TYCO ELECTRONICS eDIGEST

A series of technology briefs spanning Tyco Electronics' product portfolio

Technology Focus: High Voltage Relays

Tyco Electronics designs and manufactures a full range of relay products from highly specialized signal relays for communication equipment to general-purpose relays used in everything from household appliances to industrial machinery. Additionally, Tyco Electronics supplies high performance relays and contactors for specialized military, aerospace and commercial applications as well as a number of high voltage relays. Global technology development for these products is continuous as we seek ways to increase performance, shrink footprints and improve functionality across all relay product lines. Thorough evaluations of new materials, methods and processes augment product technology innovations; considerable efforts in Six Sigma methods and operational excellence programs target other process and product improvements that provide value to our customers.

Switching High Voltage Circuits With High Voltage Relays

Snubbers are usually employed to protect relay contacts at low voltages, but at high voltages it takes much more to protect the contacts.

Interrupting low voltage circuits is fairly straightforward. As circuit voltage increases, however, so too does the difficulty. Interrupting a kilovolt circuit with conventional switches and relays can prove nearly impossible because of arching. Since the voltage is so high, the air filling the gap between the opening contacts rapidly ionizes into a conductive path. Thus, even though the contacts are moving apart, the ionized gas maintains the circuit.

A solution to arching is removing gases that ionize from the contact area. This implies that high voltage switching works well in a vacuum. In a vacuum of 10^{-6} millimeters of mercury, for example, dielectric strengths up to 2000 volts per mil of contact gap can be achieved.

A vacuum dielectric also provides an inert atmosphere for the high voltage contacts which virtually eliminates oxidation and corrosion. When an arc appears in a vacuum, no disassociation of air or dielectric gas can occur to produce corrosive by-products.

Moreover, a "gettering" effect occurs during contact interruption. Since the vacuum is not perfect, it contains some impurities. During the short period of each arc, some of these impurities are pulled out of the vacuum and attach to nearby surfaces, thereby improving the quality of the vacuum.

Breakdown between electrodes can occur in an absolute vacuum. The sources of electrons to support the resulting arc are the contact materials themselves. The point at which the arc occurs depends upon the work function of the contact materials. Because of the work function, tungsten and molybdenum, are often used.

The work function dictates the maximum electrostatic field that can be isolated with a fixed contact gap. Note that in hot switching, an arc will be drawn and an electrostatic field increases as the contact gap closes. So, at some point while the contacts close, the electrostatic field will be high enough to result in breakdown of the remaining gap.

An arc in a vacuum, unless extremely intense, will tend to blow out. The blow out occurs because the arc, a high-pressure area of vaporized metals, is surrounded by an extremely low-pressure area; the vacuum. Since there are no physical boundaries between the two areas, pressure equalizes and reduces the arc intensity and quickly extinguishing it. Despite its short life, the arc will cause contact erosion. However, this usually does not affect contact resistance because the metal transferred is pure.

Electro-Negative Gas Dielectrics

Not all high-voltage relays are vacuum type. Inert gas dielectrics are used in high voltage components and systems. They are flexible since voltage breakdown in a pressurized enclosure can be controlled by variations in the gas mixture and/or pressure. The arc-quenching feature of gas pressurization is another advantage since complete recovery normally occurs within a few microseconds.

Gas-filled relays are used for high-voltage power switching when the function is to close normally open contacts. One reason for this is that the gas mixture and pressure can be set so that an arc is struck just before the closing contacts touch. Moreover, if the circuit voltage is above 3500 volts, the arc is stable enough to maintain current flow even though the circuit path is interrupted by contact bounce. This phenomenon contributes to the long life gas-filled relays demonstrate in capacitive discharge circuits.

Ionization doesn't help when interrupting current. In fact, it prolongs the arc and intensifies contact erosion. Tests show that vacuum relays are more suitable for power interruption because they limit arc sustenance ("arc blowout"). Arc blowout reduces erosion and prolongs contact life.

In conventional relays, contact resistance varies from cycle to cycle but in vacuum relays, resistance is low and stable over the life of a relay with 0.015 ohms being a typical value. This is because uniformly cleaned parts, lack of oxidation or contamination, and the use of pure metals in the contact areas. Because the contacts are sealed within the vacuum envelope, switching may be safely carried out in explosive or corrosive environments.

In a gas-filled relay, contact resistance is generally low, but it is not as low or as stable as in a vacuum relay. Contact resistance also varies considerably with the applied test method. Higher-volume and higher-current measuring circuits usually result in lower contact resistance. Gold plating improves stability and lowers the contact resistance of gas-filled relays.

Radio-Frequency Applications
Good insulation qualities and low, stable contact resistance are two good reasons to use a high-voltage vacuum relay in radio frequency switching. However, operating any relay at radio frequencies imposes current and voltage limitations. The “skin effect,” where current migrates away from the center of a conductor towards its surface as the frequency rises is one problem because as frequency increases, the skin depth of the conductive path decreases, forcing more current through less conductor. This results in localized heating on the surface of the conductor. High temperatures may compromise the relay seal.

When a relay is used as an insulator, there is radio-frequency voltage across the open contacts and/or between contacts and ground. For all practical purposes, the relay has a high voltage capacitance in the range of one to two picofarads. The leakage current flowing through this capacitance heats the lossy elements of the insulator which, in turn, limits the radio-frequency voltage that can be applied.

Current and voltage limitations make it necessary to de-rate the current and voltage specifications for radio frequency applications. They also limit operation to frequencies below 32 MHz. These limitations should be considered when selecting a particular relay.

Power Switching Applications
The terms “power switching” and “hot switching” deal with power being interrupted or initiated by activating a relay. When a relay is power-switched, an arc is formed during the initial closure and subsequent contact bounce. Arcing causes contact erosion and unless precautions are taken, contact welding may result. At the very least, it can result in considerable contact damage. Therefore, the duration of the arc, the level of current and voltage are critical in determining relay life and reliability.

High voltage power switching relays normally have tungsten or molybdenum contacts because these metals are hard and have high melting temperatures which help withstand the effects of arcing. Some high-voltage relays with milliamp currents use copper contacts, but are usually for “carry only” applications.

The type of circuit load is an important factor in selecting the proper relay. Circuit loads can generally be considered capacitive, inductive or resistive:

Resistive load – the interruption of a dc resistive load causes an arc to occur during the separation of contacts and continues until the contacts are further separated. At certain voltage and current conditions, arc duration is determined by the speed of contact separation, the rate of cooling and deionization with the unavoidable inductance and distributed capacitance. An ac load is easier to interrupt than a dc load at the same voltage because the ac interrupts itself each half cycle. Polarity changes prevent continued metal transfer in the same direction, a condition that often leads to early contact failure with dc loads.

Inductive load – interrupting dc inductive loads is more difficult than resistive loads. The stored energy ($1/2\ LI^2$) in the inductance induces a voltage ($-L\ [di/dt]$) that tends to maintain the current. This continues until the energy of the inductance dissipates. Unless special quick-opening contacts or other means are used to interrupt it, the arc’s persistence depends on the load’s time constant (L/R), a direct relationship. AC inductive loads do not create the same problem as dc loads because polarity reversal at the end of each half-cycle forces the current to zero. Also, the current is out of phase with the voltage and, during the last part of the current half-cycle, the supply voltage is opposing the voltage of self-induction.

Capacitive load – closing contacts in a dc circuit to charge or discharge a capacitor will cause high inrush currents. Effects on the contacts depend on the magnitude of the initial peak current and the time constant of the circuit. Similar situations in ac circuits are not common. For optimum results, the relay should be placed on the ground side of the load. If this is not done, high current arcs can occur between the contacts and case, bypassing the load. The power source is the only limitation to the current surge.

In real world applications, all three elements are usually present, but circuits with significant capacitive or inductive elements are more difficult to switch because of their stored energy. To further complicate the situation, some circuits have high inrush current. Under high inrush conditions, contacts attempt to interrupt very high currents during the period of contact bounce resulting in a heavy arc being drawn that causes melting of the contact metal. Eventually this may cause contact welding. The situation is worse in the case of sinusoidal ac because the peak voltage and current of the ac are each 41% greater than the equivalent dc current for the same load voltage.

High voltage relays are used in other applications too. Consider, for example, aerospace power distribution systems. Studies have shown that 270-volt dc systems offer improvements in reliability, maintenance, weight and life cycle compared to conventional 115/200-volt 400-hertz ac systems.

Conventional switching devices currently used with 28-volt dc or 115/200 volt, 400Hz ac systems require major modifications to reliably switch 270-volt dc circuits. The modifications result in large, heavy units, making them impractical for the intended application. The use of vacuum as an insulating medium to switch 270-volt dc loads provides a significant performance and reliability improvement without increased size and weight.

Selecting high voltage relays is not as straightforward as selecting a low voltage relay. For proper selection, a designer should consider the circuit conditions and the relay's electrical, mechanical and environmental specifications. The designer should be aware of the trade-offs in relay operating characteristics and be aware that relay terminology is a special language with special meanings.

For additional technical information, contact your local Tyco Electronics Sales Engineer, or visit http://relays.tycoelectronics.com/kilovac