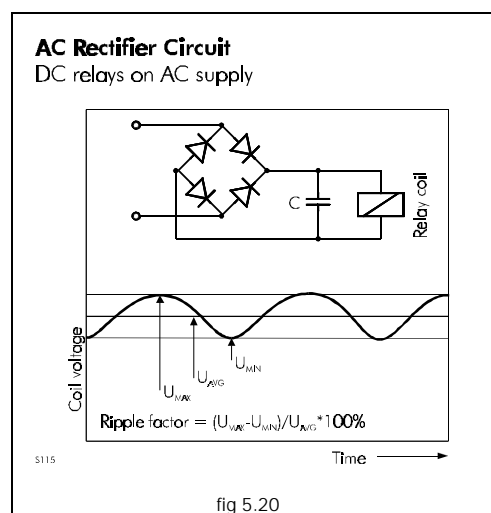
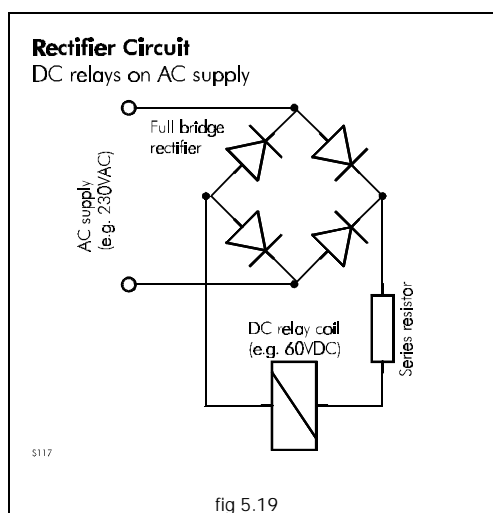




Rectification circuits, AC drive of DC relays.

It is often necessary to drive a pcb mounted relay from an AC voltage source. In general there are two possible solutions. A relay specifically designed for use with an AC supply, or the use of a standard DC relay with suitable drive circuitry.

Suggested circuits for driving a DC relay from an AC supply are:



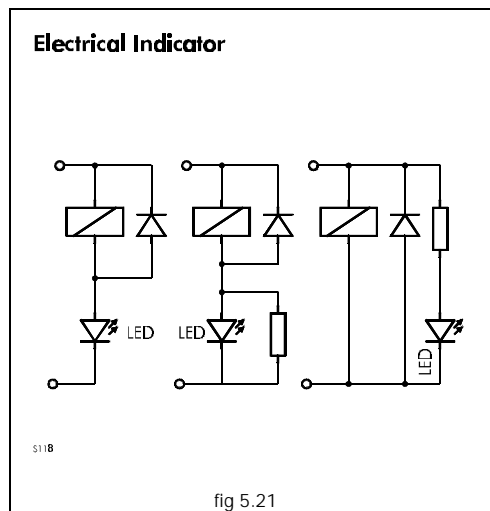
When using these methods to drive a DC coiled relay the following points should be considered:

- the ripple on the supply should be kept to a minimum because vibration of the magnetic system (buzzing) and contacts can lead to premature contact failure.
- Ripple caused by rectification, especially for half wave rectification, should be kept to less than 5%.
- The operate and release voltages may vary depending on the percentage of ripple. To check this effect testing should be carried out.
- The supply voltage must be within the coil operating range at the maximum ambient temperature specified.

## POWER RELAYS

### Electrical indicator.

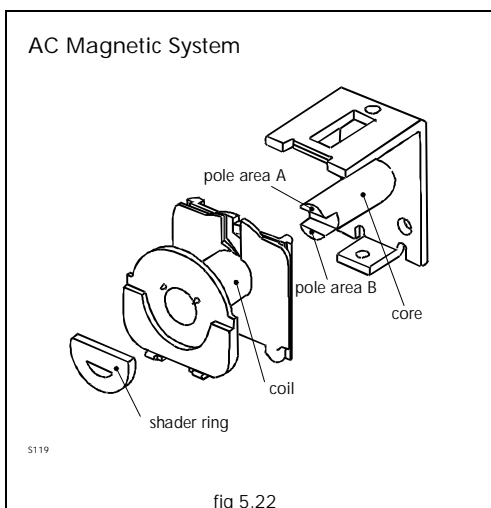
If it is necessary to indicate coil energization, an LED or lamp may be used as electrical indicator. However, the possible effects of defective LEDs, voltage loss across the LED and additional power consumption should be considered.



### AC coils

AC relays are designed to be operated by alternating current. For the operation of AC relays the power source is almost always a commercial frequency of 50 or 60Hz, with standard voltages of 6,12,24,48,115 and 230VAC.

Relays with AC coils are more expensive than their DC counterparts because of the differences in the magnetic system and extremely tight manufacturing tolerances. However, they can replace up to six components, saving pcb area, reducing production costs and improving reliability.



Since an alternating current decreases to zero every half-cycle (100 times per second for 50Hz), the relay armature tends to release every half cycle.

This continual movement of the armature not only causes a "buzz", but will cause the contacts to open and close as the armature moves. This can cause burning or welding of the contacts.

To avoid this chatter or buzzing of the armature, part of the pole face is fitted with a shading or short circuit ring.

The flux created in this short circuit is phase shifted to the main flux, preventing the total armature flux from periodically decreasing to zero.

Care is required where power source voltage fluctuations are caused by load switching. If the power source for the relay operating circuit is connected to the same supply line as motors, solenoids, transformers, and other heavy loads, the line voltage might drop when these loads are switched. In such cases buzzing might occur causing the relay or contacts to fail prematurely.

#### Coil voltage range, AC relays

For reliable operation of the relay, the coil supply should be within the range of  $+10\%$  to  $-15\%$  of the rated voltage.

Usually all voltages are given for a 50Hz supply.

For a 60Hz supply the coil impedance is higher, reducing coil consumption and altering the pull-in voltage (higher than for 50Hz).

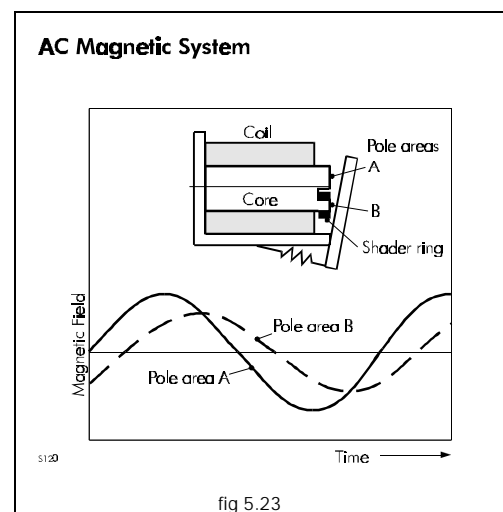
In relays with AC coils, additional losses are generated due to the shading ring resistance, magnetic circuit eddy currents and the hysteresis of the iron circuit. The coil efficiency is therefore lower and the coil temperature rise will be greater leading to a reduced coil operating range compared with DC types.

The waveform of the coil supply voltage should be a sine wave. This is not a problem when using a commercial supply, but when a stabilized AC power source is used, there may be waveform distortion leading to overheating.

#### 5.2.3 Bistable relays

Whereas a non latching relay resumes its stable state (OFF position, armature dropped out) when the coil supply is switched off, the bistable or latching relay has two stable states, set and reset. These two states are maintained even when the coil is not energized.

This phenomenon of maintaining the switched state results from the magnetic pull force of remanent magnetism stored in the hard iron magnetic circuit.



## POWER RELAYS

To change state, both operations, "operate" and "release", need energy supplied to the coil. However, bistable relays require only a short pulse of voltage to change their contact state and giving considerable power savings if the relay ON time is long.

### Advantages of bistable relays

The main advantages of latching relays are the zero power consumed after switching, the ability of the relay to keep its state even for prolonged periods and the "memory" effect of contacts not changing state even in the event of power failure.

Additionally, as the relay coil is not energized it will not generate any heat so the relay will be cooler and have a wider coil voltage range.

Bistable relays, therefore, have distinct advantages over standard monostable relays for certain special applications such as:

- where low power consumption is important.
- where heat generation has to be minimised, for example where relays are densely packed on a pcb.
- where relays have to remain in the operated condition for a long period.
- where relays must remain in the operated condition, even when the power fails in the control circuit, e.g. emergency standby units.
- where only one control pulse is available for relay energization, and where it must remain operated until a counteracting pulse occurs (e.g. switchable energy meters).

### Operating voltages for bistable relays

#### Magnetization voltage (set voltage)

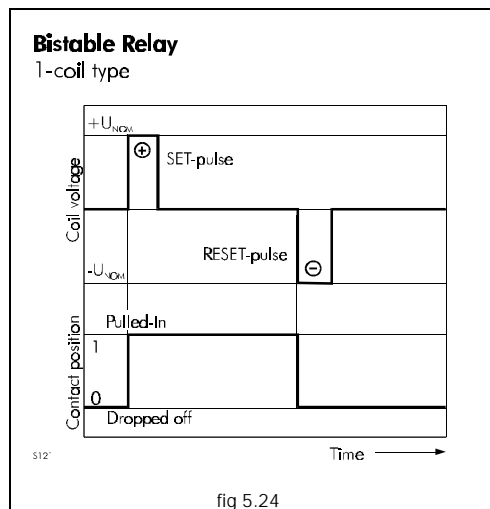
is the coil voltage at which a latching relay will change from the OFF state to the ON state.

#### Demagnetization voltage (reset voltage, reverse operation voltage)

is the voltage at which a latching relay drops out. It is the voltage that supplies enough energy to demagnetize the magnetic circuit of remanence relays, or to actively change the switching state for polarized relays.

#### Inverse non pick up voltage

is the maximum coil voltage that can be applied for demagnetization without generating a magnetic field strong enough to re operate the relay.



### Minimum pulse time

is the minimum duration of the input pulse required for the normal operation of a latching relay.

Latching relays can be categorized in non polarized (remanence type) and polarized (permanent magnet) latching types.

Latching relays may also be categorized with regard to their number of coils.

Single coil systems: energization and de-energization is controlled by a single coil applying supply voltage of different polarities.

Two coil systems: energization and de-energization of the magnetic circuit is controlled by two different coils.

### Remanence relay

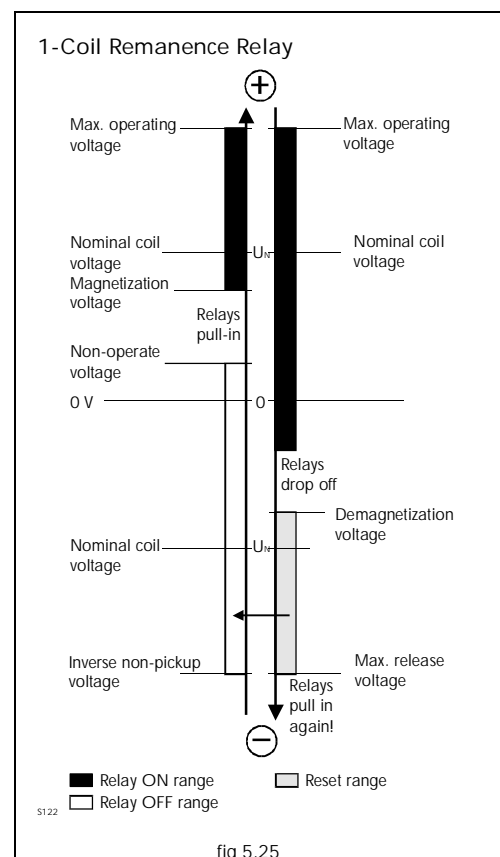
The remanence relay is a non polarized bistable relay.

Part of the magnetic circuit is made of semi-hard magnetic material (usually the core), so that the flux needed to create the pulling force necessary to maintain the set state is generated by remanent magnetism.

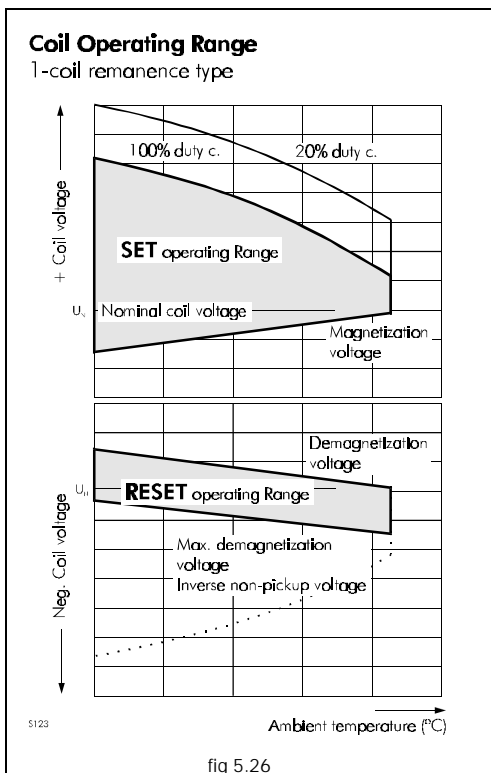
To set the relay a pulse voltage higher than the pick up voltage is applied to the coil. To reset the relay it is necessary to demagnetize the magnetic circuit by applying a reverse voltage pulse of a sufficient level.

The reset pulse for a non polarized latching type relay has an upper and lower limit. If the energizing current exceeds the upper limit then the relay will re operate as sufficient magnetic field/flux is generated (and the pull in force strong enough) to move the armature.

These limits are usually defined either as a voltage range or as an inverse non pickup value.



## POWER RELAYS



As previously explained, these voltages vary due to the change in coil resistance caused by changes in coil temperature. For applications with a low switching frequency, long periods of either ON or OFF state, the self heating effect will be negligible.

Where the coil supply is not pulsed, the self heating of the coil and the consequent higher coil temperatures must be considered.

Continuous energization is possible with some bistable relays, as per the diagram, but some types may overheat.

### Single coil latching type

This type of bistable relay has only one coil which both operates and releases the relay.

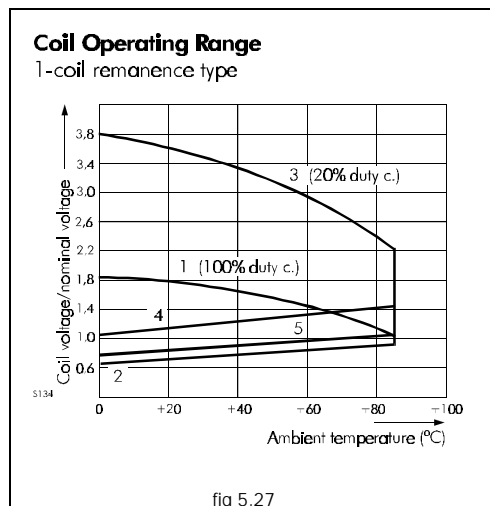
### Permissible coil operating range

Close attention should be paid to the voltage level supplied to release the coil because the magnetic system will re polarize itself if the release pulse is overvoltage. In this case the contacts will open momentarily, then snap shut, latching the relay again in the set position.

The two parts of the diagram for the different coil supply polarity as in fig 5.26 are often shown as one single graph (see fig 5.27).

The curves in 1.27 relate to the following parameters:

1. maximum supply voltage at rated contact load (100% ON time)
2. pull-in voltage (pulsed)
3. maximum supply voltage at rated contact load (pulsed, 20% load duty cycle)
4. maximum de-magnetizing voltage at rated contact load with proposed series resistor
5. minimum de-magnetizing voltage with proposed series resistor (pulsed)

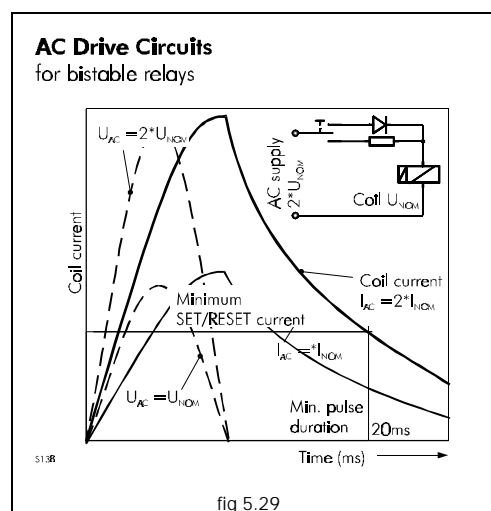
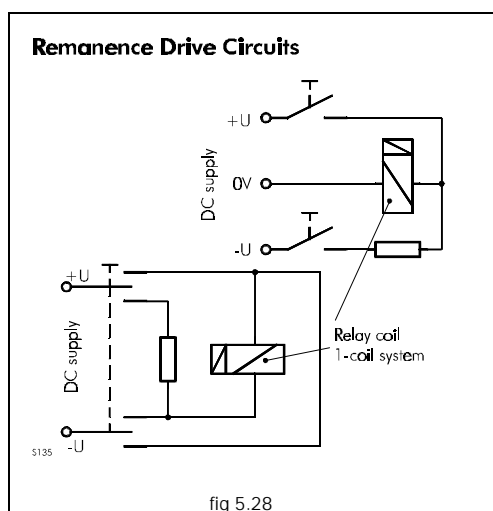


The voltage pulses to operate and release the relay must be of opposite polarity and of sufficient duration.

A minimum pulse duration is necessary due to the response time of the relay, the settling time of moving mechanical parts (e.g. bounce time) and an extra margin to take account of any tolerance variations.

#### Typical drive circuits

For all circuits, the external resistor RE has to be selected in order that the resulting coil voltage is in accordance with the coil operating range to reset the relay.



#### AC drive circuit

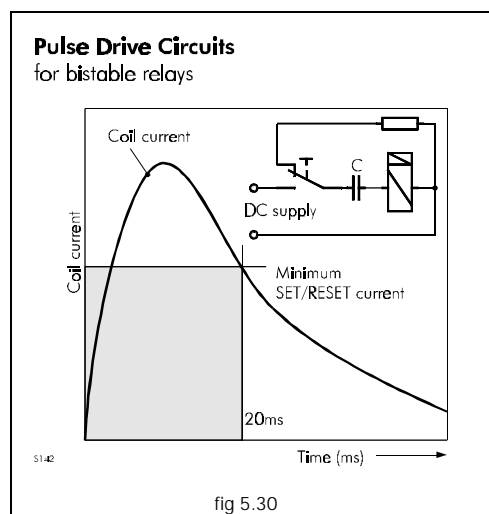
Where bistable relays are driven directly from an 50/60Hz AC source, the supply voltage has to be higher to maintain the necessary set current for the specified minimum pulse duration.

In general, the AC supply voltage has to be approximately twice the specified nominal DC voltage (e.g. a 12V remanence relay can be used directly from an 24VAC source). Again the resistor RE has to be selected to obtain an AC voltage at the coil within the operating range for reset.

## POWER RELAYS

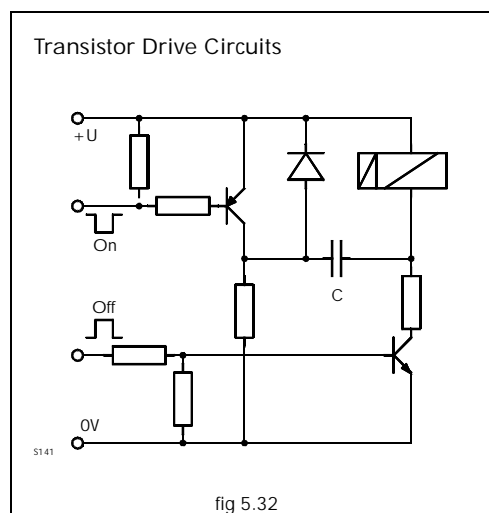
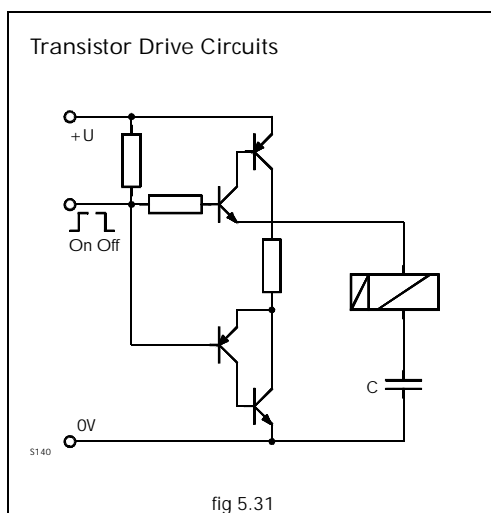
### Pulse drive circuit

Pulse drive circuits have the advantage of low energy consumption without additional electronic components. The elements of the RLC circuit should be calculated to give an aperiodic response, to ensure that the capacitor charge/discharge current does not change its direction. The capacitor value has to be selected for a sufficiently high set current during the entire minimum pulse duration (e.g. for 20ms).

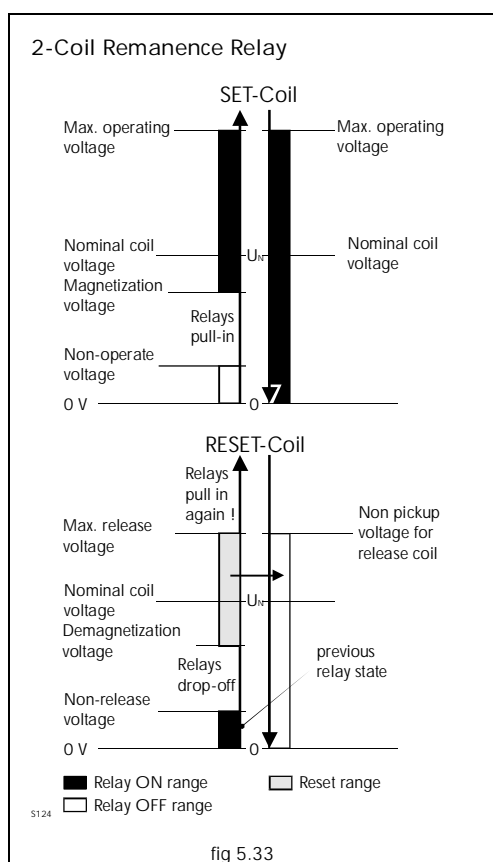


### Transistor drive circuits

Examples of transistor drive circuits for single coil remanence type relays, with one or two separate signal inputs, are shown in fig 5.31 and fig 5.32.



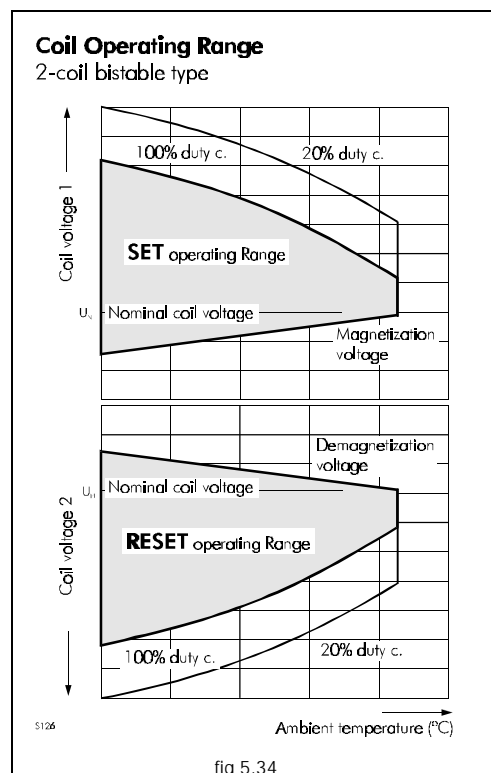




### Two coil latching type

The coil system of this type of bistable relay has two separate coils, one is used to magnetize the iron core and set or operate the relay, the other to de-magnetize the core and release, or reset, the relay.

This type of bistable relay is normally easier to operate, especially from logic circuitry, as both SET and RESET pulses are of the same polarity.



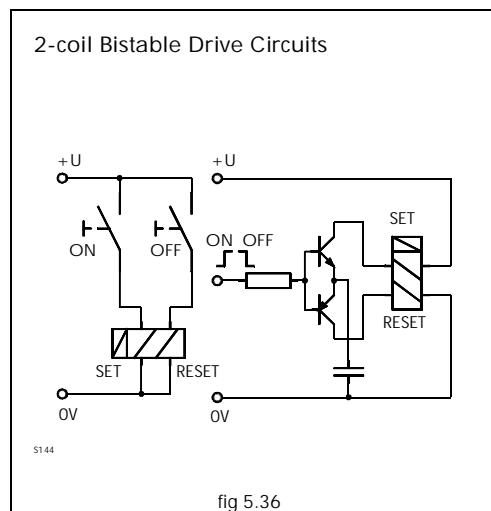
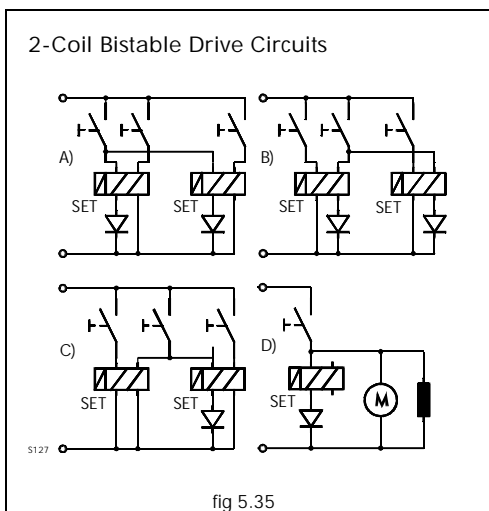
## POWER RELAYS

### Control circuits

Two coil remanence relays are normally easier to operate, especially from logic circuitry, as both SET and RESET pulses have to be the same polarity and voltage.

Some typical circuits are shown in fig 5.35 and fig 5.36.

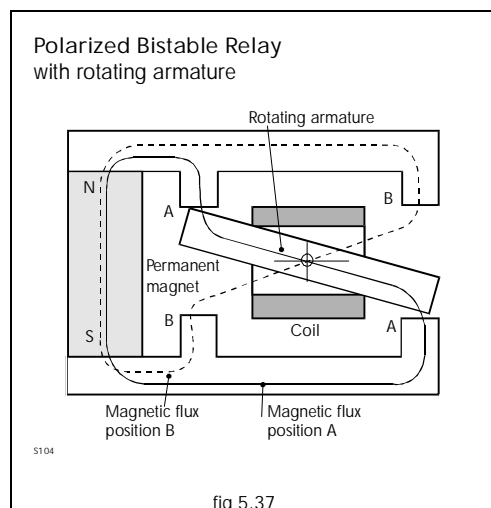
If SET or RESET coils of different relays are to be connected in parallel, a series diode should be used to prevent the relays interfering with each other. A diode should also be used where there is a parallel connection of the coil and an inductive load.



### Polarized latching type

Polarized relays use a permanent magnet to obtain the required latching characteristics. As with non polarized types, the polarized bistable relay is set or reset by applying a voltage/current pulse, but there is no upper limit for the reset pulse. The polarized relay can be reset by a pulse current exceeding the reset value.

The advantages of polarized bistable relays over remanence relays are the lower coil power and a higher resistance to vibration. Unfortunately the cost is higher.



#### Application hints for bistable relays

For certain applications bistable relays offer important advantages over the monostable design (see advantages of bistable relays).

Due to the more complex function of bistable relays, special attention to circuit design is required.

#### Application pitfalls to avoid are:

- If remanence relays are powered by batteries, the current capacity of the batteries should be checked. The relatively low resistance of the remanence coils requires high currents (constant voltage respectively) during the SET and RESET pulse time. This requires batteries with low source resistance, even at low temperatures.
- It is important that the first operation of the relay and latching circuit is from a defined state (e.g. reset of the drive circuit and relay when powered up).
- If a relay is subject to mechanical shock or vibration exceeding its specification during shipping, installation or application, the relay may change state. It is recommended that the relay be used in a circuit which initializes the relay to the required state (SET or RESET) whenever the power is turned on.
- A mechanical shock may cause an air gap between the armature and coil to develop. In this case the remanent magnetism will not be sufficient to return the relay to the pulled in position.
- Continuous energization is possible with some bistable relays, but may cause overheating on certain types.
- Avoid using bistable relays in applications where the relay will be close to strong magnetic fields.
- Avoid simultaneous application of voltages to the SET and RESET coil.
- Be aware of vibration and shock which might be caused by other devices on the same board.

## POWER RELAYS

### 5.3 Selection of coil - summary

MAGNETIC SYSTEM			
PARAMETER	CHARACTERISTIC	SELECT	CHECK
type of coil	DC, AC	✓	
	monostable, bistable (remanence, polarized, 1 or 2 coil design)	✓	
coil specification	nominal voltage	✓	
	coil resistance	✓	
	coil current	✓	✓
	power consumption transistor specification, power supply etc.		✓
operating voltages	for the entire temperature range!		✓
	pull in voltage		✓
	drop out voltage		✓
	hold voltage (power reduction circuits, supply variations, high frequency pulse control)		✓
	non operate voltage (electronic control, leakage currents)		✓
temperature	coil temperature rise		✓
	duty cycle		✓
	operating voltages at worst coil temperatures		✓
	maximum permissible temperatures		
other factors	operating times		✓
	strong magnetic fields (influence on operating voltages, bistable relays)		✓
	vibration, shock (remanence relays)		✓