RESTRIKING OF SHORT A. C. ARCS

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ABSTRACT

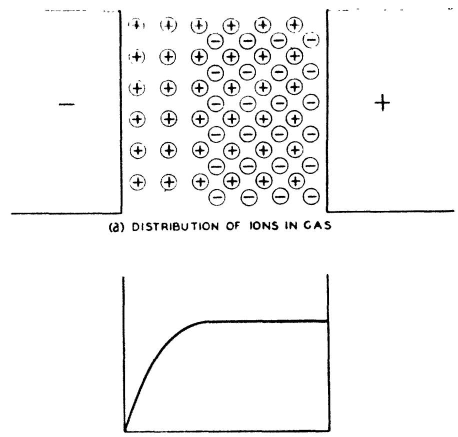
The restriking after zero current of short stationary A.C. arcs with brass, copper, zinc, iron, tungsten and carbon electrodes, and of arcs moving rapidly over copper electrodes was investigated with a cathode-ray tube of the Braun type. The volt-ampere traces on the fluorescent screen showed clearly the voltage necessary to restrike the arc after current zero, and the effect of the electrode vapor on the magnitude and variation of the restriking voltage. The arcs with refractory electrodes, i.e. carbon and tungsten, showed traces differing from the arcs with the other metals in that no high voltage for restriking the arc appeared. This is believed to be due to the refractory electrodes being at a temperature high enough for thermionic emission. For the other electrode materials, re-ignition voltages of several hundred volts were observed, suggesting that re-ignition of the arc required breakdown of a gas layer by ionization by collision alone. The arcs which were rapidly moving over their electrodes usually restruck to a glow before breaking down to an arc. The magnitudes of the restriking voltage and the glow current depended upon the condition of the electrodes, magnitude of the driving magnetic field, and the transient characteristic of the circuit in which the arc was playing.

IT IS well known that although a carbon arc can be maintained in a low voltage A.C. circuit, in general, an A.C. arc with metallic electrodes cannot be maintained with less than a few hundred volts. This has been studied by means of volt-ampere traces on the fluorescent screen of a cathode-ray tube of the Braun type, developed by Zworykin for use in television. These investigations have brought out several interesting facts about the magnitude of the voltage required to restrike the arc, and the manner of breakdown.

Slepian[1] has attributed this peculiarity of arcs mentioned, to the formation immediately after current zero of a thin deionized layer of gas next to the cathode. With thermionic emission lacking, to re-ignite the arc this layer would need to be broken down by ionization by collision and would require several hundred volts. His theory is illustrated by Fig. 1 which is taken from the paper referred to above. Starting with a uniform distribution of ions when the current and voltage are zero, the increasing voltage will cause space charge sheaths to form next to the electrodes after the manner described by Langmuir in relation to probe electrodes in an ionized gas. Because the mobility of the electrons is much greater than that of the positive ions, most of the applied voltage will be across the space charge sheath at the cathode. The current densities in this sheath are very small and in order to

* Scientific Paper No. 431.
[1] "Extinction of an A.C. Arc," by J. Slepian, Journal of the A.I.E.E. October, 1928.

restrike the arc, the space charge sheath must be broken down. If there are no other ionizing agents, the breakdown must be by ionization by collision only, and is entirely similar to the breakdown of a short spark gap. It will, therefore, require a minimum of several hundred volts. If, however, there are other ionizing agents, breakdown will occur at a lower voltage.



(a) DISTRIBUTION OF IONS IN GAS

(b) POTENTIAL DISTRIBUTION IN GAS

Fig. 1.

It seems unlikely that the temperature of the electrodes can be raised much above the boiling point. Hence, for non-refractory metals, i.e. zinc brass, copper, and iron, thermionic emission is probably entirely negligible. Hence, for these metals, the space charge sheath must be broken down by ionization by collision only. But carbon and tungsten at their boiling points

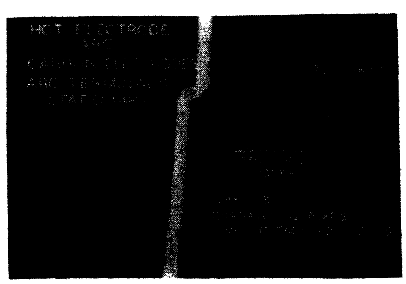


Fig. 2.

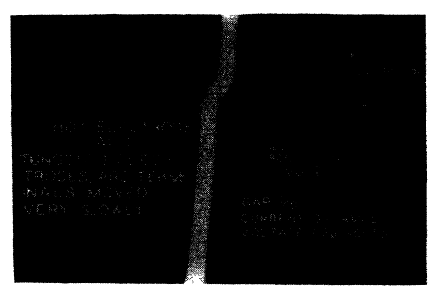


Fig. 3.

are at temperatures high enough for thermionic emission. Accordingly, for these electrode materials, we may expect breakdown of the sheath at low voltages. This occurs as is shown by the photographs of the dynamic volt-ampere characteristic on the fluorescent screen of the Braun tube. The photographs in Fig. 2 and 3 are for the carbon and tungsten arc respectively.

Fig. 4 shows the interpretation of Fig. 2 in the more familiar current and voltage against time relation. In Figs. 2 and 3 the current and voltage deflections are purposely not exactly in phase with the actual current and voltage and give the double line near current zero. The exposure for these photographs was 15 seconds, or included 900 retracings of the phenomenon.

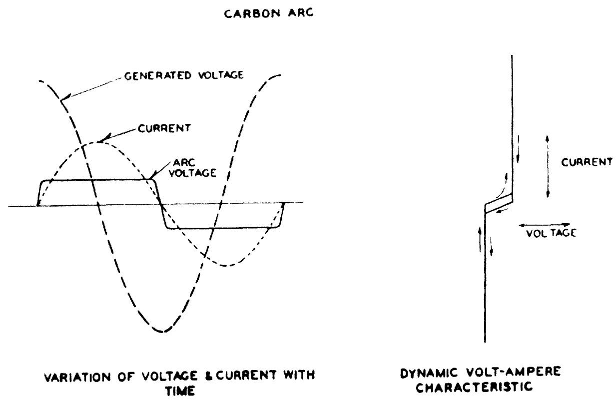


Fig. 4.

Returning now to the non-refractory metals, we shall expect to see much higher breakdown voltages, and since the space charge sheath is composed chiefly of the metal vapor, the breakdown voltages required for the various metals will in general be different. This is illustrated by Figs. 5, 6, 7, and 8 which give a portion of the dynamic volt-ampere characteristics near the reversal of current for zinc, copper, brass, and iron respectively. The current

Fig. 5.

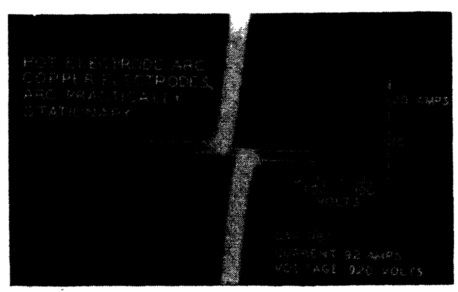


Fig. 6.

and voltage deflections are again not in phase with the actual current and voltage for Figs. 5 and 6, this displacement is to show the voltage before current zero as well as the restriking voltage. For the zinc arc, the restriking voltage is 280 volts and the voltage does not rise above arc voltage at the end of the half cycle. The stationary arc on copper has a peak restriking voltage of 360 volts, and the voltage before current zero rises to 280 volts.

The maximum restriking voltage for brass and iron were 255 and 290 volts respectively.

Fluctuations in the density of the breakdown voltage line indicates that reignition frequently occurred at low voltages in these stationary arcs. This requires some other ionizing agent than ionization by collision. What this

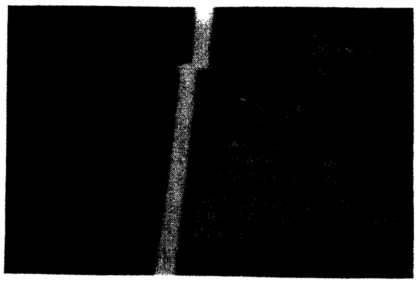


Fig. 7.

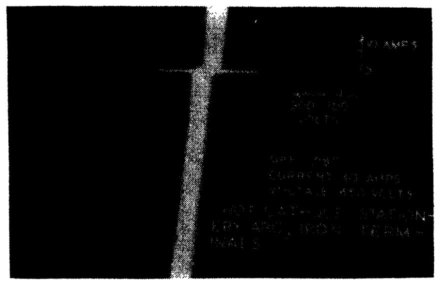


Fig. 8.

is is uncertain. Slepian suggests that the charging current to a particle or droplet making or breaking contacts with the cathode may cause a tiny spark which will make the space charge sheath collapse.

It is possible to cause an arc to move so rapidly over a clean smooth surface by means of a magnetic field that melting of the electrodes is prevented.

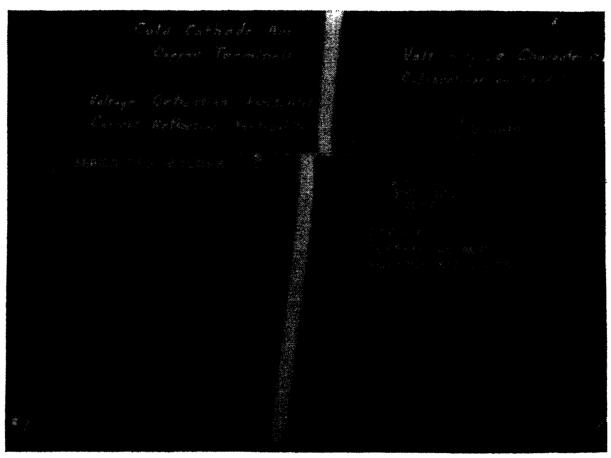


Fig. 9.

It is believed that the terminals of such an arc may be cold. The dynamic volt-ampere characteristic of such an arc is shown in Fig. 9. The maximum restriking voltage is 535 volts, the hesitation during the breakdown is at 325 volts. Fig. 10 is the interpretation of Fig. 9 in the more familiar relations, the scale is much expanded near the ends of the half-cycles for clearness. As the impressed voltage increases by an oscillation at the natural period of the circuit, and as the density of ionization decreases due to recombination and discharging of ions into the electrodes, the thickness of the cathode space charge sheath increases. At peak value, the voltage across the sheath has exceeded the recovered dielectric strength, and the short gap breaks down by ionization by collision. The voltage drops from peak value to that of the

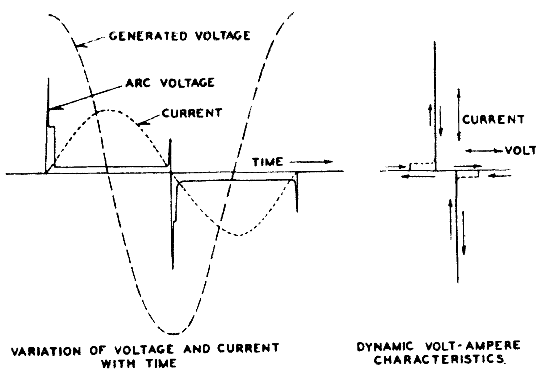


Fig. 10.

glow or occasionally even to arc voltage. The glow appears and remains a stable discharge until enough energy is put into the space adjacent to the cathode to give the conditions required by the cold electrode arc, then the transition from glow to arc abruptly occurs. The maximum glow current observed before transition to an arc was 4 amperes, and in this case meant that the glow was stable for longer than 10^{-4} seconds. The probability of a

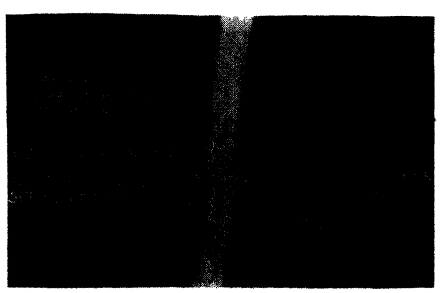


Fig. 11.

glow occurring seems to be less for the higher restriking voltage. It also appeared that the magnitude of the current to which the glow continued, and the probability of a glow occurring at all both increase as the electrode surfaces which had been initially cleaned with emery become oxidized. Slepian[2]

[2] "Theory of the Deion Circuit Breaker", J. Slepian Journal of the A.I.E.E. Feb., 1929.

had predicted that re-ignition of the cold electrode arc takes place first as a glow and his expectation is here confirmed.

Another dynamic volt-ampere characteristic similar to Fig. 9 is shown in Fig. 11, the only difference is that the driving magnetic field was 16 series turns for the former as compared to 660 series turns for the latter. The maximum restriking voltage in Fig. 11 is 1065 volts as compared to 535 volts for Fig. 9. In each case the glow occurs at 325 volts. This high restriking voltage can be obtained with the weaker field by shunting the arc with a resistance to slow down the rate of increase of voltage after current zero. This is due to the longer time the deionizing processes are active and the resulting thicker deionized layer requiring more voltage to breakdown.

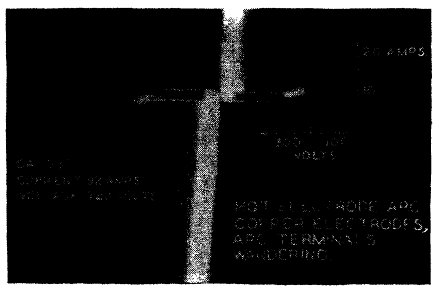


Fig. 12.

If an arc of approximately 90 amperes is drawn between plane electrodes with a fine fuse wire, generally the arc will not continue for several half-cycles where it was drawn but will wander about over the electrode surface. Judging by the trail, the arc does not move much while the current is flowing but restrikes after current zero to a position on one side of the position of the arc during the previous half-cycle. When moving in this manner tungsten and carbon arcs show a variable restriking voltage which may be quite comparable to that of non-refractory metals. The only metals among those tested which did not show this wandering behavior were zinc and to a certain extent brass. Copper arcs have a very peculiar volt-ampere characteristic while wandering as shown by Fig. 12. The hesitation at the peak of the restriking voltage varies from a minimum of about 250 volts to a maximum of about 325 volts.

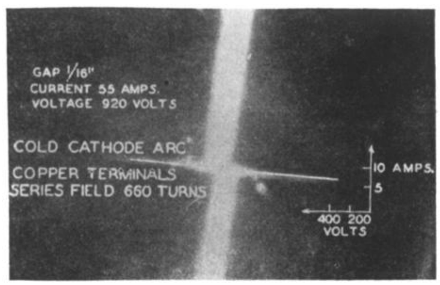

GAP 1/16"
CURRENT 55 AMPS.
VOLTAGE 920 VOLTS
COLD CATHODE ARC
COPPER TERMINALS
SERIES FIELD 660 TURNS
10 AMPS.
5
400 200
VOLTS

Fig. 11.

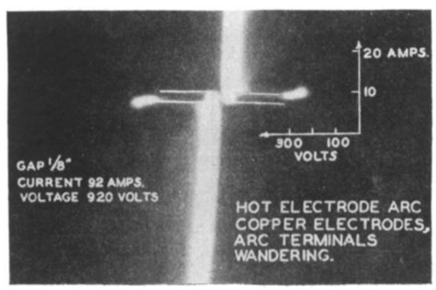

20 AMPS.
10
300 100
VOLTS
GAP 1/8"
CURRENT 92 AMPS.
VOLTAGE 920 VOLTS
HOT ELECTRODE ARC
COPPER ELECTRODES,
ARC TERMINALS
WANDERING.

Fig. 12.

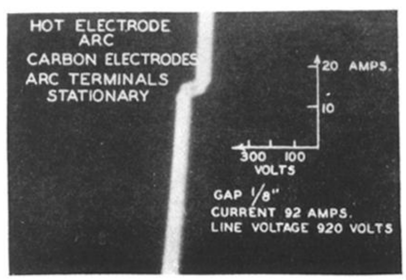

HOT ELECTRODE
ARC
CARBON ELECTRODES
ARC TERMINALS
STATIONARY
20 AMPS.
10
300 100
VOLTS
GAP 1/8"
CURRENT 92 AMPS.
LINE VOLTAGE 920 VOLTS

Fig. 2.

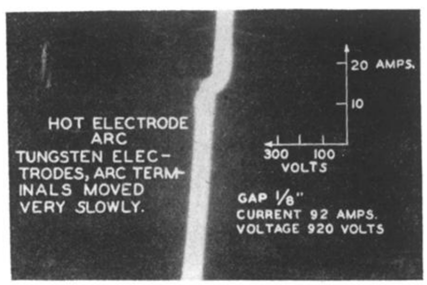

HOT ELECTRODE
ARC
TUNGSTEN ELEC-
TRODES, ARC TERM-
INALS MOVED
VERY SLOWLY.
20 AMPS.
10
300
100
VOLTS
GAP 1/8"
CURRENT 92 AMPS.
VOLTAGE 920 VOLTS

Fig. 3.

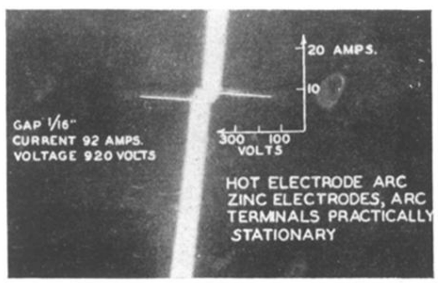

20 AMPS.
10
300 100
VOLTS
GAP 1/16"
CURRENT 92 AMPS.
VOLTAGE 920 VOLTS
HOT ELECTRODE ARC
ZINC ELECTRODES, ARC
TERMINALS PRACTICALLY
STATIONARY

Fig. 5.

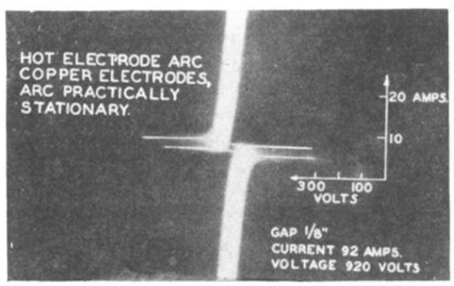

HOT ELECTRODE ARC
COPPER ELECTRODES,
ARC PRACTICALLY
STATIONARY.
20 AMPS.
10
300
100
VOLTS
GAP 1/8"
CURRENT 92 AMPS.
VOLTAGE 920 VOLTS

Fig. 6.

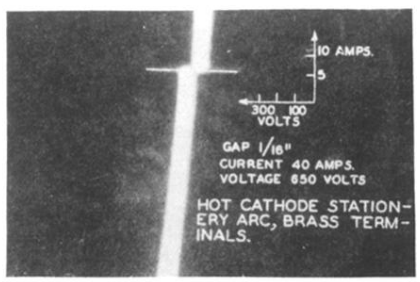

10 AMPS.
5
300 100
VOLTS
GAP 1/16"
CURRENT 40 AMPS.
VOLTAGE 650 VOLTS
HOT CATHODE STATION-
ERY ARC, BRASS TERM-
INALS.

Fig. 7.

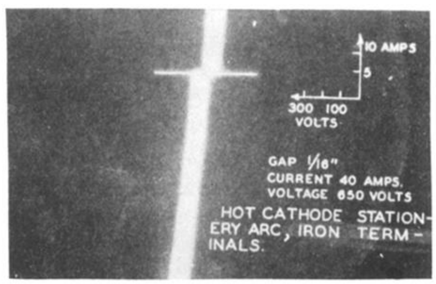

10 AMPS
5
300 100
VOLTS
GAP 1/16"
CURRENT 40 AMPS.
VOLTAGE 650 VOLTS
HOT CATHODE STATIONERY ARC, IRON TERMINALS.

Fig. 8.

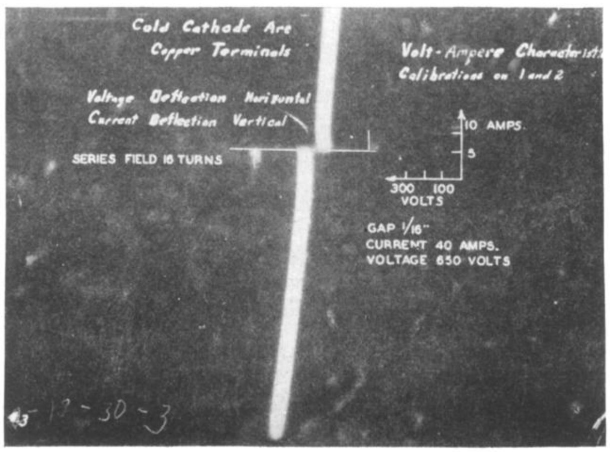

Cold Cathode Arc
Copper Terminals
Volt-Ampere Characteristi
Calibrations on 1 and 2
Voltage Deflection Horizontal
Current Deflection Vertical
10 AMPS.
5
SERIES FIELD 16 TURNS
300 100
VOLTS
GAP 1/16"
CURRENT 40 AMPS.
VOLTAGE 650 VOLTS
5-12-30-3

Fig. 9.