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EXTINCTION OF SHORT A. C. ARCS BETWEEN BRASS ELECTRODES

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Abstract

Results are given which show that the dielectric recovery after current zero, of short, stationary A.C. arcs between brass electrodes, is similar to that of cold-electrode arcs previously investigated and described. These results also show that the rate of recovery of dielectric strength of hot-electrode arcs after a current zero may be greatly increased by reducing, within limits, the electrode separation. A possible explanation on the basis of ionic diffusion to the electrode surfaces and the deionizing action of blasts of metal vapor from the boiling electrodes is mentioned.

The recovery of dielectric strength by an A. C. arc, immediately after a current zero at which it is extinguished, has been studied by Slepian[1] with the result shown in Fig. 1. The short arcs studied were kept in rapid motion over copper surface terminals which are believed to have been cold. The ability to withstand about 230 volts was regained within less

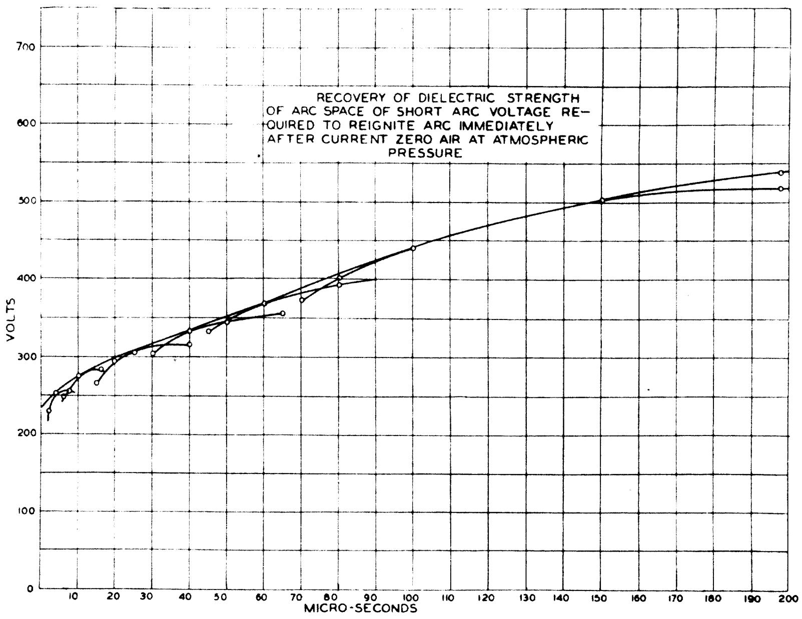

Fig. 1.

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* Scientific Paper No. 430.

[1] "Extinction of an A.C. Arc", J. Slepian, Trans. A.I.E.E. **47**, 1398 (1928).

than a few micro-seconds after a current zero, and further dielectric strength was recovered thereafter at a much lower rate. The simple theory which Slepian gives identifies the quickly recovered dielectric strength with the minimum sparking potential or normal cathode drop in a glow in the gas next to the cathode. This should therefore be independent of current and of arc length. Slepian's theory also makes the slower further recovery of dielectric strength independent of current and arc length, but this part of his theory depends on the assumption that ions are lost from the arc space only by direct recombination. If other deionizing agents are not of negligible activity, such as for example, diffusion of ions into the electrodes, or diffusion into cooler surrounding gas with more rapid recombination there, then this slower later recovery should be influenced by arc length and current magnitude. The quickly recovered dielectric strength, however, should not be influenced by these other deionizing agents. Short stationary A. C. arcs in which the electrodes are hot might be expected to behave in a generally similar manner to the cold-electrode arcs which Slepian studied, provided that the boiling temperature of the electrode material is so low that appreciable thermionic emission is unlikely. Using stationary arcs with brass electrodes, the writers have conducted experiments which show that dielectric strength after current zero was recovered in the same manner as for the cold-electrode arcs of Slepian. The quickly recovered dielectric strength was independent of arc length, but the more slowly recovered dielectric strength varied with current and arc length, being greater for the smaller currents and shorter arc lengths.

Apparatus and Method

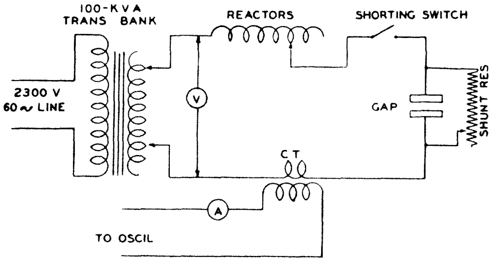
The circuit and the shape of the electrodes used in these tests are shown in Fig. 2. The source of power was a 100 KVA transformer bank with adjustable secondary voltage, whose primary was connected to a 2300-volt 60-cycle power line. The current was limited almost entirely by air-core reactors, having low power factor and comparatively low distributed capacitance. Following Slepian, the electrical transient of the circuit immediately after the extinction of the arc was controlled by shunting the arc electrodes with adjustable resistance made up of low-inductance wire-wound resistor tubes. To obtain the equivalent of exactly zero power factor in spite of resistance drops and arc voltage, a synchronous shorting switch was used to close the circuit at such a point on the voltage wave that the end of the first half-cycle of current occurred at the maximum of the sinusoidal generated voltage. An arc was formed almost immediately at the center of the electrodes by the burning of a fine (No. 40 B. & S.) copper fuse wire, and the ensuing number of half-cycles of arcing was counted by means of a direct-vision oscillograph. When the arc shunting resistance was high the arc would continue for many half-cycles; when the shunting resistance was low the arc would extinguish at the end of the first half-cycle. The resistance shunt was varied between trials until the value that would just cause the arc to go out at the end of the first half-cycle was determined within 5%. During a short time after a current zero at which the arc is extinguished the voltage across the gap is approximately given by the formula:

$$e = E_m(1 - \epsilon^{-Rt/L}) \qquad (1)$$

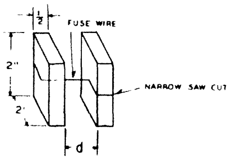
where E_m is the maximum of the generated voltage, R, the arc shunting resistance, and L, the inductance of the circuit. L was determined from the r.m.s. short-circuit current I by the relation:

$$E_m = 2^{1/2} \cdot 2\pi \cdot 60LI. \qquad (2)$$

When the value of R is small, and the arc is extinguished at the first current zero, the impressed voltage given by (1) remains below the recovered dielectric strength of the arc space. When the value of R is large, and the arc re-ignites, the curve of (1) will rise above the recovered dielectric strength of the arc space. For the critical value of R which just causes the arc to be extinguished at the first current zero, the curve of (1) must come up and just be tangent to the curve of the recovered dielectric strength of the arc space. By plotting a family of curves with different E_m's, and corresponding critical R's, the curve for the recovery of dielectric strength with time may be found by taking the envelope. No account is taken of distributed capacitance of the reactors and other parts of the circuit. Though these capacitances are comparatively small, they become appreciable when the critical value of resistance is high, and particularly when the shunt is removed altogether. The transient voltage will then generally rise in an oscillatory manner, reaching almost double the normal peak value. For this reason, tests in which nearly full voltage is recovered in less than ten micro-seconds are inaccurate and of value only for comparative purposes. Roughness of and



(a) DIAGRAM OF TEST CIRCUIT



(b) ELECTRODES

Fig. 2.

oxide formation on the electrodes after continued arcing may also cause considerable variation in results.

Experimental Results

The curves of Fig. 3, which show results obtained for 1.6 and 3.2 millimeter arcs of 300 amperes, are similar in shape to curves obtained for cold-electrode arcs (Fig. 1). From these curves we see that the immediately recovered ability to stand voltage is the same for the two arc lengths, but that after that the shorter arc recovers dielectric strength faster than the longer arc. Thus we are led to the interesting and at first sight paradoxical fact that a very short arc may be extinguished more easily than a longer arc.

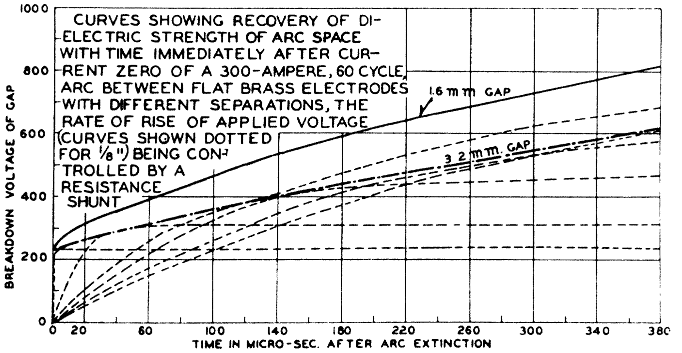


Fig. 3.

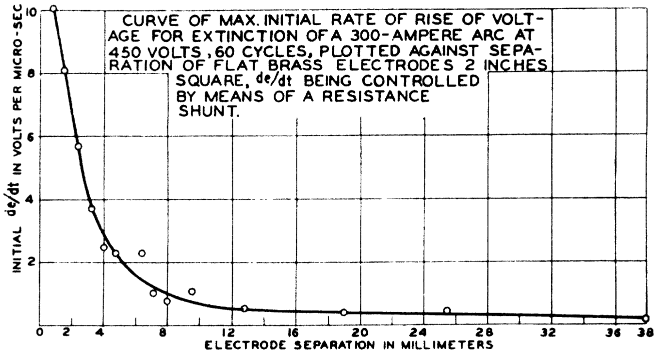


Fig. 4.

This influence of arc length on recovered dielectric strength was found to continue up to lengths of 5 cm and more, by tests on 300-ampere arcs in a 450-volt (r.m.s.) circuit. The critical shunting resistance for arc extinction was determined for different arc lengths, and the initial rate of rise of voltage for the transient corresponding to each critical resistance was computed. The results are shown plotted against arc length in Fig. 4. It is noticeable that the factor causing this variation with gap length is most effective as the electrode separation becomes less than one centimeter. As this factor is undoubtedly a deionizing one, and is probably active during the arcing period as well as during the extinction transient, we might expect it to reveal itself in the magnitude of the arc voltage. Figure 5 shows the variation of arc voltage with gap length. The definite increase in slope for the smaller lengths affirms the presence, even while the arc current is flowing, of some deionizing action which is more effective for short arcs than for long.

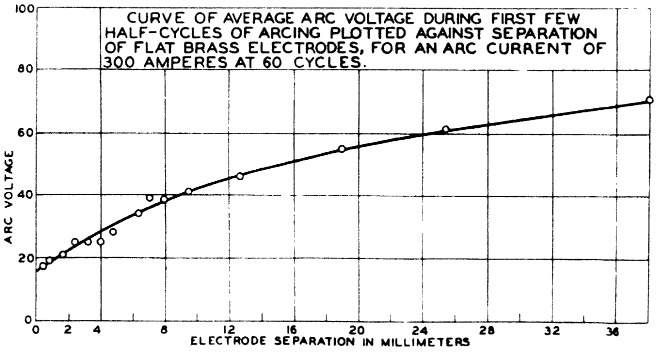


Fig. 5.

Figure 6 shows the results of tests at the same voltage and gap length but with currents ranging from 25 to 800 amperes. There is an undoubted decreasing tendency of these rather scattered values with increasing current.

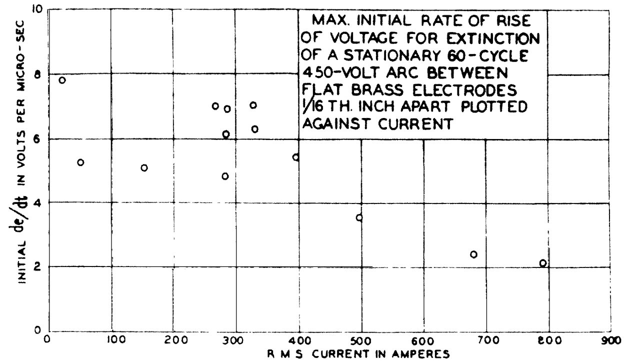


Fig. 6.

According to the approximate theory of Slepian for the dielectric recovery upon extinction of a short A. C. arc, all of the regained dielectic strength resides in a positive space sheath next to the cathode. Due to the high mobility of the electrons, this space charge sheath is formed with extreme rapidity upon application of voltage and is immediately able to withstand a minimum of two or three hundred volts, depending only on the electrode material and the gas medium. Further recovery of dielectric strength results from increase in thickness of this space charge sheath due both to growth of applied voltage and to the diminishing density of ionization next to the cathode.

In Slepian's theory the loss of ions was assumed to be due solely to direct recombination in the arc space. The results given here confirm the fundamental conception of the formation and growth of a cathode space charge sheath, but the large influence of electrode separation points to the presence of some deionizing agent other than direct recombination which becomes rapidly more effective as the arc length diminishes. Since diffusion of ions into the electrodes is a process fitting this description, approximate calculations were made to determine to what extent this can account for the observed results. So far, however, the simplified calculations, assuming all of the deionization to be due to diffusion alone, and neglecting such influences as the electric field, vapor emission from the electrodes, and diffusion to the surrounding air, seem to require a coefficient of diffusion far in excess of any reasonable value. This may indicate that diffusion to the electrodes is an unimportant factor, or it may simply mean that the present approximate method of calculation is unsound. It is also thought possible that other physical processes may enter considerably into the deionization of the arc space next to the cathode, such as for example, a blast of metal vapor from the violently boiling electrodes during the arcing period and perhaps for a very short time immediately thereafter, but this theory lacks verification as yet. Therefore, further work is being done in an effort to arrive at a more nearly satisfactory explanation of these results.