Seasons Greetings and Best Wishes for a Prosperous New Year

The AEROVOX Research Worker

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Time Delay Circuits

By the Engineering Department, Aerovox Corporation

ON numerous occasions it is required that a circuit shall be opened or closed automatically a definite time after an initiating impulse. Examples of such requirements are: The application of the plate voltage on a mercury-vapor rectifier tube after the filament has heated, the timing of arc-welding, automatic door openers, regulating photographic exposures, etc. This article will review the diverse ways wherein the desired effect can be accomplished and will show a method of calculating the required constants for a given delay.

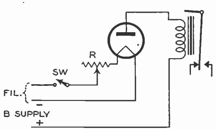

FIG. 1

According to the requirements one may distinguish between the following cases: A circuit must be opened a definite pre-determined time after an initiating impulse, it has to be closed, or it has to be first closed and then opened, both events to occur after separately controllable time delays. Finally there is the case where the previous cycle must be constantly repeated.

According to the methods employed, time delay devices may be mechanical, thermal, or depending on the discharge or charge of a condenser in conjunction with electron tubes. There can also be combinations of these.

The mechanical arrangements involve relays with plungers or electric clock mechanisms which are already well known and need not be considered here. Among the thermal methods, attention is called to the utilization of the heating time of vacuum tubes. In Figure 1 a simple circuit is shown embodying this principle. When the switch SW is closed, the tube filament begins to warm up and the plate current rises gradually until the relay pulls up and either opens or closes the load circuit. The time can be regulated between reasonable limits by adjusting the relay or by inserting resistance in series with the filament and raising the applied voltage accordingly. During the heating up period, the cold filament has lower resistance, so when it is in series with an unvarying resistance it will receive only a small part of its share of heating power, thereby increasing the time. Still further delays can be obtained by employing an indirectly heated tube but then sufficient time must be allowed for the cathode to cool before the device is used again. In other systems a bi-metallic strip is more or less slowly heated until it closes the load circuit.

CONDENSER CHARGE OR DISCHARGE METHODS

It may take considerable time to charge or discharge a condenser through high resistance. This phenomenon can be utilized if the voltage across the condenser is used to control a switch by means of a tube and relay. In most cases there are several possible solutions, some involving a charge and some a discharge of a condenser.

Consider Figure 2; when the switch SW is closed, plate current will immediately flow because the tube is heated all the time and the initial charge of the condenser is zero making the grid bias equal to the voltage drop across R2. The relay therefore pulls up immediately and closes the circuit. The condenser meanwhile charges slowly through R and the plate current gradually decreases.

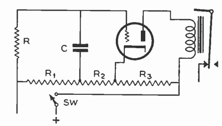

FIG. 2

When it reaches the critical point, the relay drops out. The circuit will then be ready for action again after SW is opened and the condenser is discharged. If desired, all these reset operations can be performed automatically by employing a relay with multiple contacts.

A second method to accomplish the same result is shown in Figure 3. While the switch SW is closed, the condenser is charged through R1 which is a low resistance. This brings the grid bias down to the voltage drop across R3 which is a safeguard to prevent overloading the tube. The relay pulls up when the switch is closed.

After the switch is opened the condenser discharges through R making the grid more and more negative until the relay falls back. The circuit is ready again when the switch is closed for a short period.

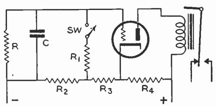

FIG. 3

When it is required to *close* the load circuit after a delay, it could simply be done by using the back contacts of the relays in Figures 2 and 3 but the circuit also can be re-arranged. So, for instance, in Figure 4 the grid starts out with a very negative bias when SW is set at A. When the condenser is nearly charged the bias becomes low enough to permit plate current to flow in sufficient amount and the relay closes. Resetting is accomplished by throwing the switch SW to the discharge position, B, when C discharges through R4.

In Figure 5 the condenser is first charged to the full B-voltage and then connected to the grid so as to make it negative when the switch is thrown. The condenser again discharges through R until the bias has become low enough to trip the delay.

There are numerous other combinations to obtain the desired effects and before proceeding to describe involved circuits it is desirable to examine the foregoing more closely.

It is essential that d.c. be employed for the B-supply although the filaments but heaters may be supplied by a.c. Therefore any conventional power supply will do and voltage dividers can be employed as shown. However, it is desirable that the voltage drop across R1 be large in all cases and that it does not vary with the plate current in the tube if the time delay is to agree with calculations. In such cases it is often best to employ two separate power supplies which are independent,

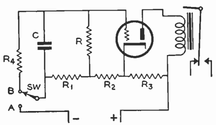

FIG. 4

one to supply the plate of the tube the other to charge the condenser. This is done most conveniently by means of voltage doubling. Figure 6 shows how Figure 3 may be modified in this manner.

CALCULATING THE TIME

The time of the delay is a function of C, R and the ratio e/E where e is the voltage across the condenser which causes the relay to operate and E is the voltage across the condenser when fully charged.

When a condenser charges through a resistor the voltage across it increases according to the curve A in Figure 6A, it can be mathematically expressed by the equation

$$e = E\left(1 - e^{-\frac{t}{RC}}\right)$$

From this equation it is easily seen that when t = RC, the exponent becomes —1 and e becomes 63% of E. Similarly if t = 3RC e is 95% of E. This product RC is called the time constant.

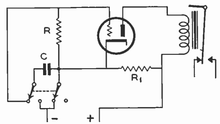

FIG. 5

In the case of discharge the condenser voltage falls according to the curve B. This one being a graph of the function

$$e = E\, e^{-\frac{t}{RC}}$$

If t equals RC, the exponent again is —1 and the condenser is discharged to 37% of its original charge. It should be clear that the time elapsed to reach a given voltage in all cases depends on R and C as well as the charging voltage.

Expressing C in microfarads and R in megohms, the time delay is given by the following equations:

for charge:

$$t = RC \log_e \frac{E-e}{E} \text{ seconds}$$

for discharge:

$$t = RC \log_e \frac{e}{E} \text{ seconds}$$

There are several possible ways of arriving at the required constants for a given time delay. In Figure 7 the chart shows the time in seconds plotted against the ratio (E-e) /E or e/E for different values of RC. An example will clarify its use. Suppose, in Figure 4 the total power supply is 250 volts d.c. across R_1, R_2, R_3, the voltage across R_2 is 10 volts and the relay is so adjusted that it will operate when the grid bias is 15 volts. If the voltage drop across R_1 is 100 volts, the critical value e is 95 volts and (E-e) /E is 0.05. In order to obtain a delay of, say 12 seconds, find the point corresponding to (E-e) /E = 0.05 and t = 12 in Figure 7. This point is located on the line RC = 4. Thus a 4 mfd. condenser and a 1 megohm resistor can be used or a 2 mfd. condenser and a 2 meg resistor, etc.

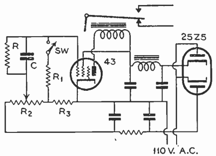

FIG. 6

In general the point will not be found exactly on one of the RC lines and interpolation may be necessary. If this is found difficult, find the corresponding time when RC is unity then divide this time into the required time to find the value of RC.

The range of the chart may be extended by multiplying all values of RC and all values of t by any convenient factor.

In the above illustration one must be sure to take into consideration the bias on the tube provided by R_2. Also, the required grid bias must be determined from the dynamic characteristic for a load equal to the relay resistance.

The entire calculation can also be done conveniently on a log-log slide rule. If all values but t are known, set RC on scale B to 1 (center) on scale A. Opposite (E-e) /E or e/E on scale LLO find t on B. The same procedure is also followed when RC and t are given. If RC is to be found, set t on B to (E-e/E or e/E on LLO). Then find RC on B opposite 1 on A.

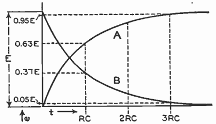

FIG. 6A

PRACTICAL LIMITATIONS

The methods of calculations are correct only when one deals with a condenser having very low leakage and provided that there are no other conditions in the circuit which modify the critical constants. So, for instance, when R is several megohms there should not be any appreciable leakage in the mounting of the parts and the input resistance of the tube should be high.

These factors become of great importance when long time delays are

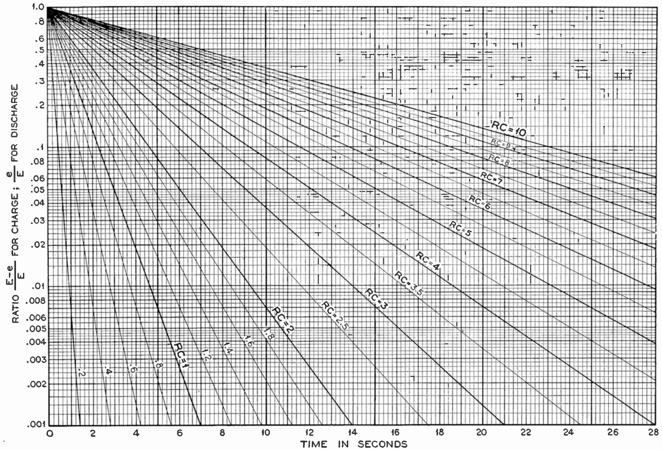

FIG. 7

required. In such cases a large condenser will probably be required. The leakage resistance of a paper condenser is inversely proportional to the capacity. With a new high grade condenser, the product of microfarads and megohms might be above 2,000. The leakage resistance to be expected can be estimated from this figure. However, this does not include possible leakage over the outside surface of the condenser. This outside leakage depends on the length of the path between terminals and the humidity. The length of the path between terminals does not necessarily vary in proportion to the capacity. When the resistance of this path becomes comparable

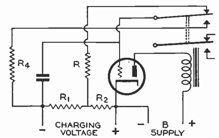

FIG. 8

to R, the time delay will be subject to erratic variations. In general, the leakage resistance should be at least 50 times, the charge or discharge resistance, R.

The next unit of importance is the resistance R. When this is a very high resistance of the grid leak type, enclosed in a glass tube, the condition of the glass becomes important. Dust and dirt collecting on the glass may offer a leakage path of less resistance than the resistor itself. The condition can be remedied by dipping the glass in paraffin wax.

The tube may represent another problem; when power tubes are used in parallel with high resistance grid leaks, the effective resistance of the two in combination may be considerably reduced due to gas current. Therefore, if the resistance of R is 5 megohms or over it is necessary to make a careful choice between possible tubes.

ADDITIONAL CIRCUITS

If it is desired to have a device which keeps on opening and closing the load circuit, it can easily be made by a slight modification of Figure 4. If the switch SW is one of the sets of contacts on the relay while it is used to connect C either to the charging resistor R or to the discharge resistor R_4, the requirements are fulfilled. The circuit then becomes as in Figure 8. In the position shown, the condenser is charging through R. When the charge is high enough to make sufficient plate current flow, the relay pulls up and starts the discharge through R_4.

Another type of circuit is shown in Figure 9; this is due to Gulliksen and described in Electrical Engineering for February 1933. The tube is heated all the time. When a switch, in series with the B— supply, is closed the plate current starts flowing but any increase in voltage drop across R_1 starts the charge of C and causes a voltage drop across R making the grid negative and retarding the increase in plate current.

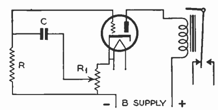

FIG. 9

When the plate current has become normal, the relay pulls up. The rate of change can be controlled by the potentiometer R_1 and the time is therefore dependent on the setting of R_1 as well as on the size of R and C. This arrangement is said to be little affected by variations in line voltage. A maximum variation of 5 percent may be expected for a fixed position of the potentiometer R_1.