A NEW EXPLANATION OF THE GENERATION OF ELECTRICAL OSCILLATIONS IN A. C. DISCHARGE

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ABSTRACT

To explain the generation of electrical oscillations in A.C. discharge, the spark process in the discharge is envisaged. There is a formation of positive cloud, which fluctuates with a frequency governed by the formative time lag. This cloud inhibits the electron avalanche so as to produce velocity modulation and acts like a buncher. A sort of feed back is envisaged between the applied field and the field of the positive cloud so as to sustain oscillations. These oscillations are independent of certain parameters for which explanation is given.

Introduction

While studying the effect of irradiation on electrodeless discharges Joshi[1] Tiwari[2] and von Engel and Harries[3] observed some high frequency pulses in the discharge. The existence of a large number of discrete R.F. oscillations in A.C. silent discharges was established by Khastgir and others[4,5,6,7]. Karnik[8] has studied apparently similar discrete R.F. frequencies produced in a 50 C/s A.C. discharge. Karnik[8] measured the discrete radio frequencies generated using a C.R.O. and a superhetrodyne frequency meter and found that their values were not affected by such different parameters as E/P, nature of the gas, circuit constants and the nature and geometry of the tube.

The tables I, II and III contain observations taken for an internal electrode tube, a flat glass electrode tube and an ozoniser type tube respectively. The observations have been taken in the media of air, organ, hydrogen, oxygen and mercury vapour. The H.T. supply was varied upto 40 K.V., while the pressures were varied from 0·01 mm. to 750 mm. of mercury. The main result obtained has been that the frequencies observed cluster round certain values, by whichever methods they were measured, and whichever tubes and discharges parameters were employed. The megacycle oscillations only appear prominently, however, at the high pressures, and for these the individual bandwidths were greater than for the lower frequency oscillations. It is natural to suspect that some of the observed frequencies could be produced by the external circuit of the discharge tube. We have, however, varied the circuit inductances and resistances very widely without effect on our results, whilst the capacities of the tube are different. We are therefore led to the conclusion that the discrete frequencies observed are peculiar property of the discharge under consideration.

TABLE I

Internal electrode tube

Method	Range	Total no. of readings for each column	air	argon	hydrogen	oxygen	mercury vapour
Cathode Ray Oscillograph	Kc./sec	1936	100±1·1	101±1·5	107±2	106±2·5	110±3
		299	—	655±7	654±8	665±15	650±0
		1573	1190±49	1240±52	—	—	—
	Mc./sec	1478	2·06±0·05	2·05±0·04	—	—	—
		191	2·30±0·07	2·20±0·01	2·22±0·04	2·27±0·02	—
		167	—	2·36±0·04	2·40±0·0	2·40±0·0	—
		173	—	—	2·61±0·02	2·6±0·01	264±0·04
		2091	2·74±0·03	2·72±0·06	2·77±0·02	2·77±0·02	2·8±0·0
		267	—	7·4±0·1	7·5±0·08	7·4±0·07	7·5±0·1
		1793	11·6±0·2	11·3±0·5	10·3±0·3	10·6±0·1	10·1±0·0
		2093	14·2±0·3	14·2±0·1	13·5±0·3	13·7±0·4	—
		1413	15·7±0·2	15·7±0·1	15±0·2	14·9±0·3	14·7±0·4
		2072	25·9±0·2	25·6±0·4	—	26·0±0·0	25·5±0·0
		2319	27·1±0·3	26·8±0·4	26 8±0·2	26·8±0·2	26·5±0·0
Super het. frequency meter	Kc./sec	54	672±50	686±51	—	—	—
Wave meter	Mc./sec	nil	nil	nil	nil	nil	nil

In Karnik's[8] experiments there appears to be a definite connection between the formative time lag and the discrete R.F. frequencies observed in the discharge. It is usual to compare this phenomenon with that of relaxation oscillations in which an increase of overvoltage could momentarily decrease the discharge current and lead to the building up of R.F. oscillations in the anode circuit at a frequency determined by formative time lag and the destruction time for the cloud. In this note we would like to suggest a plausible alternative explanation for these observations of Karnik[8]. It is suggested that the generation of discrete R.F. frequencies is due to the velocity modulation of an electron avalanche by a positive space charge cloud formed in the process of a spark discharge.

In a spark according to Townsend[9] and Loeb and Meek[10], photo electrons are liberated at the cathode, by the incidence of stray photons. Due to cumulative ionization by these electrons, electron multiplication takes place.

TABLE II

Flat-glass electrode tube

Method	Range	Total no. of readings for each column	air	argon	hydrogen	oxygen
Cathode Ray Oscillograph	Kc./sec.	198	103±2	106±2	105±3	103±4
		193	658±9	654±5	670±13	656±7
	Mc./sec.	180	2·14±0·02	2·23±0·05	2·10±0·02	2·24±0·09
		190	2·6±0·01	2·61±0·02	2·56±0·06	2·63±0·02
		185	2·80±0·02	2·78±0·08	2·79±0·01	2·79±0·02
		162	3·1±0·03	3·1±0·0	3·1±0·0	3·1±0·05
		175	7·50±0·14	7·50±0·05	7·47±0·05	7·42±0·05
		194	10·7±0·4	10·6±0·3	11·0±0·6	11·0±0·2
		206	14·0±0·2	13·75±0·25	14·1±0·3	13·9±0·2
		182	15·0±0·6	14·8±0·2	15·3±0·5	15·0±0·2
		228	26·0±0·17	26·0±0·1	26·0±0·1	26·0±0·2
		199	27·0±0·2	27·0±0·0	27·0±0·0	27·0±0·0
Super het. frequency meter	Kc./sec.	29	670±53	668±45	—	—
Wave meter	Mc./sec.	nil	nil	nil	nil	nil

This process leads to an electron avalanche. From the head of the avalanche fine filamentary streamers proceed further, and they are associated with the gap current and luminosity. The luminosity contains some photons in the short ultra-violet. These photons liberate secondary electron-avalanches. The positive space charge left behind by the initial avalanche is invoked to enhance the electron multiplication of the secondary avalanche and to guide the propagation of the discharge along a well-defined channel. This positive cloud also produces a field near the anode of considerable magnitude which can affect the velocity of the receding electrons. Further, at slight over-voltage the space charge could effectively inhibit the advance of the electron avalanche towards the anode. The electron stream is decelarated till the space charge cloud merges in the cathode by forming positive streamers. The axial field of the positive space charge has a considerable value as can be seen from the calculations after Loeb [11]. In the calculation one may consider a plane parallel gap of one cm. length in which one sq. cm. of cathode area may liberate one electron per microsecond due to incidence of stray photons. Assume that in air at atmospheric pressure the potential across the plate is 31600 volts (E) and therefore the ratio E/P=41·6 volts/cm. per mm. of Hg. If we assume the positive cloud to be a small sphere, then the strength of the field

X_1 due to this space-charge is 7800 volts per cm. which is 25 per cent of the applied field. If the over-voltage of 5 per cent or an $E/P=43\cdot6$ had been applied, the field X_1 would have been 140000 volts per cm.

TABLE III

Ozoniser type tube

Method	Range	Total no. of readings for each column	air	argon	hydrogen	oxygen
Cathode Ray Oscillograph	Kc./sec.	195	714±14	714±15	717±15	707±8
		181	961±10	953±7	952±9	955±11
		193	1025±25	1020±34	1040±7	1040±30
	Mc./sec.	159	2·04±0·05	2·04±0·01	2·02±0·02	2·01±0·01
		116	2·25±0·01	2·30±0·02	2·24±0·1	2·34±0·1
		74	2·76±0·08	2·8±0·0	2·8±0·0	—
		153	3·1±0·1	312±0·2	3·13±0·05	3·17±0·05
		187	7·5±0·16	7·5±0·1	7·5±0·1	7·6±0·2
		192	10·6±0·8	10·6±0·6	10·6±0·1	10·6±0·05
		191	14·1±0·1	14·0±0·02	14·6±0·1	14·0±0·0
		193	15·3±0·3	15·5±0·6	15·3±0·2	15·1±0·1
		209	26·5±0·5	26·2±0·2	26·1±0·2	26·0±0·0
		174	27·2±0·2	27·0±0·0	27·0±0·0	26·75±0·25
Super het. frequency meter	Kc./sec.	29	680±56	—	—	680±53
Wave meter	Mc./sec.	59	1·5±0·7	1·45±0·8	1·42±0·9	1·42±0·8

Thus it is seen that at the convensionally observed sparking potential, the space charge fields are appreciable and with a slight over-voltage they are such that they could materially inhibit the advance of the electron avalanche towards the anode. Thus in the spark process of the electrical discharge positive space charge, left behind by the electron avalanche originated from the cathode and proceeding towards anode, is gradually built up near the cathode. This positive space charge produces a field near anode of a considerable value. The axial field thus produced can affect the velocity of the receding electrons. The field of the positive space charge inhibits the advance of the electron avalanche towards the anode. The electron stream is decelarated till the space charge merges in the cathode by forming positive streamers. This behaviour of the positive space charge cloud, of decelaration of the electron avalanche is similar to that of a buncher of a klystron and thus the positive field may cause velocity modulations in the succeeding electron avalanches.

A spark is associated with characteristic intervals. They are, the statistical time-lag and formative time-lag. Loeb[10] defines the statistical time-lag as the time that elapses between the application of a break-down potential and the appearance of the first stray electron initiating the discharge. The formative time-lag (Loeb [10]) represents the actual time between the occurrence of the initiating process leading to a spark and the completion of the sparking process. During this time photo electrons are generated and a positive space charge is built up which afterwards passes into the cathode, while the electrons recede towards the anode. Thus we may assume that in the spark process a positive cloud is formed and destroyed in an interval of time which is equal to or comparable with the formative time-lag. It is thus possible that in a spark, this positive cloud which is periodically formed and destroyed with a frequency which is nearly equal to the reciprocal of the formative time-lag, can act like the buncher of a klystron. These frequencies are of the order of megacycles and for positive ions they will be independent of the pressure, potential, gap distance and the nature of the gas; because the formative time-lag for positive ions does not depend on the pressure (Ganger[12]) and the nature of the gas (Fisher and Kachikas [13], [14], [15]) but depends only on the over-voltage beyond 1 per cent (Fisher and Bederson [16]). This leads us to expect in a spark discharge discrete frequencies which will correspond to the formation and destruction frequencies of the positive ion clouds and which will be nearly equal to the reciprocal of the formative time-lags.

We now would like to suggest that we may consider the 50 C/s discharge as a series of spark processes. In each a positive cloud is gradually built up. It acts like a "buncher" of a klystron, causing velocity modulation of electron avalanches proceeding towards the anode. The positive cloud has a formative time-lag and its reciprocal is the intermittent frequency with which the cloud is built up and destroyed. The formative time-lag under normal experimental conditions, when we have over-voltages above 1 per cent, is independent of E/P, nature of the gas and gap distance, and is of the order of 10^{-6} seconds. Thus the frequency of the formation of the positive cloud is of the order of a megacycle and is independent of the above parameters. This positive cloud behaves like a buncher of a constant frequency of the order of a megacycle. Thus the velocity modulations of electron avalanche caused by the modulating positive cloud of constant frequency could produce the discrete R.F. frequencies observed in the anode circuit which may be considered to have the behaviour of a catcher of a klystron oscillator.

To consider the applicability of this analogy a little more in detail, we would like to state that the positive ion cloud whose density of charge fluctuates, acts as a buncher, the applied difference of potential (which has a frequency of only 50 C/s and which may be practically considered as a D.C. compared with the R.F. produced) which drives the electron avalanche towards the anode as a catcher. The connection between the applied field and the field of the positive space charge can and does interact in such a way that the density modulation of the positive charge modifies the applied field, thus energises the catcher. The catcher in its turn builds up the positive charge cloud and this may be regarded as a sort of feed back from the catcher to the buncher to maintain the oscillations. In this way the idea of bunching and velocity modulation may be extended to explain Karnik's observations.

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