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On the Possibility of Hg Type Arcs with Hot Refractory Cathodes

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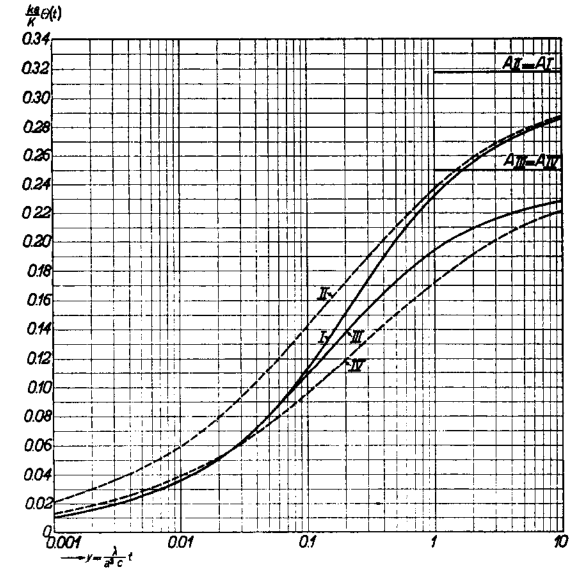

FIG. 1. The temperature rise as a function of time of contact. Curve *I*: maximum temperature according to Oosterkamp; curve *II*: maximum temperature according to Holm ($b = 0.5a$); curve *III*: average temperature in contact area according to Oosterkamp; curve *IV*: average temperature in contact area according to Holm ($b = 2/\pi = 0.64a$). A_I, A_{II}, A_{III}, A_{IV}: asymptotes of the curves *I*, *II*, *III*, and *IV*, respectively.

loading of an x-ray tube with stationary anode, whereas the problem of the sliding contact is similar to that of an x-ray tube with rotating anode.

The temperature rise in the anode of an x-ray tube has been calculated and experimentally verified by various authors,[2] though sometimes only for very specific restricted conditions. A complete treatment has appeared in my thesis,[3] part of which has been republished in the Philips Research Reports.[4] The formulas obtained can be applied right away to the contact problem. In Holm's notation, my Eqs. (8) and (12) give for the temperature rise at the center of a circular stationary contact at the time $t = (a^2c)/(\lambda)y$:

$$\theta(t) = (2K)/(\pi^{\frac{3}{2}} a\lambda) y^{\frac{1}{2}} [1 - \exp(-1/4y) + (\pi^{\frac{1}{2}})/(2y^{\frac{1}{2}})\{1 - \phi((y^{-\frac{1}{2}})/(2))\}],$$

and for the temperature rise in the stationary state ($t = \infty$):

$$\theta(\infty) = (K)/(\pi a\lambda).$$

These relations are shown in Fig. 1, curve *I*. Curve *II* gives the results of Holm's calculations, when the radius b of the hemisphere is chosen such that the correct value of the maximum temperature in the stationary state, occurring at the center of the contact area, is obtained ($b = 0.5a$). Curve *III* gives the results of my method of calculation applied to the average temperature to be compared with curve *IV*, according to Holm ($b = 2/\pi = 0.64a$).

It will be noted that Holm's calculations give values that are too high at short contact times—the difference being larger in the case of maximum temperature than in the case of average temperature. It is possible, using Holm's method, to obtain the correct temperature at short contact times by putting $b = \frac{1}{2}a\sqrt{2} = 0.71a$; (area hemisphere = actual circular contact area) but then the calculated temperature in the stationary state will be too low. Thus, by treating the temperature development in a flat contact area as a hemispherical problem, only approximate data can be obtained, if the full range of possible values of the contact time has to be covered, because of the difference of divergence of the flow of heat in both cases.

Other results of calculations on x-ray tubes can be used to calculate the temperature during the cooling down period, and to treat the problem of a sliding contact. In this respect I refer to the publications[3,4] mentioned before.

[1] R. Holm, J. App. Phys. **19**, 361 (1948).
[2] A. Bouwers, Zeits. f. tech. Physik **8**, 271 (1927); A. Bouwers, Physica **10**, 125 (1930); J. E. de Graaf and W. J. Oosterkamp, J. Sci. Inst. **15**, 293 (1938); J. E. de Graaf, W. J. Oosterkamp, and L. Philips, Tech. Rev. **3**, 259 (1938); A. Muller, Proc. Roy. Soc. **117**, 30 (1927); J. W. M. DuMond, B. B. Watson, and B. Hicks, Rev. Sci. Inst. **6**, 183 (1935); A. Muller, Proc. Roy. Soc. **125**, 507 (1929).
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[4] W. J. Oosterkamp and L. Philips, Res. Rep. **3**, 49 (1948); **3**, 161 (1948); **3**, 303 (1948).

On the Possibility of Hg Type Arcs with Hot Refractory Cathodes

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September 27, 1948

FURTHER consideration of a theory recently proposed to account for the behavior of Hg type arc spots[1] has led to the conclusion that such spots can occur even with refractory cathodes like W. Cold C and W arcs[2] are, of course, well known, but the type under consideration, unlike these, should occur even with pure inert gases and with the cathode hot enough to ensure that it is thoroughly outgassed.

The Hg type spot is characterized by a discontinuous glow-arc transition (DGA). It is thought that when increasingly larger glow currents are drawn there is increased sputtering of Hg from the cathode, thus local increased vapor density, concomitant rise in current density, and increased ionization of the vapor, hence still more bombardment of the cathode, more sputtering, and so on. At a critical value of the current density the glow becomes unstable against formation of an arc spot as the culmination of this process. Experiments of Plesse[3] and others indicate that a DGA is indeed facilitated by the presence of metal vapor near the cathode and that a more or less definite transition current density exists for a given set of conditions.

The thermionic arc, on the other hand, is characterized by a continuous glow-arc transition (CGS). The intense ionic bombardment occurring in the abnormal glow heats the cathode until it emits enough electrons thermionically to satisfy the external circuit.

The Hg spot regime would seem to arise whenever cathode vaporization or other cooling processes prevent the attainment of temperatures high enough to supply the electrons required by the external circuit by conventional thermionic emission. It thus seems reasonable to expect a spot of the Hg type to develop even on clean W, say, if the external circuit is unsatisfied by the thermionic current available at the cathode temperature determined by the balance between heating by ionic bombardment and cooling by radiation, evaporation (atoms, electrons, ions), and, to some extent, thermal dissociation or ionization of the gas, conduction, and convection.

A simple way to realize such an arc experimentally is to employ a W cathode of very small area, thereby requiring large current densities at the cathode for moderate currents in the external circuit. Of great interest in this connection are the observations of Druyvesteyn[4] on the glow-arc transition for W in rare gases. He obtained a CGA for W spheres and wires of various diameters down to 250 microns. For a wire diameter of 100 microns, however, only a DGA was obtained. Furthermore, his $V-i$ curves indicate a lower arc drop for the 100-micron wire. It is proposed that in this case the Hg spot mechanism is operative. More rapid "evaporation" of the cathode, possibly the presence of r. f. transients on transition, and the appearance of spectral lines of the cathode vapor, a different spectral distribution at the spot than that ascribable to high temperature, and other Hg spot characteristics absent for thermionic arcs, should be observable here. Similar phenomena should be observed with other refractory metals capable of supporting thermionic arcs, e.g., Mo, Ta, and Pt. The high temperature arcs with Cu, Fe, Ni, Ag, or Au cathodes may be of a similar nature,[5] the high temperature serving to supply metal vapor for the Hg spot mechanism rather than electrons by thermionic emission.

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[2] O. Becken and K. Sommermeyer, Zeits. f. Physik **102**, 551 (1936).
[3] H. Plesse, Ann. d. Physik **22**, 473 (1935).
[4] M. J. Druyvesteyn, Zeits. f. Physik **73**, 727 (1932).
[5] M. J. Druyvesteyn and F. M. Penning, Rev. Mod. Phys. **12**, 153, Table XI, Col. III, 154 (1940).

The Application of Electron Multiplier Tubes in the Measurement of X-Ray Beam Intensities and in the Determination of Crystal Structure

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In the Tungstram Research Laboratory, electron multiplier tubes have been developed whose dark current is almost entirely eliminated, and each electron emitted by the cathode—after an average multiplication of the order 10^9—can be detected at the collector plate of the tube by macroscopical measurements.[1] Such multiplier tubes were used in the measurement of x-ray intensities and its particular applicability for the determination of crystal structure was shown.

For measuring x-ray intensities the number of pulses of the electron multiplier tube can be used. The total multiplication (T) of our tube is so high, that already at a comparatively small number of impulses per second it yields a macroscopically measurable plate current. At a given supply voltage the plate current is perfectly reproducible and proportional to the number of electrons emitted by the cathode. With the variation of the supply voltage the total multiplication (T) of the tube can be varied within a very wide range. Transition from the discrete to the continuous region of current takes place continuously.

The method of counting single impulses allows the measurement of smallest intensities ranging from about one pulse per hour to about 10^4 pulses per second. The lower limit of the measurable continuous current corresponds to about 1 pulse per second, and there is practically no upper limit of the continuous current region. The possibility of measuring throughout such a wide range is due to the fact that the impulse period of the electron multiplier is very short[2] ($<10^{-8}$ sec.), and that the multiplication of the tube depends only on the interstage voltages which are practically not affected by the pulses themselves. These are the features that make electron multiplier tubes preferable to G.-M. counter tubes in measuring x-ray intensities.

The efficiency of our tube having silver cathode was determined by the comparison of the number of impulses given by the tube and the intensity of the incident Mo K_α radiation measured with the aid of an ionization chamber. According to these measurements the quantum-efficiency $w=2.75\cdot10^{-3}$ electron/photon was found.

The total multiplication of the tube was determined by measuring the plate current and the number of impulses simultaneously. If n electrons are emitted by the cathode per second and the total multiplication of the tube is T, the plate current is $i=n.T.e.$, e being the charge of the electron. Thus at a supply voltage $3060V$, $T=1.46\cdot10^{-9}$ was found. The variation of T as a function of the supply voltage is shown in Fig. 1.

Comparing the current given by a perfectly absorbing ionization chamber (filled with air) and our multiplier tube in case of the same radiation (Mo K_α line in our case) of the same intensity, the electron multiplier yields a current

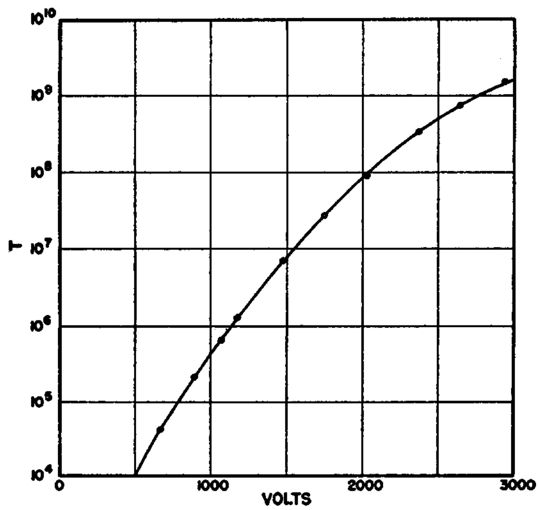

Fig. 1.