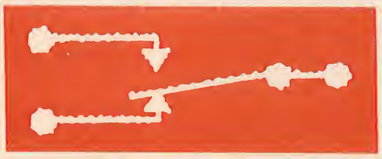

Designing with relays is more subtle than you think

Little-known fine points of design show that the relay involves more than power-driving an isolated set of ideal switches

RELAY OPERATING LIFE and performance often fall below par when the designer stresses only one or two of the relay's features in specification or circuit design. Unknowingly, he may be sacrificing some other desirable characteristic.

This situation most often occurs when the design is limited to merely applying rated coil power and considering the contacts to be perfect switches independent of the load, which they're not.

Instead, the designer must dig into the fine points of relay design and weigh the performance tradeoffs. His attention must be addressed to such matters as:

- The factors that affect switching times.
- How temperature influences performance, life and parameter margins.
- Interference: its causes and suppression.
- Contact loading and relay selection.

When given sufficient consideration, these design criteria may mean the difference between optimum and adequate performance or between one million and ten thousand operations. Some apply directly to the relay as a whole; others focus on the relationships between the various elements that compose the relay (Fig. 1).

Contacts not near-ideal switches

The speed of switching is sometimes a paramount design consideration. There is a tendency on the part of many design engineers to dismiss contact circuitry design from their efforts because of its seeming simplicity. The contacts cannot be thought of as near-perfect switches, despite their very low ON resistance and very high OFF (isolation) impedance. The switching of contacts involves the type of relay being used, the loading of the contacts and the nature of the coil signal.

Most relays are abruptly switched ON or OFF. In many practical applications, it is satisfactory to use a multiple contact relay with a slowly changing signal, even if the contacts do not snap and/or complete their switching simultaneously. However, when this occurs at full load ratings, shortening of contact life may result. If severe vibration is also present, contact chatter may result. (See article covering switching times and chatter on p 45.) It should be noted that some relay types that always snap when slowly energized might still experience contact bounce if slow energizing is combined with high-vibration amplitude.

Small-size ac relays are inherently slower to release than dc relays (of the same size), because they must contain a delaying device to prevent their following the ac input signal. At 60 cps, the release time must be about 10 msec or longer to prevent contact release at each polarity reversal. On the other hand, the ac-type turns on faster, because it has higher in-rush currents.

Single-pole relays are generally faster than multipole types of the same contact

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rating because of smaller inertia. If several poles must be switched, but only one needs to be switched quickly, this can be done using a separate, fast relay for the one pole.

Operate (pickup) and release (dropout) times of some relays may be affected by a factor of 10 or more according to the type of circuit in which they are used. Here are some common circuit features to be considered that affect the switching times:

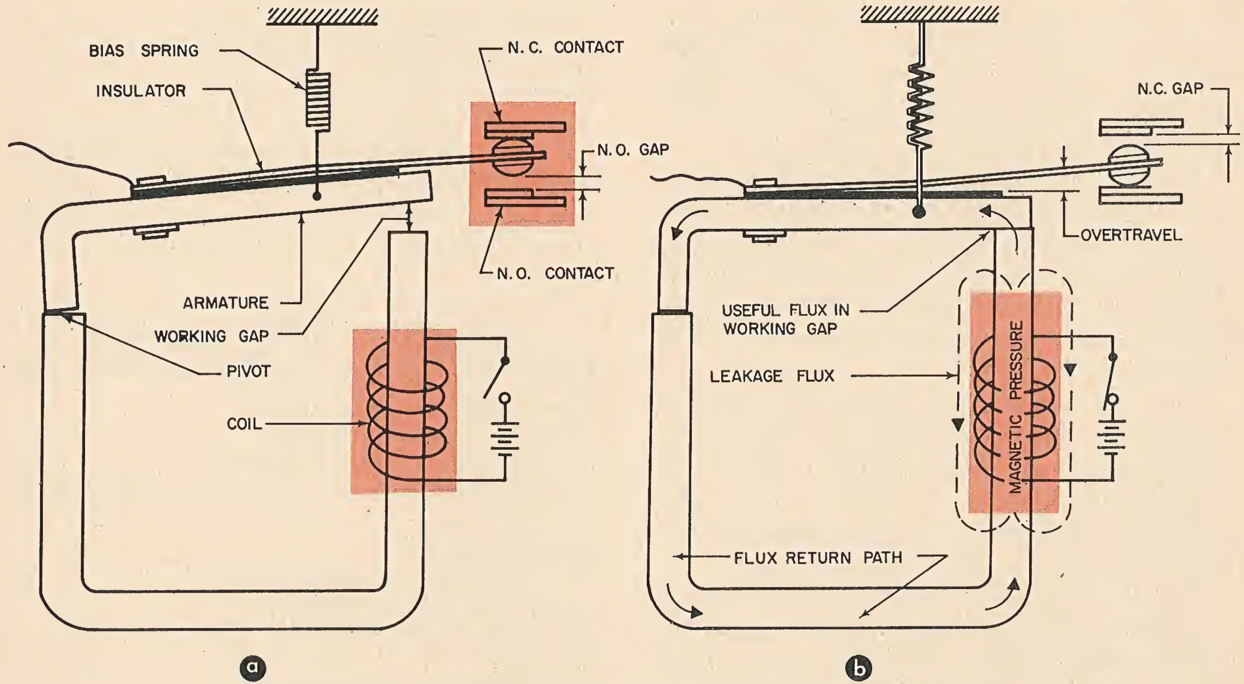
- Arc suppressors in the coil circuit cause the largest release delays.
- Coil shunts (such as indicator lamps) delay the release time.
- Inductance of the power supply, power cables or of elements in series with the coil will retard the coil current rise and, therefore, the operating speed. Energy storage due to current flow through such inductances also prolongs the release.
- Increasing the coil-circuit power beyond the normal energizing level increases the operating speed, although not proportionally.
- Pre-energizing a relay almost to the point of causing it to operate will enable it to operate faster when full voltage is applied. Likewise, pre-energizing with reverse polarity will delay the operation of the relay. Pre-energizing makes most relays (except the polar types) more sensitive to shock, vibration and constant acceleration. Pre-energizing polar relays in the reverse direction affects them favorably.
- Two relay coils in parallel can interact to affect the release times of each. If the time constant, L/R, of the two relays is equal, the release times remain unaffected. If the time constants are unequal, the current will continue to flow in the direction of the relay having the longest time constant. The net effect of unequal time constants is an increase in the release time of the relay with the larger time constant and a slight decrease in the release time of the relay with the smaller time constant.

Thermal change impairs sensitivity

As in other devices, the effects of temperature variations markedly influence performance, most importantly the sensitivity (of the coil pickup) and efficiency.

By definition, relays rated for a given voltage have effective sensitivities that are inversely proportional to the coil resistance. Thus, a 2000-ohm relay is twice as sensitive (drawing half as much power) as a 1000-ohm relay, if both are rated for the same supply voltage. When temperature changes occur, the relay with the larger resistance coil will exhibit wider variations in switching margins (tolerance of pickup and dropout levels). Thus, increased sensitivity is accompanied by a sacrifice in thermal stability.

The typical temperature effects on various basic relay types for an increase of 100°C appear in the table. For smaller changes of temperature, the effects may be assumed to be proportionately smaller. In each case, the mechanism is the same. The coil impedance is



1. **Basic single-pole relay** shows both normally open and normally closed contacts. Unenergized coil state (a) and energized coil state (b) demonstrate relay action.

temperature dependent. Thus the coil current, which determines the flux, varies with temperature. Since the flux establishes the magnetic forces, pickup and dropout are affected by the temperature change.

In the non-polarized dc type, the circuit's magnetic reluctance remains constant. However, polarized-type dc relays feature permanent magnets which are temperature-sensitive. This causes a decrease in pickup current requirements which largely offsets the increase in pickup voltage due to temperature rises. With ac relays, the portion of coil impedance that is resistive is small, and the effect on pickup voltage is negligible.

Compensation achieved by compromise

A number of temperature-compensation schemes are available. Of these, the most common involve Jeliff wire, thermistors, bimetals and external circuit techniques.

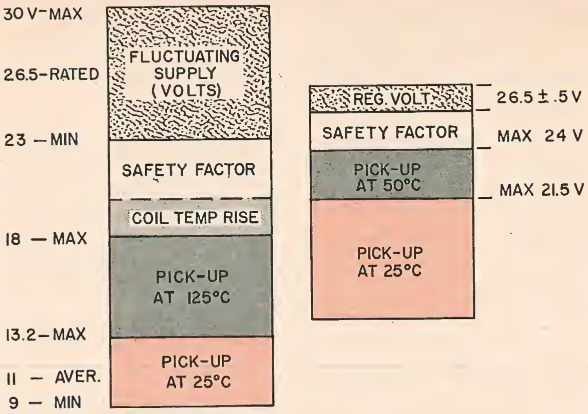
Jeliff wire is often used on the coil winding. It has a lower temperature coefficient than copper and is therefore less susceptible to temperature variations. However, its resistance is considerably higher (nearly 30 times), resulting in a much greater coil-power demand. It has given way to thermistors.

Thermistors are used in series with the coil. Occasionally, a resistor is placed in shunt with the thermistor to confine the compensating range to that which is needed (and which cannot be directly met by the thermistor itself). The negative temperature coefficient of the thermistor offsets the positive coefficient of the coil. However, more coil current is needed because of the increased network resistance, and the pickup-voltage parameter now exhibits a smaller, but nonlinear, drift (because of the thermistor).

Bimetal spring compensation also produces a net smaller temperature coefficient. A mechanical technique, it does not alter the power requirements. However, it is applicable to either the pickup or dropout function. Thus the difference between these levels varies with temperature change.

The use of external circuit-compensation methods, such as regulators, ovens and thermal-sensitive feedback loops, may not appreciably involve increased power consumption. However, it is accompanied by increased circuit complexity and cost.

Figure 2a shows the typical relationship between nominal pickup voltage and the actual supply voltage for military-type relays. Maximum pickup voltage at room temperature must not be greater than about one-half the nominal voltage. Thus, for a nominal supply of 26.5 volts, room temperature (25°C) pickup should be about 13.0 volts max. At 125°C the increase of coil resistance causes the pickup to be about 18.0 volts.



2. **Coil-voltage criteria** show how temperature and safety factors are accounted for (a). Power savings result when the relay's pickup voltage approaches the nominal supply voltage (b).

The difference is an allowance for coil-temperature rise, for fluctuations in line voltage and to provide a factor of safety. When the voltage is well regulated and the ambient temperature is lower, one may select a relay having a pickup voltage much closer to the nominal supply voltage. A relay with this higher rated pickup voltage will typically have a higher resistance. It will then draw less power at the nominal voltage. In the case shown in Fig. 2b, the power saving is 62%.

Suppressing arcs, surges, noise

Fast-opening contacts suddenly insert a very high electrical resistance and tend to develop a surge of 1000 volts or more that stops the flow of current. If a suppressor is not used and the full peak voltage develops, a flashover may occur at any of these high-voltage points. In small relays, this causes the contact gap to break down, thus short-

Temperature effects on relays (Results of a change to 125°C from 25°C)

Dc non-polar (general purpose)
1. Pickup current unchanged.
2. Coil resistance increases 40%.
3. Coil voltage increases 40% (13 v at 25°C; 18 v at125°C).

Dc polar relays
1. Pickup current usually decreases.
2. Coil resistance increases.
3. Pickup voltage usually increases ($\Delta v < 40\%$).

Ac relays
1. Coil resistance increases 40%.
2. Coil inductance does not change.
3. Coil impedance increases about 10%.

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ening the life of the contact.

On the other hand, there is a voltage phenomenon that causes a transfer of material to the negative contact in the form of a spike. Such a spike has been known to grow tall enough to bridge the gap of open contacts. Thus, an arc suppressor may have to be modified or even omitted to permit a slight arcing to occur. The small amount of arcing would erode this spike and thus limit its harmful effect on bridge transfer.

RF noise is most effectively suppressed with LC-type filters, but these are too large and too heavy for most aerospace applications. Here, RC suppression is usually the best compromise. The use of a diode reduces the needle-like bridge transfer to the negative contacts, but RF noise is usually increased. This is because the diode itself is an active noise source (as contrasted with the filter elements, which are passive).

Six common types of arc suppression, along with their principal features, appear in Fig. 3. The choice depends upon which features are the most important in the given situation. The governing considerations are release-time effects, noise levels, surge and arc requirements, and ease of accommodation of relay and contact load.

RC suppressor. Good suppression with only slight release delay is provided. In terms of components, it is economical, but bulky. Low RF noise results. Select the value of C to limit the peak voltage at the contact gap. Select $R \leq R_L$ both to limit the inrush when closing the contacts and to maintain 10 volts or less across the gap at the instant of opening. Adding a diode, CR, reduces the initial peak voltage and bridge-transfer.

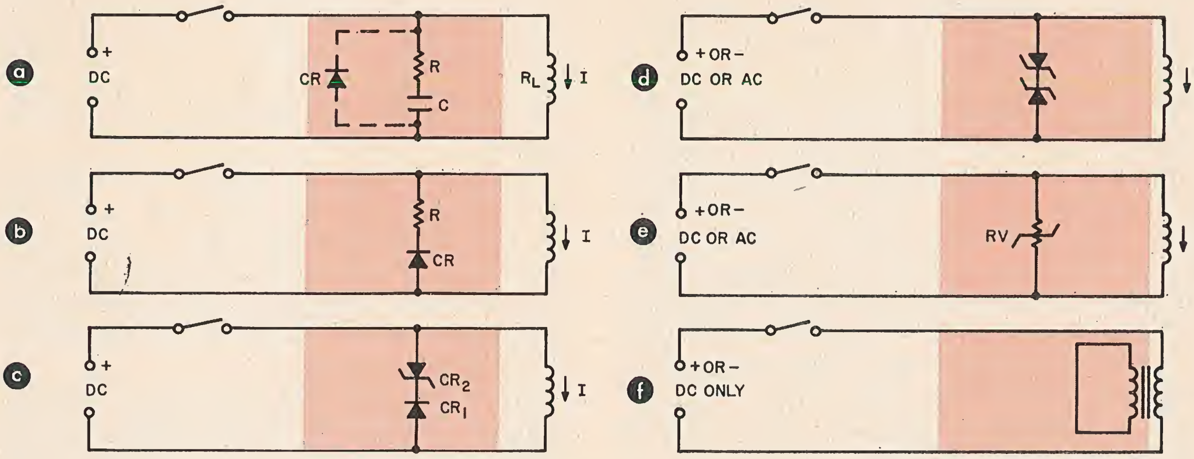
Diode-resistor suppressor. Diode CR, when used alone (no resistor), eliminates voltage surges. However, the release delay is maximized by this means of suppression. Adding a resistor, R, reduces the delay but causes an instantaneous voltage across the opening contact gap. A capacitor is sometimes used to bypass R momentarily. This keeps this IR product down until the gap is wide enough to withstand the IR voltage.

Zener and blocking-diode suppressor. This network is similar to the diode-resistor technique, except that a zener diode, CR_2, is used instead of resistor R. The high zener voltage causes faster release but a larger IR voltage drop across the opening contacts. Zeners also tend to raise the RF noise level. Neon bulbs may be substituted for the zeners for high-breakdown voltage situations.

Back-to-back zener suppressor. This technique is suitable for ac and for either dc polarity. In principle, it resembles the zener-blocking diode network. However, the zener voltage must exceed the peak line voltage. This is a restriction that is not required in the previous suppressor circuit (Fig. 3c).

Varistor shunt suppressor. Varistor RV becomes much more conductive as the voltage rises, tending to clip the voltage somewhat like a zener diode. Its nominal resistance is selected to be about 10 times larger than the load resistance to prevent high-voltage surges from damaging the circuit.

Bifilar dual-coil suppressor. By winding two coils simultaneously and shorting one of them, a bifilar arrangement is achieved. No exterior components are needed. Special coil



3. **Arc suppression techniques** have a pronounced effect on relay release time. Shown are: R-C network (a), diode-resistor leg (b), combined zener and blocking diode (c), back-to-back zeners (d), varistor shunt (e) and bifilar dual-coil (f). Types (d) and (e) are applicable to both ac and dc relays. Types a, c, d and e may shunt the switch instead of the load for less RF noise and more effective absorption of inductive energy in long lines.

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construction requires twice the nominal pickup and operating power. Some delay of the operate and release functions also occurs.

Military specifications for determining release times do not usually call for an arc suppressor. Release is fastest when arc suppression is not used in the relay-coil circuit. However, this is true only if the switching contacts open fast enough and far enough to prevent an arc. The larger the relay, the more difficult it is to open the coil circuit without an arc.

An arc is a fairly good conductor, developing about 12-20 volts potential in typical small switches. This arc forms a conducting path, thereby prolonging coil current and delaying relay release. Of the various suppression methods discussed above, the RC type is usually fastest and produces results very close to rated (nonsuppressed) release. The plain-diode-in-parallel-with-the-coil approach causes the longest delays.

Note that in all cases, the amount of delay is affected by the type of relay, the sensitivity of the relay and the amount of coil overdrive. Also note that the effect of overdrive is inconsistent between relays. In other words, the best way to determine release delay is to test it.

Loading is a key to selection

In addition to its effects on the speed of switching and interference suppression, the loading on, and nature of, the contacts will exert a major influence on over-all relay performance and relay specification. For example, the actual load instead of arbitrary noninductive load ratings should be specified. Consider two relays which are equally capable of switching 5-amp noninductive loads for 100,000 operations. Based on catalogue ratings that reflect these capabilities, they would be considered equals. But it may be that the load being switched is actually the primary side of a transformer. A typical inrush of 10 times the steady-state current would cause contact sticking in one of the relays. The other relay does not stick because it may happen to have silver-cadmium oxide contacts, which do not show their advantage in noninductive load testing. Does this make a nonsticking relay better? Not necessarily. The other relay may have silver contacts with gold flash, making it more reliable under dry-circuit loading.

The load will also influence the choice of contact force. High-voltage loads and inductive loads should be switched with a relatively large gap to prevent arcing. Low-level loads are more easily accommodated by small contact gaps, because the reliability of the contact "make" is greater for smaller gaps than larger ones. The wider the gap, the greater the power required to generate the contact force. Thus, the load should be considered as part of the coil power requirement, in selecting one type of relay over a number of others.

Contact size is also linked to the magnitude of the contact load. The size should not be larger than is actually needed. The dictates of the load (arcing requirements, amplitude of currents, etc.) fix the contact size.

Engineers sometimes overspecify the contact size to "play it safe." However, the larger the contact, the greater the amount of contact bounce. Thus, the overspecified contacts, which might suggest ruggedness and long life, are slower and actually less durable!

This overspecifying of the load may take on another form. Non-simultaneous requirements should not be written in specifications as if they applied simultaneously. Suppose separate relays are to be used in two distinct applications. In one of them, the load is 10 amps and will be switched only 1000 times. Another relay is being considered for use elsewhere to switch 0.5 amps for a million operation application.

The engineer, thinking of cost-savings, may settle on one relay type (instead of two) and specify a 10-amp rating for one million operations. But these two functions will not occur simultaneously. The result is two overspecified relays and the ensuing higher cost and lower reliability.

The load environment also influences the contact selection. High-temperature ambients make the contacts' particle contaminants more active. The erosion of contacts, bearings and armature stops all increase markedly. The net result is a shorter relay life-span. Dielectric capabilities are also impaired.

Contrary to popular belief, high humidity may greatly increase relay life. It is one reason nonhermetically sealed relays often last ten times as long as the same mechanism in a hermetic enclosure. A low-humidity environment tends to retard the lubricating action on the contacts.

Hermetic sealing excludes many undesirable environments and is mandatory for most military applications. It reduces the number of contact misses. However, relay life is usually prolonged if the same mechanism is open to reasonably clean, ordinary air. The use of a dust cover is more desirable than a hermetic enclosure for most industrial applications. ■ ■