ON THE ANODIC SIDE OSCILLATIONS OF LOW PRESSURE DC GAS DISCHARGES

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The more important results available so far in the literature dealing with the anode oscillations are reviewed and the author's own investigations of the anode oscillations appearing in low-pressure direct current mercury-argon discharges are described. It is found that direct and alternating current heating of the cathode influence the anode oscillations and curves showing the dependence of the amplitude and frequency of the oscillations on the cathode heating current are given. The influence exercised by an external magnetic field on the anode oscillations is also studied.

1. Introduction

The experimental and theoretical investigation of the characteristics of oscillations which appear in the anode space has been undertaken by several authors [1—13].

No unanimous view, however, has been formed so far concerning the explanation of the origin of the anode oscillations. The investigations carried out so far have demonstrated that there are a number of discharge factors that play an important part in the development of the oscillations and that have a strong influence on the characteristics of the oscillations.

Some of the authors [4, 8] trace the development of oscillations back to the periodic fluctuations appearing in the anode fall. Others [11] regard the displacement taking place in the heat equilibrium of the anode as being the cause of these oscillations. The investigations carried out so far [8, 12, 13] have also demonstrated that the surface and shape of the anode have a considerable influence on the oscillations and further that in the case of anodes arranged close to the wall of the discharge tube the disturbing effect of the wall will make itself felt in the characteristics of the oscillation [14]. Also the appearance of the anode spots with their glow balls may exercise an influence on the oscillations of the anode space [15].

In the course of his earlier investigations [13] the present author — after a detailed analysis of the relevant literature — has dealt with the dependence of the characteristics of the anode oscillations on the shape and the dimensions of the anode, on the intensity of the discharge current, as well as on the voltage of the auxiliary electric circuit applied at the anode.

The object of the investigations reported in the present article is to show that there are further factors influencing the oscillations and to analyse the influence of some of them in more detail. In particular the results of investigations of the influence exercised by the cathode heating and the external magnetic field on the anode oscillations will be reported.

2. Method of investigation

The experimental setup employed in the experiments may be seen in Fig. 1. The discharge tube T was fed by the stabilized direct current source SDC, and the current of the discharge limited by the symmetrically arranged ohmic resistances R_1 and R_2. The discharge current could be read on the instrument I_t and the tube voltage of the discharge on the instrument V_t.

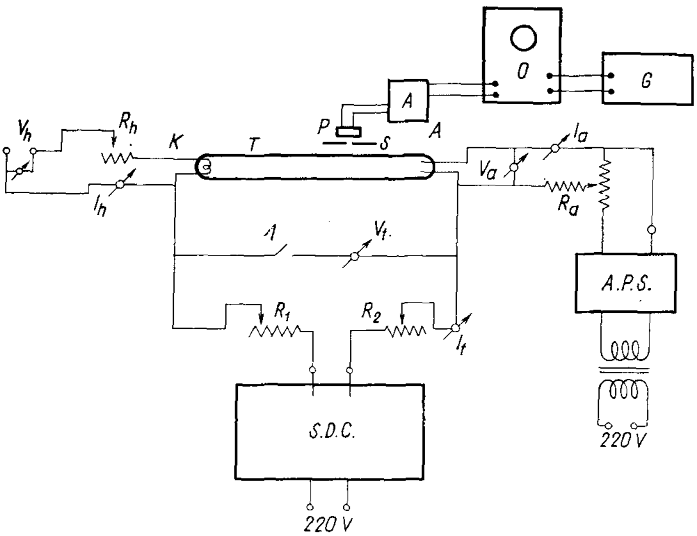

Fig. 1. Circuit diagram of the experimental setup

The current of the heating circuit which was placed next to the cathode K could be adjusted through the variation of the voltage V_h and the resistance R_h respectively. The heating current was measured by the instrument I_h, the heating voltage by the instrument V_h.

At the anode A an auxiliary electric circuit was used which was fed by the stabilized direct current source APS. The current of the circuit was shown by the instrument I_a, the voltage by the instrument V_a.

The measurements were effected partly by using a rotating disc and partly with the help of a photocell. The rotating disc method was applied mainly in the investigation of oscillations of lower frequency. Both with the photo-cell and the rotating disc method the observations took place directly at the anode.

In the photo-cell measurements the light, the fluctuations of which could be observed at the anode, passed to the photo-cell through a slit which had been appropriately adjusted. The current fluctuations obtained from the photo-cell were amplified by the amplifier A and the signals then passed to the vertical input of the oscilloscope O. The horizontal input obtained oscillations of known frequency of the generator G. The frequency of the anode oscillations was determined by the Lissajoux curve method. The investigations of the oscillations (determination of frequency, amplitude) were limited to investigating the light fluctuations of the anode space, as it appeared from earlier investigations [7, 13], that the frequency of the current oscillations of the anode space is equal and their amplitude proportional to the frequency and amplitude, respectively, of the light fluctuations observed there. This statement was oscilloscopically checked for some value of the discharge current prior to the measurements, under the appropriate experimental conditions.

3. Test conditions

The length of the glass-walled discharge tube was 500 mm, its internal diameter 36 mm, its wall thickness 1 mm.

The cathode of the discharge tube was formed by a wolfram double spiral provided with an oxide coating promoting electron emission. On both sides of the cathode at a distance of 3 mm from the spiral one auxiliary electrode was arranged, each being of a thickness of 0,2 mm, width of 5 mm, length of 14 mm, which had a potential identical with that of the spiral. The anode of the discharge tube was composed of two parts. In the course of the experiments two anode constructions made of nickel were used, which are shown in Fig. 2. In the one case (Fig. 2a) the anode was formed by a cylinder and a disc arranged in it, while in the other a needle was co-axially arranged in the cylinder (Fig. 2b). The tip of the needle pointed in the direction of the positive column. The dimensions and characteristic data of the individual types may be seen in Figs. 2c and 2d, respectively. Both the wall thickness of the nickel cylinder and the thickness of the nickel disc were 0,2 mm. Both anode parts were provided with separate copper terminals.

The discharge tubes passed through the customary vacuum treatment, at the end of which it was filled with argon purified in a FeBa arc and of 3 mmHg pressure, and mercury of some 60 mg weight. In the course of the experiments neither the gas pressure, nor the type of gas has been varied. The adjustment of the gas pressure of the tube was effected to a precision of $\pm 0{,}05$ mmHg. The pressure of the mercury vapour was determined by the wall temperature of the discharge tube which depended on the ambient temperature. In the course of the investigations the ambient temperature mounted to 25 ± 1 C.

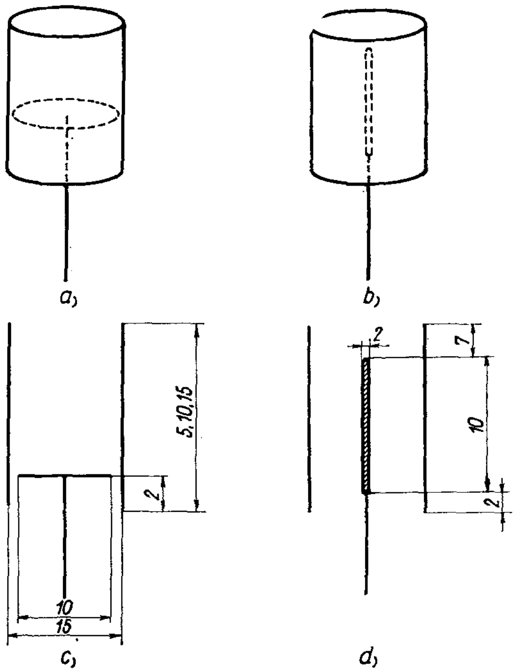

Fig. 2. The nickel anode constructions and their dimensions employed in the tests

Prior to starting the measurements the discharge tube was operated for 30 minutes, under the same conditions as those of the measurement.

The starting of the discharge was effected through the provision of proper cathode heating and the high-frequency pre-ionization of the discharge space.

4. Results

The investigations have been carried out at a discharge current of 100 mA and 400 mA. The voltage-current characteristics typical of the discharge tubes employed in the tests can be seen in Fig. 3. In the region of both the 100 mA and the 400 mA discharge currents the characteristics can be substituted to a good approximation by a straight section of negative slope, hence here there is no distinguished section of the characteristics as would influence the oscillations or bring about further oscillation effects.

SAGGAU [16] has studied the influence of cathode heating on the oscillations of the discharges. In the course of his investigations he has found that the cathode heating has no influence on the frequency of the oscillations in the case of neon gas of 2 mmHg pressure. From his results it appears that under the investigated discharge conditions the frequency of the oscillations does not depend either on the cathode fall or on the positive anode fall.

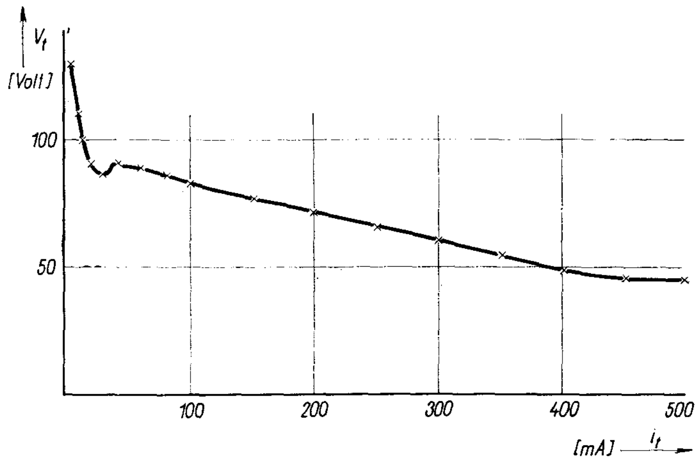

Fig. 3. The tube voltage vs. discharge current characteristics of the discharge tube

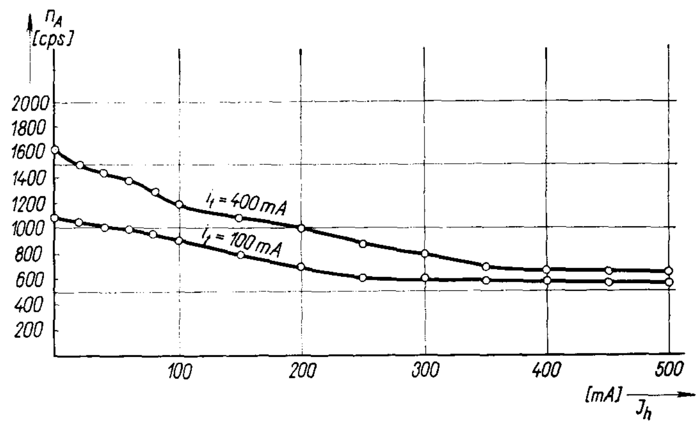

Fig. 4. The dependence in the case of direct current heating of the frequency n_A of anode oscillations on the heating current I_h at a discharge current of 100 mA and 400 mA

His measurements were carried out at a discharge current of 5 mA and the frequency of the observed oscillations was in the 1000 cps frequency range.

Our own investigations also included the determination of the dependence of the oscillation frequency on the cathode heating. The results of the measurements effected under the discharge conditions described above did not agree with the results of SAGGAU [16].

What resulted was that the oscillations of both the positive column and the anode space were influenced by the variation of the cathode heating current. Fig. 4 shows the dependence of the frequency of the oscillations on the intensity of the cathode heating current (direct current heating), at a supply voltage of 400 V in the case of discharge currents of 100 mA and 400 mA. It may be seen that at the given constant discharge current the frequency of the anode oscillations diminishes with the increase of the heating current intensity. The shape of this decreasing curve may be well approximated by reciprocal functions. As it could be expected on the basis of former investigations [13], the growth of the discharge current increased the frequency of the oscillations in this case as well.

Fig. 5 demonstrates the dependence of the oscillation amplitudes on the heating current at a discharge current of 100 mA and a supply voltage of 400 V. The curve *a* was obtained with alternating current heating, while the curve *b* shows the dependence resulting in the case of direct current heating. With the increase of the heating current the amplitude diminishes in both cases. This decrease is considerable particularly in the curve obtained in the case of direct current heating. From Fig. 5 it may also be seen that higher oscillation amplitudes will result with alternating current heating than in the case of direct current heating. Besides, the shape of the oscillations will also be distorted and more harmonic oscillations of the oscillation frequencies will appear, a fact that may be connected with the heating current of 50 cps frequency.

In any case it may be seen from Figs. 4 and 5 that the stability of the anode spaces is considerably affected (at least in the case of the discharge tubes of 500 mm length used and under the discharge conditions described) by the cathode heating, its intensity, and whether it is of a periodic (in this case of 50 cps frequency) or constant character. What may further be seen is that with the increase of the heating current the stability of the anode space will grow both in the case of direct and alternating current, while the amplitude and frequency of the oscillations will diminish.

The results shown in Figs. 4 and 5 have been obtained when the anode construction to be seen in Fig. 2a was employed. When that shown in Fig. 2b was used the frequency and amplitude of the oscillations increased as this could be expected on the basis of the results of [13]. The amplitude and frequency dependence on the heating current is not reproduced here as also in this case these were found to be similar to the dependence obtained in the case of the anode construction shown in Fig. 2a.

The increase of the casing height of the anode cylinder led also in this case to a decrease of only the amplitudes and the number of the harmonic oscillations. The character of the dependence on the heating current remained unchanged.

Summarizing the results it may be seen that under the measuring conditions employed here it is possible to influence not only the characteristics of the oscillations of the positive column but also the oscillations of the anode space from the cathode space through the cathode heating. The results obtained here do not agree with those of SAGGAU [16]. This might possibly be ascribed to the differences between the discharge conditions.

Investigations have also been made concerning the influence exercised by the external magnetic field on the anode oscillations. So far no report has appeared in this connection in the available literature. The effect of the

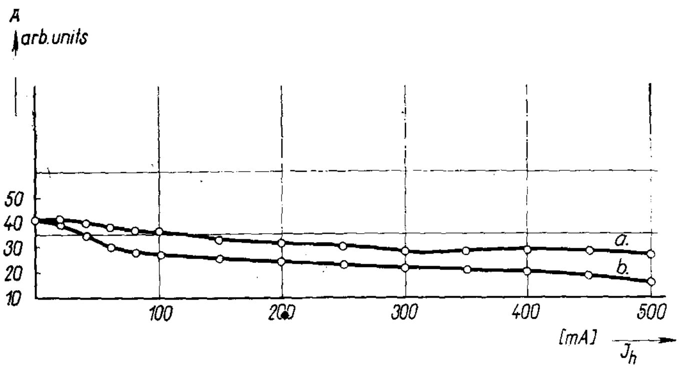

Fig. 5. The dependence of the amplitude A, recorded in arbitrary units, of the anode oscillations on the heating current with direct (b) and alternating current (a) heating

magnetic field upon the positive column and upon the basic processes of the plasma of arc discharge are known [17] but regarding the oscillations of the anode space no investigations have as yet been made.

The conclusions which could be drawn from the present experiments are mostly of a qualitative character. The external magnetic field parallel to the axis of the discharge leads in a known manner [17] to the contraction, perpendicularly to the direction of the field, of the anode glow-space and the shift of the discharge away from the wall. As a consequence, the amplitudes of the oscillations are reduced and the number of harmonic oscillations decrease correspondingly yet the oscillation frequency remains unchanged. Fresh oscillations of any considerable amplitude did not arise up to 20 kcps. Beyond this no investigations have been made. When the discharge current grew, the influence of the magnetic field increased and the amplitudes diminished accordingly. This stabilized the anode space to some extent probably through the reduction of the wall losses.

In certain respects it appears as if the phenomenon observed here may be caused by the same factor [14] as that influencing the oscillations and mentioned in the introductory section, i.e. the part played by the nearness of the wall. When the wall of the discharge tube is sufficiently near to the axis of the discharge and to the discharge electrode, a significant part of the electrons may reach the wall surface by way of diffusion and thereby near the electrodes for instance in the present case in the space before the anode, the number of ionizations as well as the concentration of the space charges will be reduced. In order to neutralize the electrons accumulating at the wall an ion current will start from the anode space, which will result in further displacements around the anode. If complete neutralization does not result a radial electric field will develop which will strongly influence the value of the anode fall.

The axial magnetic field parallel to the axis of the discharge tube, at the same time, stabilizes also the anode-side end of the positive column. This stabilization has shown itself in the reduction of the oscillation amplitude and the noise level.

When the direction of the magnetic field was perpendicular to the axis of the discharge tube, eddy-like turbulent phenomena, well visible to the naked eye, developed both in the anode space and in the part of the positive column close to the anode. These decayed rapidly, without spreading any further. Here investigations using a photomultiplier have shown that a large number of new frequencies arise while in the centre of the turbulence very high but rapidly decaying amplitudes could be observed.

In the course of previous investigations [13] it was possible, by using the anode construction presented in Fig. 2a, to achieve that one glow light from the discharge should appear also on the tube end side of the anode plate.

This effect could be reproduced also in the present case by using the disc arranged in the cylinder at the anode and leaving the cylinder electrically unconnected. The same could be achieved, however, also through employing a magnetic field, by shifting the external magnetic field of perpendicular direction to the discharge, from the anode-side end of the positive column towards the end of the discharge tube. One may say that the plasma space, originally induced by the magnetic field at the anode-side end of the positive column had become frozen into the magnetic lines of force. Through the displacement of the magnetic field this also was shifted to the end of the tube. The glow light behind the electrodes at the back plate of the anode remained as long as the magnetic field existed there.

Similarly to the influence exerted on the anode oscillations [13] by the electric circuit arranged at the anode, the stabilizing effect (lower amplitudes, lower noise level) of a magnetic field could be observed also in the case of an external magnetic field parallel to the discharge axis. When in addition to the anodic circuit also the magnetic field perpendicular to the discharge axis acted upon the anode space, the turbulent effects described above increased considerably at low currents of the anode circuit I_a.

It will have become clear from the above that also the cathode heating influences the oscillations of both the positive column and the anode space. In the case of direct current cathode heating it was possible to achieve a more stable anode space as against that of the alternating current. A similar stabilizing effect was also found when an external magnetic field was applied parallel to the axis of the discharge.

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ОБ АНОДНЫХ КОЛЕБАНИЯХ ГАЗОВЫХ РАЗРЯДОВ ПОСТОЯННОГО ТОКА НИЗКОГО ДАВЛЕНИЯ

Й. БИТО

Резюме

Автор ознакомливает читателя с важнейшими результатами, относящимися к анодным колебаниям газовых разрядов и встречающимися по настоящий день в литературе. Появляющиеся при газовом разряде анодные колебания исследуются в ртутно-аргонном разряде постоянного тока низкого давления. В работе рассматривается далее, какое влияние сказывает нагревание катода постоянным и переменным токами на анодные колебания. Даётся зависимость амплитуды и частоты колебаний от тока нагревания катода. Исследуется влияние внешнего магнитного поля на анодные колебания.