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T. S. Gray and W. B. Nottingham

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Half-Cycle Spot-Welder Control

T. S. Gray and W. B. Nottingham[1]
Massachusetts Institute of Technology, Cambridge, Massachusetts
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A circuit for controlling a small spot-welder is described which utilizes simple, inexpensive, cold cathode tubes. Variation of the welding heat is accomplished by control of the fraction of a single half-cycle during which current is supplied to the welder transformer. Increased pressure is found to be necessary for satisfactory welding.

Introduction

It is generally recognized by the research worker who uses a spot-welder in the construction of special apparatus that a high current applied[2] for a precisely determined and very short period of time is desired for welding operations.[3] Commercial equipment no doubt meets the demands of many of the users of large spot-welders; however, it has long been felt that a simple circuit which could be adapted to standard low power welders (1 to 3 kva) would be of value. Circuits of this type have been experimented with by one of us (WBN) for the past three years with the final result that the one described here is considered by us to be both the simplest, cheapest, and, at the same time, the most reliable of all those tried. It has been used extensively at this institute in both the physics and electrical engineering departments.

Strobotron and Band-Igniter Arc Tubes

In this circuit, which is shown in Fig. 1, the two elements of prime importance incorporated are the "strobotron" (T_2) and the "band-igniter arc tube" (T_1). The band-igniter arc tube is shown schematically in Fig. 2, and consists of the simplest pool-type mercury arc. We have given our tubes a careful exhaust, using vacuum-distilled mercury distilled over to the tube after it has been thoroughly baked. The anode was heated by induction, and the tube finally operated for some hours while on the pumps before it was sealed off. The development of this tube dates back at least to Peter Cooper Hewitt,[4] but has

[1] Collaborators in this development to whom the authors are greatly indebted are H. E. Edgerton, K. J. Germeshausen, M. R. Saslaw and A. B. White, all of M. I. T.

[2] The polarity is important in certain cases of dissimilar metals.

[3] H. W. Lord and O. W. Livingston, Electronics 6, 186 (1933).

[4] U. S. patents No. 682,691, Sept. 17 (1901); No. 955,460, Apr. 19 (1910).

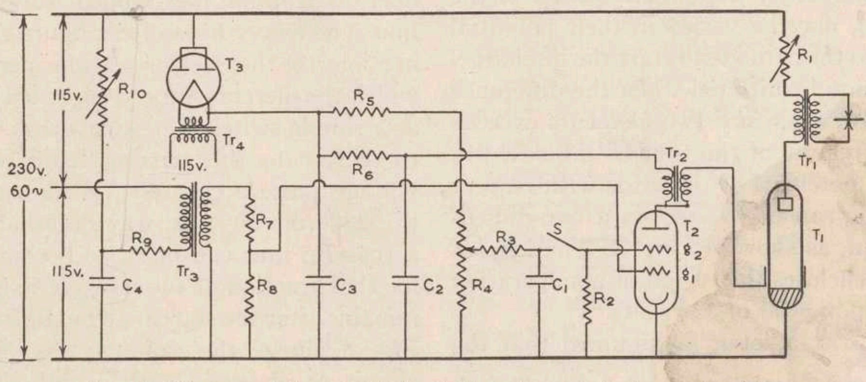

Fig. 1. Diagram of the circuit for half-cycle control of a spot welder.

T_1—band-igniter mercury arc tube
T_2—strobotron
T_3—type 80 tube
Tr_1—welder transformer
Tr_2—Ford spark coil assembly No. 18-12024-A
Tr_3—peaking transformer
Tr_4—filament transformer
C_1—0.5 mf (paper, 200v)
C_2—4.0 mf (paper, 400v)
C_3—8.0 mf (electrolytic, 450v)
C_4—1.0 mf (paper, 600v)
R_1—10 ohms
R_2—100,000 ohms
R_3—200,000 ohms
R_4, R_5, R_7, R_8—50,000 ohms
R_6—20,000 ohms
R_9—5000 ohms
R_{10}—5000 ohms (50 watt)

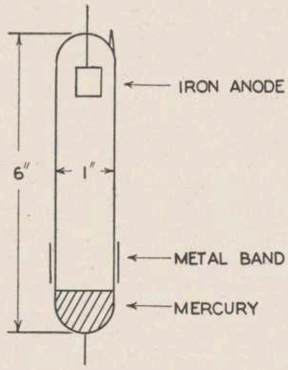

FIG. 2. Band-igniter mercury arc tube.

recently been used extensively by H. E. Edgerton[5] and his collaborators.

Since the strobotron has been developed quite recently,[6] and although it is closely related to the "grid-glow tube" and the "thyratron," a short explanation of its operation is perhaps justified. Fig. 3 shows the four essential elements, which are (1) cathode, (2) an inner grid, (3) an outer grid, and (4) an anode. All leads are connected to the four prongs of a standard radio tube base.[7] The type of discharge observed in the tube may be either a glow or an arc, depending on the current conducted.

Typical characteristics as tabulated elsewhere[8] are in Table I.

More detailed information as to the operation of one of these tubes may be had from a typical diagram of the starting characteristics[8] shown in Fig. 4. In many cases, the anode-cathode voltage is constant and set by the circuit. Either of the grids, or both, may be varied in their potential with respect to the cathode to start the discharge. Such conduction is initiated when the difference of potential between any two elements exceeds values characteristic of the tube as tabulated in Table I. The potential of the grids with respect to the cathode can be located on a two-dimensional diagram, as shown in Fig. 4. The loop of this diagram encloses the region of nonoperation for an anode potential of 320 volts.

To illustrate this, let it be assumed that the

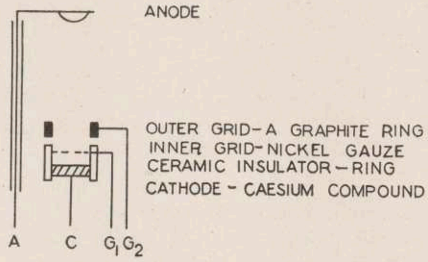

FIG. 3. Arrangement of elements in the strobotron.

potential of the outer grid is set at any arbitrary value, such as +70 volts measured from the cathode. The vertical dotted line through the point +70 on the horizontal axis cuts the loop shown at −25 volts and at +125 volts. This means that as long as the inner grid voltage is between these limits when the anode potential of 320 volts is applied, the strobotron will remain nonconducting. Conductivity sets in, however, in case the inner grid is made more negative than −25 volts, or more positive than +125 volts. Thus, if any arbitrary values be assigned to the inner and outer grid potentials and the corresponding point be located on the plot shown in Fig. 4, it will be seen at once whether or not the tube will conduct depending on where the point falls. If the point falls inside the loop, then the strobotron *does not conduct.* If the point falls outside the loop, then the tube *does conduct.*

Operation of Welder Circuit

The circuit shown in Fig. 1 is designed to operate from a mid-tapped 230-volt 60-c.p.s. line. The heavy lines of the figure show the connection to the welder-transformer primary in which the mercury tube, designated by T_1, serves as a simple switch. The strobotron circuit serves to deliver to the starting band on T_1 a high voltage pulse accurately timed with respect to the 230-volt 60-c.p.s. wave normally impressed across T_1, thus causing it to become conducting for that fraction of the positive half-cycle which remains after the starting-band pulse is delivered. Fig. 5 shows the voltage wave-forms in the circuit as observed with a cathode-ray oscilloscope. The arc extinguishes itself at the end of the half-cycle and the tube remains nonconducting until another pulse is delivered to the starting band.

[5] Edgerton, Germeshausen and Grier, J. App. Phys. **1**, 2 (1937).
[6] Germeshausen and Edgerton, Elec. Eng. **55**, 790 (1936).
[7] The name and address of the distributor of these tubes will be furnished on request.
[8] A. B. White, W. B. Nottingham, H. E. Edgerton and K. J. Germeshausen, Electronics, March (1937).

The type 80 rectifier tube T_3 serves to charge up the 4 mf condenser C_2 which, when discharged through the strobotron and the primary of the Ford spark coil Tr_2, generates the high voltage pulse used by the starting band to set up the arc in the mercury tube T_1.

Between welding operations, the outer grid of the strobotron is maintained at cathode potential (i.e., zero) while the inner grid has impressed upon it a 60-cycle "peaked" wave of a maximum amplitude of about 50 to 60 volts obtained from a potential divider R_7-R_8 across a peaking transformer[9] Tr_3 whose primary is supplied from a "resistance-condenser" phase shift circuit R_{10} and C_4. The negative peak of this wave, with respect to the positive peak of the line voltage, can be varied at will from 20° to 160° lagging. Referring to Fig. 4, we see that as long as the outer grid potential is zero, the point representing the inner grid potential remains inside the loop for all parts of the cycle. Line *ab* represents the locus of this point. When the welding pulse is desired, the switch S is closed. At the corresponding time "t_1," which may be anywhere in the cycle, the voltage of the outer grid rises to about 70 volts, as shown in Fig. 5, as the 0.5 mf condenser C_1 is charged to that value by the potential divider R_4. The condenser discharges through the resistor R_2 in an exponential manner, but since the time constant is greater than 0.05 second, the voltage of the outer grid remains substantially constant as in Fig. 5 (*a*). With a shift of outer grid potential from 0 to +70 volts, the locus of the peaked wave *ab* in Fig. 4 shifts to the right and crosses into the "conducting" region at point "*c*." The pulse then delivered to the starting band ignites the mercury arc at the time "t_2" in Fig. 5, and conduction through the mercury-arc tube and welder transformer continues for the remainder of the half-cycle.[10] Since the cross over into the conducting region of Fig. 4 occurs at a well-defined point on the peaked wave, and, since the angle of lag, θ, between the negative peaked wave and the line voltage can be controlled by the "resistance-condenser" phase shifter consisting of R_{10} and C_4, it is clear that the starting pulse can be delivered to the band on T_1 at an accurately preassigned time measured with respect to the a.c. voltage applied to the tube T_1 and thus the fraction of the cycle during which it conducts can be controlled.

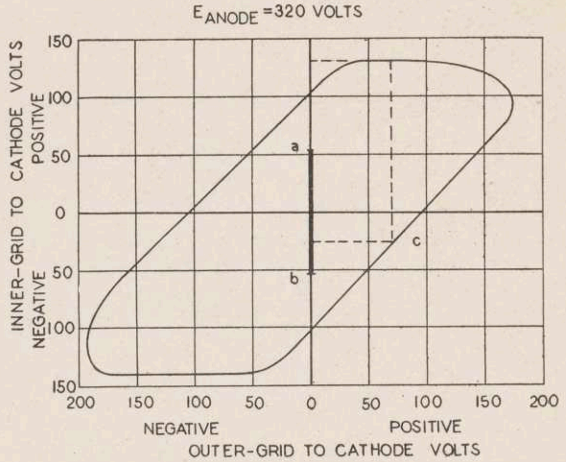

FIG. 4. Relation of grid voltages for starting the strobotron tube.

TABLE I. *Strobotron data.* Number of electrodes, 4: caesium covered cold cathode: gas, 1.5 cm, neon. Typical initial glow potentials in volts.

Positive Electrode	Negative Electrode	Normal Potential Difference	Expected Variations
Outer grid	Inner grid	96	+15–5
Inner grid	Outer grid	110	+50–30
Anode	Outer grid	500	+50–100
Cathode	Inner grid	130	+15–10
Outer grid	Cathode	175	+25–15
Inner grid	Cathode	130	+10–10
Cathode	Outer grid	200	+40–60
Anode	Inner grid	600	+50–40

Average anode current (max.)	100 milliamperes
Instantaneous anode current (max.)	250 amperes
Average tube drop for arc	20 volts
Average tube drop for glow	80 volts

There are two methods of controlling the intensity of the welding heat using this circuit, one being by phase control, and the other through amplitude control by means of R_1 in the primary line. The condenser C_1 is discharged by the grid current when the strobotron becomes conducting, and as long as the switch S remains closed, it can charge up to only one-third its normal voltage because of the current drain through R_2. The

[9] The transformer we have used is designed to operate from 115 volts a.c. with a 5000 ohm resistor in series with the primary, and to deliver a peaked voltage of about 110 volts. If a different transformer is used, resistors R_7, R_8, and R_9 should be modified.

[10] Actually, conduction continues for a short time into the next negative half-cycle, due to the leakage inductance of the transformer.

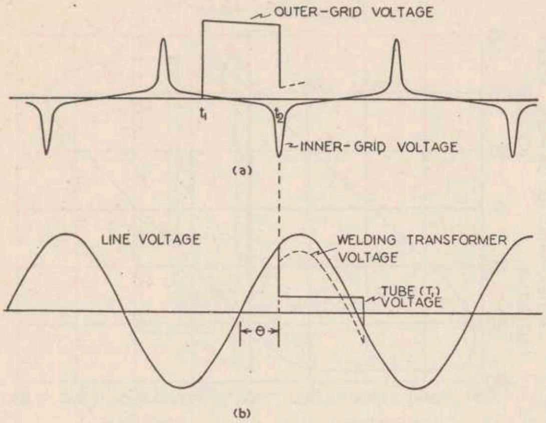

FIG. 5. Wave form of voltages in the circuit.

contact point on R_4 is adjusted so that the corresponding shift in outer grid voltage is insufficient to cause the locus of the peaked wave in Fig. 4 to cross into the conducting region, and therefore only one pulse is obtained each time the switch is closed. The anode voltage of the mercury arc tube T_1 must be more positive than a critical value of about 50 volts in order that an arc start when the external band is excited. The useful range of phase control is therefore from about 10° to 170°.

Pressure Requirements for Strong Welds

A spot weld produced by a very high current over a short time has the advantage that the neighboring metal does not become hot. To force the high current through the transformer, it has been found suitable to operate the primary winding normally rated at 115 volts from the 230 volt line. Peak currents of 300 amperes occur in the primary line, thus it is necessary to use heavy wiring for low resistance.

With the intense local heating at the weld, higher than normal pressure is required to prevent vaporization of the material and to provide the requisite forging action. By means of a pendulum type tensile tester, we have measured the strength of about two hundred welds made between round nickel wires of the three sizes, 10, 35, and 50 mils in diameter, using various values of current and force. The results of these tests indicate that a force of 40 lb. is desirable to produce the best welds in the larger sizes of wire, but that for the smallest wire a force of 20 lb., together with a reduced current, is satisfactory.

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