Capacitors in Control Circuits
(Continued)

value. When S_1 and S_2 are subsequently opened, the relay does not drop out immediately but continues to hold through action of capacitor discharge current flowing through the two resistors in series. Dropout occurs at the instant that the discharge current falls below the minimum value required to maintain the holding ampere-turns. This circuit is employed in cases where low pickup requirements permit a low value of relay ampere-turns. A high-resistance, high-turn coil may thus be used, and the capacitance of the control capacitor materially reduced.

The relay shown in Figure 6 has two coils wound upon the same core. One has a large number of turns; the other a small number. The low-turn coil provides the high value of ampere-turns required for picking up the relay armature against strong spring bias or gravity pull. When switch S is opened, the armature is held during the delay interval by discharge current from capacitor C flowing through the high-turn coil and control resistor R.

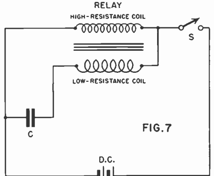

FIG. 7

The circuit of Figure 7 has been designed for rapid pickup and rapid dropout. A special dual relay winding is provided, consisting of high-resistance coil and a low-resistance coil, both containing the same number of turns wound upon a common core. The low-resistance coil provides a high-value of ampere-turns for quick pickup. When switch S is closed, current flows through the coil and into capacitor C, picking up the relay. This charging current is of short duration. When the switch is later opened, capacitor discharge current flows through the two coils in opposite directions, giving rise to bucking fields, and the relay quickly drops out.

REFERENCES

For additional information on the subject of capacitor-type control circuits, the reader is referred to the following:

General Electric Review. Vol. 42 No. 11 (November 1939) p. 462

Electrical Engineering. Vol. 59 No. 2 (February 1940) p. 65 (Transactions)

Electronics. Vol. 9 No. 8 (August 1936) p. 28; and Vol. 11 No. 2 (February 1938) p. 26

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Capacitors in Control Circuits

By the Engineering Department, Aerovox Corporation

THE operation of fixed capacitors in industrial time-delay control circuits is based upon the time constants of resistance-capacitance and resistance-inductance combinations. The phase-shifting property of R-C and L-C circuits is employed to obtain operation of an electrical device or circuit interruption at some instant subsequent to applying the operating voltage. The simple resistance-capacitance circuit is the basis of a number of timing devices in present industrial use.

The time constant of a resistance-capacitance circuit is the time required for a current flowing in the circuit to fall to $1/\varepsilon$ or 0.37 of its initial value. Such is the case of capacitor discharge current flowing through fixed resistance, and is given as:

$$t = RC \text{ microseconds} \tag{1}$$

R is expressed in ohms and C in microfarads

$\varepsilon = 2.718$

The time constant of a resistance-inductance circuit is the time required for a current flowing in the circuit to change to a value of $1 - \frac{1}{\varepsilon}$ or 0.63 of its original or final value. This is the case of a current forced through a series inductor, and is given as:

$$t = \frac{L}{R} \text{ microseconds} \tag{2}$$

R is expressed in ohms and L in microhenries

Equations (1) and (2) may be multiplied by 10^6 to give the time constant in seconds.

Two rudimentary applications of the time constant of circuits to obtain time-delay operation in a simple manner are illustrated by Figures 1 and 2. In Figure 1 it is assumed that the capacitor C has been fully charged from a direct-current source, that the charging potential has been removed from the circuit, and the arrangement shown in the schematic circuit established. The capacitor will then discharge through the circuit containing the resistor and any other series-connected electrical device (such as the relay coil shown) at a rate determined by the C and R values, assuming that the reactance and resistance of the relay coil are negligible.

The progress of current decay in similar circuits of low, medium, and high resistance is shown by the curves of Figure 1-A. It is seen from these curves that a high current may be maintained for short time or a low current for a longer time, depending upon the circuit resistance. The curves are plotted for a given capacitance. From such operation, it is easily understood that the relay contacts in the R-C circuit will be held closed by the capacitor discharge current until such instant as the latter falls below the minimum value necessary to maintain closure ampere-turns. From Equation (1) and Figure 1-A, we observe that the interval of closure may be prolonged by increasing the value of C, R, or both.

The circuit of Figure 2 shows a rudimentary arrangement for obtaining a time-delay effect of the opposite kind. Here it is assumed again that the reactance and resistance of the relay coil are negligible and that the useful time lag is supplied by the series inductor L and series resistor R. When the main switch is closed, connecting the direct-voltage source to the circuit, a current builds up gradually to the level required to close the relay contacts at a rate determined by L/R. Thus, we have in Figure 1 a relay which picks up immediately when the main switch is closed and continues to hold for a predetermined time interval after the

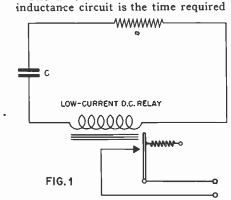

FIG. 1

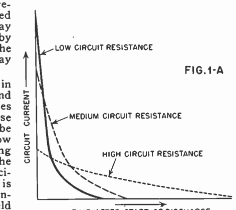

FIG. 1-A

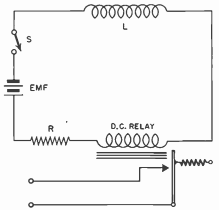

FIG. 2

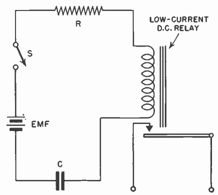

FIG. 3

switch is later opened. In Figure 2, on the other hand, we have a relay which picks up at some preset instant *after* the main switch is closed and drops out immediately upon opening the switch.

Figure 3 shows a simple capacitor circuit in which relay pickup occurs at the instant the main switch is closed and drops out at some later instant determined by the circuit time constant. Operation is based upon charging current which diminishes to the dropout value according to the RC rate. The charging current flowing through the circuit into the capacitor C is equal at any instant to:

$$I = \frac{E}{R}\,\epsilon^{-\frac{t}{RC}} \tag{3}$$

I is the instantaneous charging current (amperes)
E is the charging potential (volts)
R is the circuit resistance (ohms)
t is the time interval measured from the instant of circuit closing (seconds)
ϵ = 2.718
C is the capacitance of control capacitor (farads).

The circuits of Figures 1 and 3 are useful for obtaining a delay in dropout, while those of the type illustrated in Figure 2 are employed for delayed pickup. The relay contacts in the capacitive circuits are shown normally open, but reverse performance might be obtained by arranging the contacts in the normally-closed condition. In practical industrial timing circuits where a succession of operations are to be performed at various instants, special relay construction is employed in which several armatures are arranged on a single magnetic structure to be dropped out individually at preset instants.

In any of the simple circuits discussed thus far the size of the relay coil must be such that the required ampere-turns for efficient operation will be obtained with the current value available at the desired instant of operation. Likewise, C in Figure 1 must be large enough to deliver the required discharge current over the selected interval of operation.

In practice, both the resistance and reactance of the relay coil must be taken into account in the design of the circuit. Simple circuits of the capacitive type, such as Figures 1 and 3, would demand low-current d.c. relays for direct application.

REQUIREMENTS FOR CONTROL CAPACITORS

For most industrial timing-circuit applications, large capacitances will be required in order that the maximum amount of energy (expressed in watt-seconds for a given charging voltage) may be stored. The present availability of very high capacitance electrolytic units enables the design of capacitor-control circuits of high energy storage capability affording long time-delay intervals. The actual length of the delay interval may, of course, be governed by the control-circuit series resistance and does not depend largely upon the magnitude of charging voltage. The electrolytic capacitor is not applicable, however, to circuits in which zero current level must be reached, due to the normal leakage of these units. For these circuits, there are available oil capacitors of reasonably high capacitance.

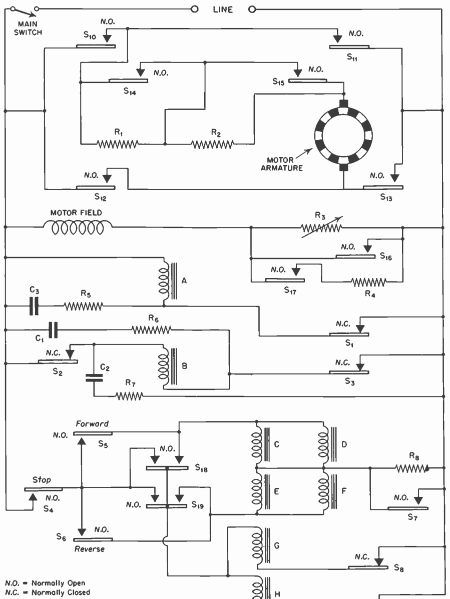

FIG. 4

CAPACITOR-CONTROL IN MOTOR ACCELERATION

One of the most important present uses of capacitor control is in the provision of successively-timed operations preceding or following interruption of the operating voltage. Motor acceleration is one such application. In the capacitor-controlled motor-accelerator, successive values of starting resistance are cut out of the circuit automatically after the main power switch has been closed, this operation being performed entirely by capacitor-control circuits. An interesting circuit for a motor controller of this type has been described by Stansbury and Jochem[1]. Employed in this circuit (see Figure 4) are relays which pick up and drop out at preset times by means of capacitor control, and relays which drop various of their armatures at preset intervals.

The latter type relay is constructed by providing several separate armatures and sets of contacts for a single magnetic structure. The control mechanism (aside from the R-C control) which determines the instant at which these armatures are dropped out is the reluctance of the independent magnetic circuits—the dropping ampere-turns are adjusted by setting the magnetic gaps of the independent armatures when in the closed position.

[1] *Capacitor Relay Timing in Industrial Control.* Carroll Stansbury & Theo. B. Jochem. *Electrical Engineering;* Feb. 1940 p. 65 (Trans.)

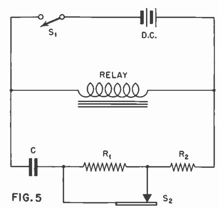

FIG. 5

This is a simple and effective means of adjustment and its direct effect upon the time constant may be understood from examination of the equation:

$$t = CR \log_{\epsilon} \frac{ni_o}{ni} \tag{4}$$

C is the capacitance of control capacitor (farads)
R is the control resistor value (ohms)
i_o is the initial transient current (amperes)
i is the transient current (amperes)
t is the time constant (seconds)
n is the number of relay-coil turns.

The motor controller of Figure 4 is arranged to start up a motor automatically and bring it up to its various safe speeds either in the forward or reverse directions. The arrangement is such that the starting resistors R_1 and R_2 are in series in the starting condition and are automatically cut out successively as the motor gains speed. These operations are performed at the proper safe time intervals.

The capacitor-timed relay A has two independently-timed armatures for motor field acceleration and a third to insure proper operating sequence. This relay controls contacts S_{16} and S_{17}, both of which are normally open. The capacitor-time relay B actuates the armature acceleration contactors S_{14} and S_{15} and operates the contacts S_7, which is normally open, and S_8 and S_9 which are normally closed. The various contactors are C with contacts S_{12} and S_{18}, D with contact S_{11}, E with contact S_{13}, F with contacts S_{10} and S_{19}, G with contact S_{14}, and H with contact S_{15}. Contactors C and D are for the forward direction of rotation, and E and F are for the reverse direction. Contactors G and H are for armature acceleration and actuate the contacts S_{14} and S_{15} which cut in or short-circuit the starter resistors R_1 and R_2. The rheostat R_3 is for manual field control.

Operation of the controller circuit is explained briefly as follows: When the main switch is closed, relay B picks up and its contacts S_8 and S_9 are opened, while its contact S_7 is closed. C_1, C_2, and C_3 are accordingly charged through R_6, R_7, and R_5 respectively. Relay A operates simultaneously, closing its contacts S_{16} and S_{17}. The motor armature is connected to the line through the entire starting resistance R_1 plus R_2 when the *forward* pushbutton S_5 is closed since contacts S_{11} and S_{12} are closed at this time by C and D. However, as S_{12} closes, it opens auxiliary contact S_2 disconnecting relay B through which C_2 now discharges, starting the timing process.

Contactors G and H then short-circuit the starting resistors successively through the contacts S_{14} and S_{15}, the contactor coils having been connected

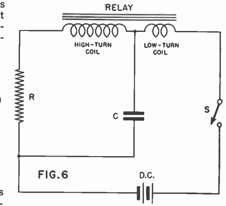

FIG. 6

to the line through the timing action which closed S_8 and S_9 successively. Contact S_7 has opened during this course of events, and not until it has again closed will contactors C and D be picked up. The armature carrying S_7 is mounted on the same magnetic structure as S_8 and S_9, however S_7 has the larger magnetic gap so that S_8 and S_9 are opened before contactors C and D close. This arrangement prevents contactors S_{14} and S_{15} from closing simultaneously with C and D and thereby connecting the motor armature directly across the line.

An auxiliary contact S_1 is operated by S_{15} when the latter closes, disconnecting relay A and allowing C_3 to discharge through A. S_{16} and S_{17} then open successively at predetermined instants, due to the timing in relay A, inserting R_4 in series with the motor field. When the motor is operating *forward*, C_2 discharges through the coil of relay B for timing. When the motor operates *reverse*, the opening of S_3 permits C_1 to discharge through the same relay. Thus one capacitor controls timing, with the motor running in one direction, while the other capacitor (in reserve for timing when direction of rotation is reversed) is being charged to the full line voltage.

ADDITIONAL SPECIAL-PURPOSE CIRCUITS

Figures 5, 6, and 7 show capacitor-control circuits suggested by F. H. Winter[2] for various particular functions. In Figure 5; when the main switch S_1 is closed, current from the source DC picks up the relay. The auxiliary contacts S_2 are closed at the same time by ganging with S_1, short-circuiting the high resistance R_1 to permit control capacitor C to charge rapidly through the low resistance R_2. The latter has been inserted in the circuit specifically to limit the current through the S_2 contacts to a safe

[2] *Some New Uses of Capacitors in Control Circuits.* F. H. Winter. General Electric Review, Nov. 1939 p. 462.