A TRANSIENT SUPPRESSION GUIDE¹

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When the current flowing through an inductor is interrupted, a transient self-induced voltage is produced. The magnitude of the switching transient is primarily determined by (a) the strength of the magnetic field at the moment of switching, (b) the time rate of decay of the field, and (c) the resistance of the circuit across which the reverse polarity potentials induced by field decay appear.

First consider the situation in the absence of a suppression network for a contact or a semiconductor in series with an inductor. For a set of contacts, the air gap of the opening contacts initially has a high resistance and only a minute amount of current flows. This allows the induced potential to reach a value high enough to ionize the air gap between the contacts. Then, the resistance of the air gap drops to a very low value and the instantaneous current flow is very great. The stored energy is then dissipated throughout the electromagnetic spectrum as light, heat, and broad band transients. The heat generated vaporizes some of the contact material. As the circuit continues to be opened across the contact, the contact face becomes pitted, and condensation of metal vapor may form a weld between the contacts. For semiconductor components, resistance is again high until the peak inverse voltage of the unit is exceeded. Leakage current then becomes high and damage results.

Arc suppression has three purposes: (1) It protects relay contacts from erosion. (2) It pro-

tects electronic devices by reducing transient energy in a controlled manner. (3) It eliminates spurious signals which would otherwise trigger electronic circuits.

The suppression circuit provides an alternate parallel path for discharge of the induced voltage before it reaches a level at which arcing will occur. The inductive loads most frequently encountered in behavior laboratories are the coils of relays, counters, feeders, solenoids, motors, and stepping switches. Protection devices either present a low initial resistance to current flow, *e.g.*, resistor capacitor (RC) networks and reverse-biased diodes; or the time course of the resistance change in the protection circuit is shorter than that of the unprotected discharge path, *e.g.*, neon bulbs, zener diodes, and the varistor. A varistor is a resistance inversely proportional to the rate of the applied voltage. The latter devices absorb energy only after a certain critical voltage is reached.

Boren (1958) and Powell (1958) recommend neon lamps for arc suppression. But Gumley (1956) notes that neon bulbs require too long an ionization time to prevent some contact damage. Depending upon the energy dissipated, the neon bulb would be short-lived because of the electrode sputtering. Similarly, due to their high threshold, many users have reported no improvement with varistors (De Lallo, 1960). The present paper discusses the proper use of diode and RC suppression circuits. Recommendations for suppressing conventional electromechanical relay systems and the newer hybrid circuits which contain both transistors and inductors are presented separately.

The theory behind RC suppression is that neither the current through the inductor nor the voltage across the capacitor can change instantly. When the contacts to an inductive load open, the rate of change of the current

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has changed sign and the polarity of the voltage begins to reverse. A capacitor in parallel with the inductor functions like a short circuit at the instant of voltage reversal. Therefore, the energy in the inductor is transferred to the capacitor, but the capacitor transfers the energy back to the inductor and the circuit oscillates. Since the inductor is not perfect, its resistance produces heat as oscillation occurs and the energy is dissipated. The resistor in series with the capacitor controls the amplitude of the first oscillation.

In the case of diode suppression, the alternate path for the load current is the reactor's coil resistance. Although diode suppression is most effective insofar as transient reduction is concerned, a penalty is paid in terms of the performance of the reactor being suppressed. For example, the time constant of a solenoid is controlled in part by mechanical and in part by electrical considerations. The longest possible time constant occurs for the minimum possible resistance shunting the solenoid. With diode suppression this resistance is effectively the solenoid's own coil resistance, and hence the time constant is maximized. This may result in increased retraction time for solenoids, drop out time for relays, *etc.* In general, most animal feeders are not adversely affected since their time constant is almost completely controlled by mechanical considerations.

ELECTROMECHANICAL SYSTEMS

DC Relays and Counters

Hill (1958) reports that suppression circuits other than the RC type delay the release time of relays. Therefore, unless this delay is permissible, the most effective suppression device for dc conventional and reed relays and counters is a resistor and a capacitor in series. The RC unit may be installed in parallel with the load, or in parallel with the contact to be protected. According to circuit theory, there is no difference in the protection provided by the two methods. An RC unit should be connected in parallel with all relay and counter coils since this method protects any and all contacts used to operate the coil. Additional protection may be provided for contacts especially prone to erosion, *e.g.*, keys, magnetic switches, and relay contacts which operate highly inductive coils, such as cumulative recorders and steppers.

There are several ways to determine values of R and C. The following equations are useful for computing the appropriate values for RC quenching circuits:

$$C = \frac{I^2}{10} \text{ (answer in microfarads)}$$

$$R = \frac{E}{10 I (1 + \frac{50}{E})} \text{ (answer in ohms)}$$

where:

I = Amperes of load current immediately before the opening of the contacts.

E = Source voltage immediately before the closing of the contacts.

The derived values will provide a good point of departure for additional adjustment. The equations emphasize that each suppression problem must be dealt with individually for maximum results. C. P. Clare and Co. (3101 Pratt Blvd., Chicago 45, Ill.) provides a graph for their mercury wetted contact relay which specifies the values of R and C given the peak load current and the peak load voltage. Another method is to select R and C to provide minimum transients on a high speed oscilloscope such as the Tektronix 530 and 540 series. Finally, it has been found that the load is properly suppressed when no spark is visible in a dark room or when an NE 2 neon lamp temporarily connected in parallel with the coil and the RC unit does not fire. If the no-spark method is used when the coil in question is operated by ac, numerous trials must be undertaken if the experimenter is to be certain that he has not opened the contacts at those instants when the coil current was at or close to the minimum.

The resistor should be of the same general magnitude as the resistance of the load. A low resistance would minimize contact erosion on break but would draw a large current on make, so the load value is a compromise. The recommended value for the capacitor, which should not be electrolytic, is between 0.1 and 2.0 m μ , with a peak voltage of 200 to 400 v dc. The appropriate capacitance can be determined empirically in combination with a given resistance. Encapsulated RC units are available from Presin Co., 226 Cherry St., Bridgeport 5, Conn. Prices range between 42 and 80 cents a unit with quantity discounts available.

DC Steppers, Solenoids, and Highly Inductive Coils

Arc suppression of loads which draw appreciable current such as steppers, cumulative recorders, and heavy duty solenoids is particularly difficult. RC units mounted in parallel with the coil have been more effective than varistors. For these loads a capacitor of up to 5 m μ may be required for complete suppression. However, Hill (1958) notes that a life test with a .5 m μ capacitor in a situation calling for a 2 m μ capacitor showed negligible contact erosion. Contrary to Norris and Kelleher (1958), a diode should not ordinarily be used to arc suppress a stepping switch which is self interrupted, as in automatic reset, since the diode slows down the action of the coil.

AC Relays and Motors

The same degree of arc suppression is generally not possible with ac operated devices unless the contacts are open when the change of current with respect to time equals zero. Because of the jitter associated with most relays it is not possible to open the relay at 0 v. Suppression which does not allow a transient slightly greater than the peak voltage can be accomplished by using two selenium rectifiers attached in parallel with the coil. Two rectifiers are essential for ac since the unit must block both voltage polarities. Selenium rectifiers designed for arc suppression are available from Bradley Semiconductor Corp., New Haven 11, Conn. For larger currents, such as needed to operate an ac solenoid, a power resistor or light bulb wired in parallel with the coil is sometimes effective. Where experimenters are undertaking physiological measurements, dc circuitry is strongly recommended, as high ac voltages interfere with the operation of physiological recording devices.

HYBRID CIRCUITS

DC inductors less than 50 v

The combination of transistors with electromechanical devices in a hybrid circuit creates difficulties because the transients induced in the coils may trigger electronic circuits or permanently damage the transistors. A general discussion of voltage transients in silicon controlled rectifier circuits is found in the SCR Manual Third Edition (Gutzwiller, 1964).

Diode suppression is more effective than other methods (Saslow, 1964).

The diode should be installed in parallel with the inductor so that the diode is normally reverse-biased when the contacts are closed. That is, the cathode is attached to the positive side and the anode to the negative side of the coil which in operant circuitry is connected to the operate stud. A quick-acting fuse should be placed in the positive line of the power supply in series with the diode load combination to prevent accidental short circuits which may permanently damage transistors. The peak inverse voltage of the diode need be only slightly greater than that of the supply voltage. The diode should be capable of conducting in the forward direction a current equal to the dc current through the reactor. The selection of specific diodes depends upon the load current. For loads less than 100 ma use 1N456, for loads between 100 ma and 1 amp use Mallory A 100 or equivalent, and for loads between 1-5 amp use 1N1342. Diode prices range from \$.53 for the 1N456 to \$2.09 for 1N1342. These techniques are useful only for dc power supplies of less than 50 v.

Lamps

Lamps are not reactive and do not require arc suppression, but they may draw up to 10 times their steady state current upon initial operation from a cold condition. This current surge may exceed the current ratings of the transistor circuit used to operate the lamp or even cause sticking in light duty relay contacts. This problem can be eliminated by permitting a standby current, less than required to illuminate the filament, but enough to keep it warm to flow through the lamp. For example, the lamp can be connected directly to the normally-open contact of a control relay and via an appropriate resistor to the normally-closed contact. If a reduced lamp intensity can be tolerated, a resistor may be placed in series with the contact which operates the lamp. The series method has the additional advantage of increasing lamp life.

It is wise to discuss arc suppression requirements with the supplier before ordering. Before commercial or locally built equipment is installed, it should be checked in operation for adequate arc suppression.

Arc suppression is an active area of research by engineers concerned with relay manufac-

ture. Papers on arc suppression are frequently read at the annual Relay Conference of the National Association of Relay Manufacturers. A program may be obtained from Dr. D. D. Lingelbach, Relay Conference Director, School of Electrical Engineering, Oklahoma State University, Stillwater, Oklahoma.

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