ON THE POULSEN ARC AND ITS THEORY*

(SUPPLEMENTARY NOTE)†

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A. MAGNITUDE OF PEAK ARC VOLTAGE REQUIRED FOR MAINTAINED OSCILLATIONS OF THE FIRST KIND

An approximate solution of this question is quite simply obtained, and may, therefore, be of some interest. Figure 1 shows the arc current, i_1 , and arc voltage, e_1 , in the case of sustained oscillations of the first kind. The arc voltage is supposed to be

FIGURE 1—Diagram of arc current (i_1) and arc voltage (e_1) for oscillations of the first type (that is, oscillations without interruption of current thru arc)

* PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, number 4, page 255. The nomenclature given on pages 315 and 316 of that paper applies also to the present paper.

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constant and equal to E_b for currents greater than I^o . The part $a b c$ of the current curve can, therefore, be written in the form

$$I_o - i_1 = i_{10} = I_m^s \varepsilon^{-\kappa t} \cos(2\pi n t - \phi), \quad (1)$$

where I_m^s is the initial maximum amplitude of the current; while

$$\kappa = \frac{R}{2L}, \text{ and } 2\pi n \sqrt{LC} = 1.$$

At the point c of the current curve, the voltage commences to increase, and $f g h$ represents the peak; the corresponding part of the current curve is $c d_o a'$. We shall now determine the relation between the curves $f g h$ and $c d_o a'$.

For the arc voltage e_1 we have

$$-e_1 = L \frac{di}{dt} + Ri + \frac{1}{C} \int i dt, \quad (2)$$

i_1 being the arc current and L , R , and C the constants of the r.f. circuit.

If we put $i = i_{10} - i_1'$ where i_{10} is a current as determined by (1), then i_1' is the difference between this current and the actual arc current, that is, between the curves $c d e$ and $c d_o a'$ in Figure 1.

Substituting the above expression for i_1 in (2), we get the following equation:

$$e_1' = e_1 - E_b = L \frac{di_1'}{dt} + Ri_1' + \frac{1}{C} \int i_1' dt. \quad (3)$$

However, i_1' is so small that the last two terms may be neglected, and (3) may therefore be written

$$e_1' = e_1 - E_b = L \frac{di_1'}{dt} \quad (4)$$

or

$$i_1' = \frac{1}{L} \int_f^t e_1' dt = \frac{1}{L} \int_f^t (e_1 - E_b) dt. \quad (5)$$

At the point h , the arc voltage again reaches its normal value E_b , and at the corresponding point a' the current curve again begins to be represented by an equation of the form shown in (1). The maximum amplitude in the point d is reduced to I_m^s , and if the oscillations are to continue with the same intensity, the maximum amplitude at the point d' must be equal to I_m^a . The peak $f g h$ must, therefore, be such as to be able just to cause this increase in maximum amplitude from I_m^a to I_m^s , if the oscillations are to continue. If the peak is lower, the amplitude will

decrease continually and the arc becomes "inactive" or non-oscillatory. If the peak is higher, the amplitude will increase, and eventually becomes greater than I_o , the oscillations then being of the second kind.

The area U of the peak such, that it is just possible to sustain the oscillations is, according to (5), determined by

$$U = \int_f^h (e_1 - E_b) dt = L i_{1h}', \quad (6)$$

where i_{1h}' is the greatest value of i_1' and corresponds to the point a' of the current curve. For oscillations of constant amplitude, this value i_{1h}' must very nearly be equal to $I_m^s - I_m^a = \delta I_m^s$, where the logarithmic decrement $\delta = \pi R \sqrt{\frac{C}{L}}$. Equation (6) may, therefore, be written

$$U = L \delta I_m^s = \pi R \sqrt{LC} \cdot I_m^s = \frac{\lambda R}{6 \cdot 10^{10}} \cdot I_m^s. \quad (7)$$

This formula agrees with formula (59) of the former paper.

Formula (7) may easily be obtained in another way. During one complete period, the feeding current delivers an amount of energy A to the r.f. circuit, and to the arc, such that

$$A = \int_t^{t+\tau} I_o e_1 dt = I_o E_b \tau + \int_f^h I_o (e_1 - E_b) dt = I_o E_b \tau + I_o U \quad (8)$$

The first term, $I_o E_b \tau$, represents the energy spent in the arc, while the second term, $I_o U$, is the energy delivered to the r.f. circuit.

Accordingly we have

$$I_o U = I^2 R \tau = \frac{1}{2} I_m^{s2} R 2 \pi \sqrt{LC} = \pi R \sqrt{LC} I_m^{s2} \quad (9)$$

But I_m^s is very nearly equal to I_o , and (9) accordingly reduces to

$$U = \pi R \sqrt{LC} \cdot I_m^s$$

which was to be shown.

B. MAGNETIC FIELD OF THE POULSEN ARC

The experimental evidence given in the former paper showing that the arc in too weak a field behaves as shown by the sketch in Figure 19 of that paper, may, perhaps, be deemed somewhat meagre. In fact, the evidence consisted only of part *b* of Figure 17b. Some crater oscillograms and side views which will probably be more convincing are therefore given in Figure 2 of this paper. Parts *b*, *b'* correspond to a normal field, *c*, *c'* and *d*, *d'* to fields which are too weak. A comparison with Figure 19 of the first paper shows a complete agreement.

In parts *a*, *a'* of Figure 2 the magnetic field is too strong. The crater curve in this case, however (contrary to what is the case in parts *c* and *d* of Figure 17b of the former paper), consists only of a single curve for each period. It thus appears that the crater curve in strong fields does not always split up into a number of separate parts. This being so, there is some probability

FIGURE 2—Side Views of Arc and Corresponding Crater Oscillograms

Anode to the left. $\lambda = 9,000$ m.; $R = 0$; $I_o = 20$ amperes

Parts *a*, *a'*—magnetic field too strong ($V_o = 120$ volts)

Parts *b*, *b'*—normal magnetic field ($V_o = 60$ volts)

Parts *c*, *c'*—magnetic field too weak ($V_o = 100$ volts)

Parts *d*, *d'*—magnetic field too weak ($V_o = 118$ volts)

that the preliminary hypothesis relative to the behavior of the arc in excessively strong fields put forth in the former paper, and referred to in connection with Figure 18 II, is not altogether correct. The different parts of the crater curve corresponding to the time of one period may possibly be formed simultaneously, the arc consisting of separate parts which are forced outward in the same manner by the magnetic field. From the data at hand I have not yet been able to decide which of the two views is the correct one. To quote the former paper: "A full elucidation of these phenomena will, therefore, necessitate further investigation" (former citation, page 297).*

* In the bibliography given in my former paper I had unfortunately overlooked an important paper by G. Grandquist (Nova Acta Reg. Soc. Sc. Ups., Series IV, volume 1, 1907) dealing with the theory of the Duddell arc.

SUMMARY: Continuing the discussion of sustained oscillations of the first or second type produced by Poulsen arcs, as given in his earlier paper in the **PROCEEDINGS**, the author derives an approximate value for the peak voltage required for the maintenance of such oscillations.

He then presents further experimental data on the nature of the arc in normal or too weak or strong magnetic fields. He also considers the question of the simultaneous versus sequential production of separate arcs during a period, when the arc takes place in a very strong field.