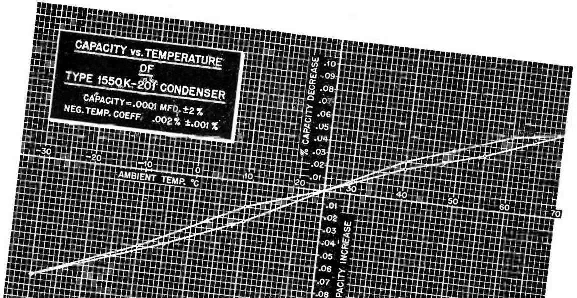

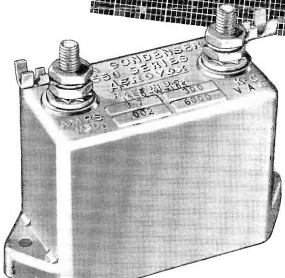

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INDUSTRIAL APPLICATIONS OF ELECTRONIC DEVICES

PART III

By the Engineering Department

AEROVOX
Corporation

A paper by the Engineering staff of Aerovox Corporation. In order to preserve the unity of the text, this material which is too lengthy to be included in the usual four page edition of the Research Worker, has been published in three eight-page editions. Part I appeared in the combined August-September issue; Part II in October-November; and this issue, Part III, which concludes the series.

AEROVOX PRODUCTS ARE BUILT BETTER

Printed in U. S. A.

Industrial Applications of Electronic Devices

PART III

CONTINUING our discussion of inverters, attention is called to a self-excited circuit lately described by Tompkins.[1] This hookup, shown in Figure 1, was derived from the conventional parallel type of inverter and is arranged for variable-frequency operation.

The circuit will be seen to contain few additional components. Direct current is supplied to the anodes of the two thyratrons, V_1 and V_2 through the reactor, L_3 and the primary winding of the output transformer, T_o. Between each thyratron grid and cathode a fixed inductor and variable resistor, such as the L_1R_1 combination, are connected in series; and a fixed capacitor, such as C_1, is connected from each grid circuit to the anode of the opposite tube. C_c, shunting the output transformer primary, is a fixed commutating capacitor whose function will be described later.

T_s is a suitable transformer for introducing an a.c. exciting voltage across the thyratron grid circuits for starting purposes. (This inverter must be started, with reduced d.c. input, as a separately-excited unit, after which the switch, S may be opened to remove the exciting voltage, and the d.c. input raised to the maximum operating value).

In this circuit, the successive charge and discharge of the capacitors, C_1 and C_2 cause the tubes to fire alternately and at a regular rate, sending through the output transformer primary the pulses of current which set up an alternating voltage across the secondary. The capacitor discharge is made oscillatory by the constants of the RL circuits in the grids and the capacitors, C_1 and C_2. These constants likewise determine the rate at which the primary pulses are delivered, and hence the a.c. frequency. By varying the settings of R_1 and R_2, the frequency of the output voltage may be controlled over a reasonably wide band.

Actually, operation of the circuit of Figure 1 is a much more detailed process than the simple explanation given in the preceding paragraph. In analyzing the circuit action, let us observe that both anodes will be positive by reason of their connection through the transformer to the positive side of the d.c. supply, and let us assume that tube V_2 is conducting and V_1 is not. Capacitor C_2 is then effectively connected across the entire output primary and, as a result, is charged to a voltage equal to the primary voltage less the drop due to V_2, its "anode end" being positive. C_c is charged to a voltage equal to the drop across the transformer primary occasioned by current flowing in the right half of the winding. The right-hand terminal of this capacitor is then negative.

When the grids exchange polarity near the end of the cycle, current is permitted to flow through the second tube, V_1, effectively connecting the left-hand terminal of C_c to the negative side of the line. This places a momentary negative voltage (commutating impulse) on the anode of V_2, restoring control to the grid of that tube and extinguishing the V_2 discharge.

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[1] F. N. Tompkins, "Operation of a Self-Excited Inverter," *Electronics*, Sept. 1940. Pt. 1. p. 36. By permission, McGraw-Hill Pub. Co., Inc.

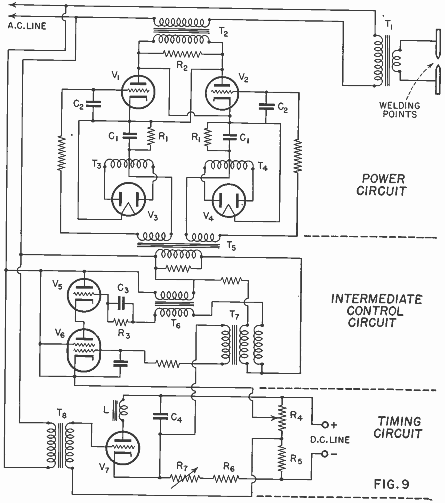

FIG. 9

secondary of the series transformer, T_2, is short-circuited at the same rate, the thyratrons in the power circuit receiving corresponding grid pulses from the control circuit.

In the timing circuit, the thyratron (V_7) anode is supplied with d.c., but its grid is also supplied with a.c. of peaked waveform from the saturated-core transformer, T_8. The thyratron does not conduct immediately when the d.c. operating voltage is applied because the instantaneous anode-cathode potential is zero. This is due to the fact that the voltage across the capacitor, C_4, is zero (the full voltage is the drop across R_6 and R_7). The negative grid potential is then equal to the supply voltage minus the drop across R_5 and the alternating component supplied by T_8. Both of the latter two are small values.

The voltage drop across R_6 and R_7 decreases, however, as C_4 charges and the capacitor voltage rises. At a certain point, the voltage across C_4 will be sufficient to initiate the discharge in V_7. The capacitor will then be discharged through the inductor L, which will cause C_4 to charge a small amount in the opposite direction, (reactive effect). This places a negative potential on the anode of the tube and extinguishes its discharge, restoring the circuit to the original starting condition. The operating sequence will be repeated, with the interval between capacitor discharges equal to a definite number of cycles due to the synchronizing potential supplied by T_8. The total welding cycle is governed by this interval. The length of the total welding cycle and the *on-time* to *off-time* ratio are determined by the settings of potentiometers R_4 and R_5 and by the capacitance of C_4.

RADIO INTERFERENCE

The operation of industrial electronic devices frequently causes interference to radio reception. Circuits embodying thyratrons, ignitrons, mercury-vapor rectifiers, and vacuum-tube oscillators may give rise to one or both of the common types of radio interference—the kind transmitted back over the power lines and that radiated directly into space.

In the case of radiation from low and medium-power industrial r.f. oscillators, the community immediately adjacent to the industrial machinery suffers most. However, high-powered, unshielded r.f. oscillators are capable of causing interference over a widespread area.

Radiation of broad, widely-interfering, undamped waves occurs when high-power circuits are interrupted, and particularly so when the process is attended by violent sparking. Such waves, capable of interfering over a broad band of frequencies, occasionally are produced also by the firing of thyratrons or other controlled industrial rectifiers.

It has even been known for secondary, high-frequency oscillations of the "parasitic" type to be generated in certain gaseous-tube circuits (such as inverters) and to find their way into neighboring radio receivers by way of the power line.

The remedy for any type of radio interference resulting from industrial electronic operation will depend upon the nature of the interference, and may generally be applied in the conventional manner as outlined in the various treatises on man-made radio interference.

CONCLUSION

Our limited space has not permitted us to elaborate upon the subject of industrial applications as extensively as we might have desired. Condensation has been imperative. For this reason, we have been compelled to select for explanation those examples known to be of the widest general interest.

The reader is invited to augment the information we have presented in the last three issues by a study of the articles and books to be found in any current listing under *industrial electronics*, *industrial applications of vacuum tubes*, and *industrial control circuits*.

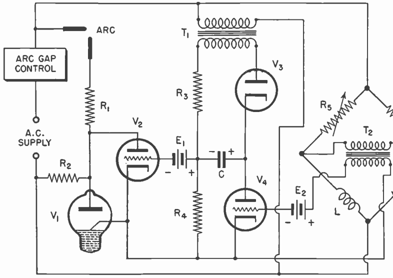

FIG. 7

welder control. And it is in the machinery of welding that the controlled rectifier has been playing its greatest industrial role.

The fundamental circuit for welder switching is shown in Figure 8. In series with the a.c. power supply and the welding transformer is connected a series transformer. When the secondary terminals, A-B, of this series transformer are open, the primary current which flows through the primary of the welding transformer as well, is only the exciting current of the series transformer and is insufficient for the welding operation. When the terminals, A-B, are short-circuited, however, the reactance of the primary winding of the series transformer is reduced to its minimum and maximum current flows through the welding transformer. It remains alone to provide an automatic switch to short-circuit the secondary terminals, A-B, to render the welder operation intermittent. If such a switch were synchronized with the a.c. supply frequency, the welder might be made operative over as short a period as one-half cycle, or this *time on* might be extended to several cycles.

It has already been pointed out that mechanical devices are difficult to maintain in a state of synchronism. However, grid-controlled, high-current rectifiers, such as thyratrons, are readily synchronized from alternating current sources, and they might be connected so that their anode-cathode circuits will effectively short-circuit the secondary of the series transformer when the tubes are conducting. Two tubes may be so arranged that one conducts during one half-cycle; the other tube conducting during the other half-cycle. By appropriately controlling their grids, the "on" time of the welder might then be adjusted over a range varying between one cycle and several cycles.

The top third of the circuit in Figure 9 is such a dual-thyratron power control circuit operating into a series transformer.

T_1 is the welding transformer. V_1 and V_2 are the thyratrons with anodes connected to the high-voltage secondary of the series transformer, T_2. V_3 and V_4 are high-vacuum rectifiers, energized by the transformer secondaries, T_3 and T_4, which supply separate negative d.c. bias to the thyratron grids sufficient to maintain V_1 and V_2 non-conducting in the absence of excitation. R_1 and C_1 constitute bias supply filters. The thyratron grids also receive from transformer T_5 an a.c. exciting pulse which is in phase with the anode potential, and it is this pulse which fires V_1 and V_2, producing the short-circuit of the series-transformer secondary. The grid pulse is delivered by the components making up the middle half of the circuit, the *intermediate control circuit*, and is timed by the *timing circuit* of the lower section. The capacitors, C_2, and resistor R_2 are safety components. The capacitors reduce the effects of high-frequency transients which tend to drive the thyratron grids to the firing point; while the resistor, which possesses a negative voltage-resistivity coefficient, protects the tubes from surge voltages arising in the welding circuit.

In the intermediate control circuit, V_5 and V_6 are thyratrons controlled by the timing circuit and arranged to conduct current each in the opposite direction, thus applying a full-wave alternating voltage to the primary of T_5. Thyratron V_5 derives its negative bias voltage from the grid leak and capacitor, R_3-C_3. Transformer T_6 delivers to V_5 an alternating grid voltage 180 degrees behind the anode voltage, rendering this tube accordingly non-conducting.

The timing-circuit voltage pulse fires V_6, whereupon current flows through the primaries of T_5 and T_7. T_7 has a saturated core and its secondary voltages are sharply peaked. One secondary feeds the V_5 grid, while the other supplies the V_6 grid. The alternating voltage impressed upon the V_5 grid causes this tube to fire immediately after the half-cycle of V_6 conduction. The secondary delivering voltage to the V_6 grid limits the firing of this tube to the beginning of the cycle.

When the intermediate control circuit is operating properly, the two tubes conduct alternately at a rate determined by the timing circuit, V_5 always taking up immediately where V_6 leaves off. The result is that the

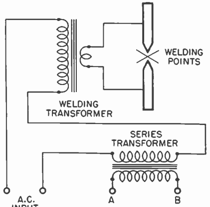

FIG. 8

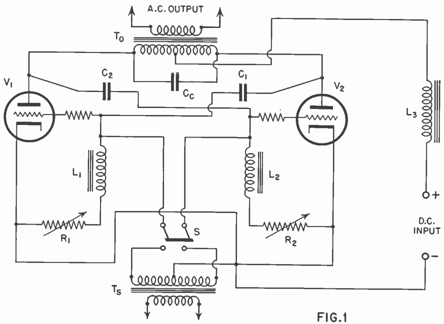

FIG. 1

During the preceding process, C_2 has been charging. When V_1 fires, the capacitor C_2 then begins to discharge through that tube and the rate-determining series circuit, L_2R_2. The V_2 anode potential rapidly becomes positive after the commutating impulse from C_c, but this tube cannot yet conduct because the recent C_2 discharge maintains its grid negative beyond the critical point. As the discharge continues, however, the voltage applied to the grid of V_2 grows steadily smaller until the critical value is finally reached, whereupon V_2 again fires and C_c discharges, extinguishing the arc in V_1.

Meanwhile, a charge has been building up in C_1 and this capacitor will subsequently duplicate the action of C_2, causing the chain of events to be repeated. The net result is that the two tubes fire alternately at a rate determined by the values of C_1, C_2, L_1, and L_2 and the settings of R_1 and R_2.

The self-excited inverter, of which there are several possible arrangements, offers the advantage that no locally-generated alternating voltage is necessary in the circuit except for starting purposes. Like the self-excited vacuum-tube oscillator, however, it is apt to suffer from frequency instability under load circuit variations. For certain applications, particularly where the load is of a steady value and voltage regulation requirements are not too severe, the self-excited circuit shown will be quite serviceable.

DIRECT-CURRENT TRANSFORMER

Since it is entirely feasible to obtain high-voltage d.c. by rectifying the stepped-up a.c. output of an inverter, the inverter-rectifier combination (Figure 2) is useful for converting low-voltage d.c. to high-voltage direct currents. The voltage step-up will be determined by the turns ratio of the output transformer in the inverter.

Operation of the device is very simple. In the inverter section, alternating current is produced from the relatively low d.c. source. The a.c. output is then delivered through a transformer of suitable turns ratio directly to the tube rectifier. The output of the rectifier is thus d.c. at a higher voltage than that of the original d.c. source. Operation is fully electronic.

Considerable latitude may be exercised in the choice of both inverter and rectifier circuits. For example: either unit may be single- or dual-tubed, as individual requirements demand, and the rectifier may be controlled or uncontrolled.

Because the inverter-rectifier combination makes it possible to obtain high-voltage d.c. from a low-voltage d.c. source, it has become generally known by the term *electronic d.c. transformer*.

THYRATON TEMPERATURE CONTROL CIRCUITS

The gaseous, controlled rectifier figures in the automatic control of temperature in various contrivances ranging from laboratory ovens to industrial electric furnaces, and is finding increasing application in this direction. In some heavy industrial ovens and furnaces, electronic control enables the maintenance of extremely high temperatures within a few degrees of change.

One circuit for thyratron control of temperature is shown in Figure 3. In this arrangement, both anode and grid potentials are alternating. The controlled heater elements are connected directly in the anode circuit of the thyratron, V.

The tube grid is supplied by a bridge circuit, the four arms of which are the "resistance thermometer", R, in the furnace; the two halves of the center-tapped secondary winding of the transformer, T; and the variable capacitor, C.

The resistance of R varies with the furnace temperature. The capacitor, C, is set for a phase shift of 90 degrees, with the oven at the desired temperature, whereupon any change in the furnace temperature will produce a corresponding change in the resistance of R and therefore a phase shift which will be proportional to this resistance change.

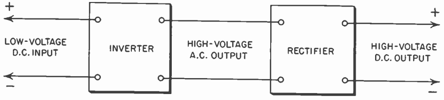

FIG. 2

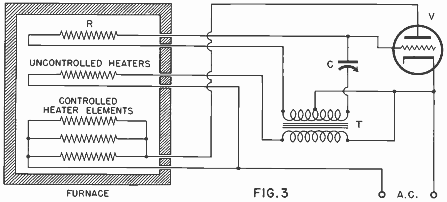

FIG. 3

This system affords control which is proportional to the temperature deviation, since the current flow through the heater elements is directly proportional to the temperature change.

Figure 4 is another gaseous-triode circuit for temperature control. In this arrangement, the tube circuit consists of the thyratron, V; the photocell, PC, in the thyratron anode-grid circuit; the grid phasing capacitor, C; and the grid voltage transformer, T. The grid potential is supplied by T, and its phase with respect to the anode potential controlled by the variable resistance of the photocell. For a particular phase relationship, the tube is caused to fire. The oven heaters are connected, as shown, directly in the thyratron anode circuit, obviating the necessity of a relay.

Illumination falling upon the photocell varies the cell current which charges the capacitor, C, in accordance with the intensity of illumination. However, this circuit utilizes the actual start and stop of light, rather than variations in its intensity. The photocell receives its illumination from a light source, through a lens which directs the beam through a pin hole and through a mercury column thermometer.

Normally, the mercury column interupts the light beam and indirectly extinguishes the discharge in the thyratron, cutting off the oven heat. But, when the oven temperature falls, the column drops and its surface eventually passes down past the pin hole and exposes the photocell to the light beam. The thyratron then fires, passing its anode current through the oven heaters until the resultant heating drives the mercury high enough in the thermometer tube again to intercept the light beam.

A somewhat comparable system which has been tested and described in several places is diagrammed in Figure 5. In place of the mercury-column thermometer, this arrangement employs as a light gate an electropyrometer consisting of a sensitive d.c. microammeter connected to a thermocouple inside the oven. The deflection of the meter is proportional to the temperature experienced by the thermocouple.

A small hole is punched through the meter card, along the path of the pointer at the position corresponding to the desired oven temperature, and a similar aperture aligned in the rear of the meter case to permit the passage of a pencil of light through the instrument. A photocell, connected into the grid circuit of a thyratron tube, is situated to receive this light beam.

At normal oven temperature, the meter pointer covers the hole and interrupts the light beam. The photocell is darkened and the thyratron passes no current to the oven heaters.

When the oven cools, the meter pointer drops, eventually uncovering the pin hole to admit light to the photocell. The discharge is then triggered off in the thyratron which effectively connects the heater elements to the power supply.

THYRATRON-IGNITRON ARC-LIGHT TIMER

Bowditch, Dull, and MacPherson[2] have described a thyratron-ignitron circuit for the intermittent operation of carbon arcs in motion picture photography and projection. The purpose of this circuit is to limit operation of the arc to the short intervals during which the camera or projector shutter is open and the light is actually being used. During the remainder of the time, the arc is extinguished.

The basic circuit for arc switching is shown in Figure 6. The two series-connected resistors, R_1 and R_2, are connected in series with the carbon arc and the power supply, and a switch, S, is connected in parallel with one resistor. When the switch is closed, a part of the series resistance is removed from the circuit and the arc is placed into operation. When the switch is opened, the added series resistance reduces the current sufficiently to extinguish the arc.

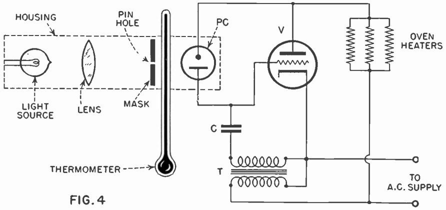

FIG. 4

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[2] *Journal of the Society of Motion Picture Engineers*, July 1941. By permission, S.M.P.E.

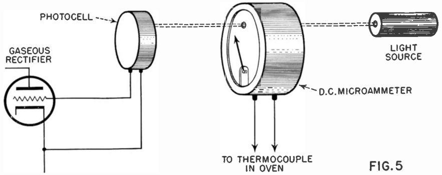

FIG. 5

In the complete circuit (Figure 7), the simple switch is replaced by the anode-cathode circuit of a controlled rectifier tube which effectively short-circuits R_2 during intervals in which the tube conducts. The controlled rectifier in this case is an ignitron tube, V_1. The circuit renders the discharge in this tube repetitive, conduction intervals occurring at a predetermined rate corresponding to the action of the camera or projector shutter.

Circuit components, in addition to the ignitron, include mercury-vapor thyratron V_2, high vacuum rectifier V_3, gaseous thyratron V_4, phase-shifting bridge network R_5-R_6-R_7-L, thyratron bias batteries E_1 and E_2, capacitor C, transformers T_1 and T_2, and load resistors R_3 and R_4.

Transformer T_1 is connected across the a.c. line. The voltage developed across its secondary is applied to the plate of the rectifier, V_3, the d.c. output of this tube on each positive half-cycle of supply voltage charging the capacitor, C, through R_3. The result is that the anode potential of thyratron V_4 is raised to the firing point. the grid of this tube having also received a voltage pulse from the bridge output transformer, T_2.

When the discharge takes place in V_4, the mercury-vapor thyratron, V_2, also fires, its grid having received a voltage pulse of proper magnitude from the drop across R_4, and the discharge occurs likewise in the ignitron. R_2 is effectively shorted out by the conducting ignitron and the carbon arc is placed into operation.

T_2 delivers its voltage pulse to the V_4 grid once during each positive half-cycle of supply voltage, the phase of this pulse (referred to the power source) being controlled by the setting of R_5 in the phase-shifting network. As V_4 fires, C is discharged, V_1 and V_2 cease conducting, and the carbon arc is extinguished. The circuit is then ready for a repetition of the cycle.

By means of this circuit, the arc becomes a source of intermittent illumination, timed entirely by electronic means. Considerable economy, due to the extinguishing of the arc during "dark" periods, and greater brilliance of illumination are claimed for this timed arc.

ELECTRONIC WELDER CONTROL

The processes and machinery of electrical welding have seen extensive improvement during the last few years and a growing number of industries have come to regard electrical welding as an indispensable modern tool. The domain of the art ranges from the heaviest to the lightest jobs and from painstaking "one-time" operations to high-speed repeated processes in mass production lines. One fine extreme is represented by the spot welding at General Electric laboratories of nickel-chromium wires, one-quarter of the diameter of human hair, for thermocouples.

One of the most widely applicable types of electrical welding is *resistance welding*, i. e., the type in which an electric current is passed through the two pieces of material and the necessary heat for the weld developed by the resistance between them. Resistance welding includes *line* or *seam welding*, *spot* and *projection welding*. Several important improvements which have advanced the art of resistance welding enable the rapid, automatic intermitting of the welding current. And it is in this connection that electronic methods have demonstrated their superiority over mechanical systems.

Decided advantages are gained by applying the welding current for short spaces of time rather than continuously. These are, principally, that welds of more uniformly good quality are obtained, stock is not burned in the machine because of sudden thinning, the necessity of repeated heat readjustments in continuous welding is disposed of, and the general appearance of the welds is greatly enhanced. The current must very often be applied for only a fraction of a second, although the "on" period for some types of work may be as much as several minutes. The ratio of *time off* to *time on* is very important.

First systems for intermittently applying the welding current were electromechanical, and in order to function during the fractional-second intervals which were frequently required, they were synchronized with the power-supply frequency. However, it is extremely difficult to synchronize electromechanical apparatus with frequencies even as low as 60 cycles per second, and such apparatus offers a number of maintenance annoyances. The arcing and pitting of contacts and the wear resulting from rapid vibration severely reduce economies. Electromechanical welding timers are, at the same time, almost always incapable of the accuracy required for fine work. The ability of certain thyratron circuits accurately to time power switching operations adapts these circuits admirably to

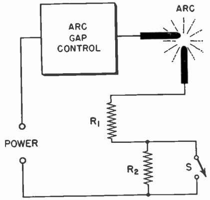

FIG. 6