Motion of a Short Arc in a Magnetic Field*

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When an electric arc with an evaporating cathode (e.g., copper) is exposed to a strong transverse magnetic field in atmospheric air, its motion can be made to change from the conventional to the reverse direction by reducing sufficiently the electrode separation.

The effect is discussed in terms of an earlier idea based on the resultant magnetic field acting on the cathode region. This field is composed of the applied field and the "loop" field of the curved current path above the cathode spot. At low pressure, an increase of the former is accompanied by a rapid increase of the latter and thus the resultant field changes its sign. Here at high pressure and constant external field, the change of sign at small electrode separation is caused by a forced reduction of the radius of curvature of the deflected positive column.

1. INTRODUCTION

IF a transverse magnetic field acts on a direct current arc between metal electrodes, the positive column of the arc is always deflected in the direction given by Ampere's rule. Under certain conditions however, the cathode spot is found to move in the opposite direction, dragging the deflected column with it. The arc as a whole then moves contrary to Ampere's rule.

The reverse driving effect was first observed in a low-pressure mercury arc by Stark[1] and Weintraub.[2] (For further work see St. John and Winans.[3]) It has been studied at low currents for a variety of electrodes in different gases: the motion of the cathode spot is always in the reverse direction if the gas pressure is sufficiently low. A change to the Ampere direction occurs if, other things being equal, the pressure is increased above a critical value. This reversal pressure is the greater the lower the current and the stronger the magnetic field. It depends on the nature of the gas but appears to be almost independent of the cathode material.

The experiments of Himler and Cohn[4] indicated that the electrode separation affected the reversal of the motion. They found that the reversal pressure increased when the distance between the electrodes was decreased. A similar dependence can be inferred from curves of Yamamura,[5] although the reversal pressures were well below atmospheric in both cases.

In order to investigate whether an arc could be driven in the reverse direction in open air, the most favorable conditions for reverse motion were chosen, namely low current, large magnetic field, and small electrode separation.

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[1] J. Stark, Physik. Z. 4, 440 (1903).
[2] E. Weintraub, Phil. Mag. 7, (6) 95 (1904).
[3] R. M. St. John and J. G. Winans, Phys. Rev. **94**, 1097 (1954).
[4] G. J. Himler and G. I. Cohn, Elec. Eng. **67**, 1148 (1948).
[5] S. Yamamura. J. Appl. Phys. **21**, 193 (1950).

2. OBSERVATIONS ON A SHORT ARC IN AIR

Two wedge-shaped copper electrodes were set up in air with their sharp edges parallel and transverse to the field of an electromagnet which could produce a steady magnetic field of up to 5000 gauss (Fig. 1). The electrodes were connected to a dc generator through a resistance and the current could be varied between 0.5 amp and 5 amp. An arc was struck by touching the electrodes at one end with a carbon rod. The arc was driven the length of the electrodes by the magnetic field and blew out at the end of its run.

When the separation was about 2 mm, the arc ran always in the Ampere direction throughout the range of currents and fields at our disposal. However, when the separation was decreased to 0.5 mm, it was found that for low current and high field the arc ran in the reverse direction. For a separation of 0.5 mm and a current of 3 amp, the motion of the arc was in the Ampere direction at low fields but changed to the reverse direction when the field exceeded 3000 gauss. Also, for a field of 4000 gauss the motion was reverse at low current but changed to the Ampere direction when the current exceeded 5 amp. The reversal of the arc in these cases was not sharply defined, and immobility occurred over a definite region of current and magnetic field.

In another experiment, the edges of the electrodes of Fig. 1 were not set parallel but formed a gap which tapered from 2 mm at one end to less than 0.5 mm at the other. The taper was such that an arc moving in the Ampere direction would move towards the narrow end. When an arc of 3 amp was started at either end

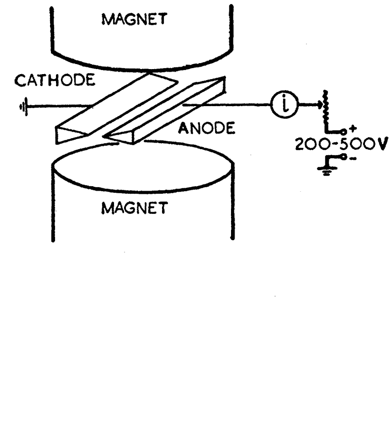

FIG. 1. Experimental arrangement.

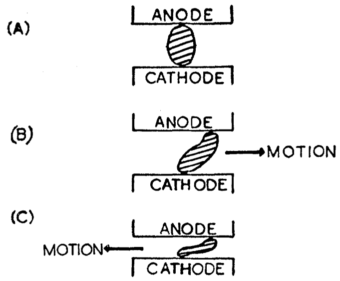

FIG. 2. Stages in the deformation of the arc: (A) arc without magnetic field; (B) magnetic field applied into the paper, electrode separation 2 mm: motion in Ampere direction; (C) conditions as in (B) but electrode separation decreased to 0.5 mm: motion in reverse direction.

in a magnetic field of 5000 gauss, it was observed that the arc moved quickly away from the end and took up an equilibrium position at some point along the electrodes. When either current or field was varied, the arc took up a new equilibrium position: the arc would move towards the narrow end of the gap if the field was decreased or if the current was increased, and vice versa.

The dependences of reversal on current and field correspond exactly to the conditions of reversal of long arcs at much lower pressures. However, by decreasing the electrode separation, the reversal pressure for a low-current arc in a strong magnetic field can be increased above one atmosphere, so that reverse driving, normally regarded as a low-pressure effect, can occur in open air. The importance of the electrode separation appears to have been overlooked in earlier investigations.

3. THEORY OF THE SHORT ARC

In a previous communication,[6] the authors have suggested that the applied magnetic field deflects the positive column in the Ampere direction with respect to the cathode spot and the current path in the arc is therefore sharply curved in the vicinity of the spot. This deformation of the arc sets up a local self-magnetic field of the order i/R, where i is the arc current and R an effective radius of curvature of the arc which depends on the actual field and other discharge parameters. This field will act so as to oppose the applied field H_0 and so the resultant field H in the cathode spot region will be given by

$$H = H_0 - i/R.$$

For a low-pressure arc, R may be sufficiently small for the self-magnetic field to exceed the applied field, and thus H changes its sign and may reach quite large values. The cathode spot will then obey Ampere's rule with respect to the resultant field while appearing to violate it with respect to the applied field.

Consider an arc in air between parallel copper electrodes a few mm apart. In the absence of a magnetic field, the anode and cathode spots will be opposite each other [Fig. 2(A)]. When a transverse magnetic field is applied, the column is deflected in the Ampere direction with respect to the cathode spot. The anode spot will move with the column and so will be displaced in the Ampere direction with respect to the cathode spot [Fig. 2(B)]. At atmospheric pressure, R would be large enough to allow H_0 to predominate and such an arc would therefore normally move in the Ampere direction.

If now the electrode separation is decreased the arc will be compressed [Fig. 2(C)]. It is suggested that on account of the relative displacement of the anode and cathode regions the anode will now act as a confining wall for the column near the cathode, since now the electrode separation is smaller than the diameter of the unobstructed column.[7] The column will therefore along its whole length tend to move away from the anode "wall" and so the radius of curvature of the column near the cathode will decrease. The proximity of the anode will assist the applied field to decrease R, and may cause the self-magnetic field to predominate. The arc will then move in the reverse direction, as has been described.

The significance of the short-arc experiment is that it supports the view that the reverse driving effect is connected with the deformation of the arc column and is not an intrinsic property of the cathode spot. It has been shown that the motion of an arc can be reversed by decreasing the separation from 2 mm to 0.5 mm. This can have no direct effect on the cathode spot since the dimensions of the cathode region are probably at least an order of magnitude smaller: it can, however, act on the cathode region through the deformation of the column. No other theory has been proposed which takes the electrode separation into account.

[6] A. E. Robson and A. von Engel, Phys. Rev. **93**, 1121 (1954).

[7] A. von Engel, *Ionized Gases* (Clarendon Press, Oxford, 1955).