Estimates of the Glow Discharge Ignition Conditions in Penning's Ring Plural Cell System

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Abstract – This paper summarizes some common aspects of gas spark gap breakdown – "the common anode sectional cathode" – in the divided ring parental plasma oscillator with radially converging ribbon electron beam. Modified Pashen's law is used to obtain functional dependences of ignition potentials in crossed *E*×*B* fields. It is shown that rated dependencies of working gas pressure, correlated with the trough area and the right part of Pashen's branch confirm experimental ones, taking into consideration precision of measurements.

1. Introduction

The over increasing effect of ion current in glow discharge following magnetic field forcing, discovered by Penning, gave start to investigations in low pressure magnetic field forcing of self-maintained charge.

At bottom the results of researches in this field created preconditions for making not only cold-cathode ionization gages and pumps, but also a whole series of plasma charged particles sources.

In spite of a certain interest of theorists in important experimental facts of gas discharge formation in crossed electric and magnetic fields, at present the only complete theory is the theory of permanent discharge.

The difficulties of Penning's discharge quantity theory construction are conditioned by the necessity of taking into account its dynamic forms which include the complicated dependence of Townsend's factor upon the value of electric and magnetic fields, kinds of gas and geometry; conditions of electrode material surface, and many other factors

2. Description of the discharger

The research was carried out in the plasma emitter framed by electrodes of the required pattern and the efficient combination of E×H fields.

Figure 1 demonstrates the assembled appearance of the device (a); the one with the upper anodic ring unscrewed (b); the componentry of fabricated structure (c); and the sketch of the crossed electric and magnetic fields topography (d).

The specific character of the flash chamber is con-ditioned on the electrode system construction. The cathode is divided into 28 conducting ferromagnetic cores (1), which expel a sudden change of potential in the area, close to the electrodes, since the area of cathode S is much smaller than the anode area. Besides, the cores concurrently function as pole pieces of the surface magnetic field formed by constant magnets (2) of SmCo5 alloy.

The flat symmetrical gap between the cores (1) and the anode ring (3) with the ferromagnetic insertions (4) pressed on their edges, was discontinuously modi-fying from 0.95 up to 2 mm by force of the threaded connection of two rings of hooked shaped section on the anode cylindrical base (5).

The magnetic field of each functional electronic cell is deformed due to the ferromagnetic anode insertions (4); the field B induction "deflects" from 0.1 up to 0.08 T towards the emission slot (6). As sketched in Figure 1 (a), the direction of magnetic field lines al-ternates, as the twin axial magnets (2) are placed into the notches in the supporting cathode (7) generating line with back-to-back poles.

Plasma gas Ar was fanned along the dielectric tubes through beans (8) from four quarters into the circular vacuum rug, formed by closing of the upper (9) and lower (10) rings. Using split vacuum-tight connection it went through intercommunicated canals and leaked into 28 functional electronic cells along the coupling holes in core cathodes. The flash chamber was cooled off by the canal of compressed air through the beans (11), joined with the circular rug in the lower ring (10).

3. The issue and target setting

The experiments carried out before [1–3] quite in detail showed how the reflecting discharge was negotiated in the device described above. Consequently, to keep the discharge in the space, which is limited by magnetic flux directed along the anode frame, and crossing the face of axial cathodes – magnetic enhancers of the outlying magnetic field, it was provided that the electrons in crossed E×H fields could drift in speed direction of

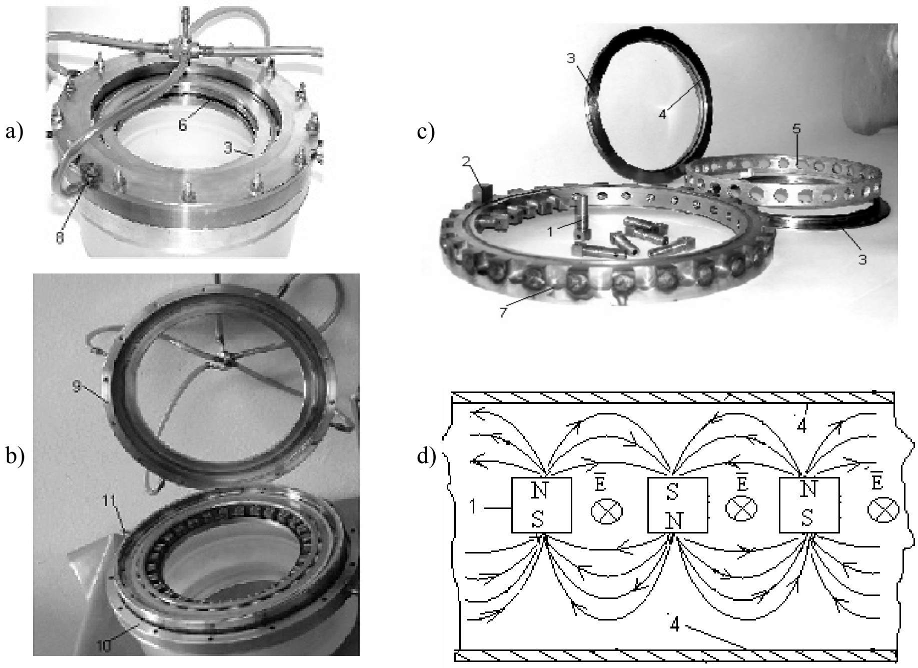

Fig. 1. The discharger: outward appearance (a), the basic constituents (b, c), and a sketch of crossed $E\times H$ – fields (d)

$$\vartheta = c\cdot\frac{(ExH)}{H^2} \qquad (1)$$

and the condition of charge $H>H_{cr}$ magnetizing was met.

One can neglect the effect of the magnetic field on the motion of ions promptly getting on to the cathode. To optimize the plasma physical process, keyword parameters – gas pressure, field density, and firing potential of discharge were adjusted.

The paramount parameter, which by and large de-termines emittive plasma behavior in electronic source [4], is the value of discharge firing potential; therefore the estimation of gas interval breakdown between the divided cathode and general hollow anode, and the analysis of the obtained dependency of the discharge medium on operational factors is the major task of this work.

4. Results and discussion

The genuine Pashen's law [5] and the modified one [6] are described by the corresponding functional de-pendencies and are held in gas blend and in rare gases in the electric field free of the magnetic one.

As was stated above, in the presence of magnetic field the electron paths warp, and the form of $B_\perp$ – field is supposed to promote the electronic retention in the place of their overall oscillation, i.e. in cathode fields.

In such a case one should take into consideration the change of the situation in the interelectrode space, and it can be supposed that the basic process in it is electrons encounter with gas particles; and on the axial cathode surface it is the electron emission following the positive ion bombardment. It is apparent hence that one can apply the avalanche effect theory to the ignition of ring symmetrical discharge in Penning plural cell system.

As a result of experimental and theoretical investigations [7], theoretical model of equivalent pressure was formed

$$p_э = p(1+\frac{\omega^2}{\nu^2})^{\frac{1}{2}}, \qquad (2)$$

$$p_Э = p\cdot\left(1+c^2\cdot\left(\frac{B_\perp}{p}\right)^2\right)^{\frac{1}{2}}; \quad c=\frac{e}{m}\cdot\frac{\lambda_e}{\upsilon_e}, \qquad (3)$$

where: ν – is the collision rate of an electron with neutral atoms; ω – is Larmor's electron frequency; p_e – equivalent pressure in the magnetic field presence; λ_e, υ_e – the normal length of free pass and electron speed ; m, e – the electron mass and charge.

The concept of equivalent increasing pressure pro-ceeds from the magnetic field imposition.

By the model one can perform calculations of punch stamp characteristics in the given electrode system using the formula expressing another modified Pashen's law [8]

$$U_{ign.} = \frac{B\cdot p\cdot d\cdot[1+(\omega/\nu)^2]^{\frac{1}{2}}}{\ln[p\cdot d\cdot[1+(\omega/\nu)^2]^{\frac{1}{2}}]+\ln[\frac{A}{\ln(1+1/\gamma)}]} \qquad (4)$$

or,

$$U_{ign.}=\frac{B\cdot p\cdot d\cdot\left[1+c^2\cdot\left(\frac{B_\perp}{p}\right)^2\right]^{\frac{1}{2}}}{\ln\left|\frac{A\cdot p\cdot d\cdot\left[1+c^2\cdot\left(\frac{B_\perp}{p}\right)^2\right]^{\frac{1}{2}}}{\ln(1+\frac{1}{\gamma})}\right|},\qquad(5)$$

where A and B are absolute symbols dependent on the kind of gas; and γ is epy Townsend second factor.

After we introduced the absolute symbols A and B, appropriate for the argon, taking into account the typical values of γ=10^{-1}–10^{-4} into the formula (5), we performed the calculations of ignition potential threshold values for two interelectrode distances of d=0.95 and 2.0 mm in alterable range of gas pressure, and specified nonhomogeneous transverse magnetic field.

In Fig. 2 six rated dependencies are represented in the form of broken line segments, which clearly represents the points available in the confidence inter-val of measurements. The diagram shows that the coordinate points, corresponding to the discharge ignition trough $U_{\min}$~324 V are the functions of not only the multiplication of gas pressure by interelectrode distance; by also of the magnetic field induction to gas pressure ratio (one shouldn't view this as $B_\perp$ and p taken severally).

If the d=0.95 mm, i.e. in a slow discharge interval, and relatively low pressure in a rather nonhomogeneous magnet field with the induction 0.09–0.1 T high E-field density is required for breakdown. The dynamic equilibrium condition of newly generated charges, and the ones getting to the cathode, is realized when the anode voltage is high (the left branch crest of modified Pashen's law).

In small magnetic fields the ignition potential decreases abruptly with the field amplification; at that

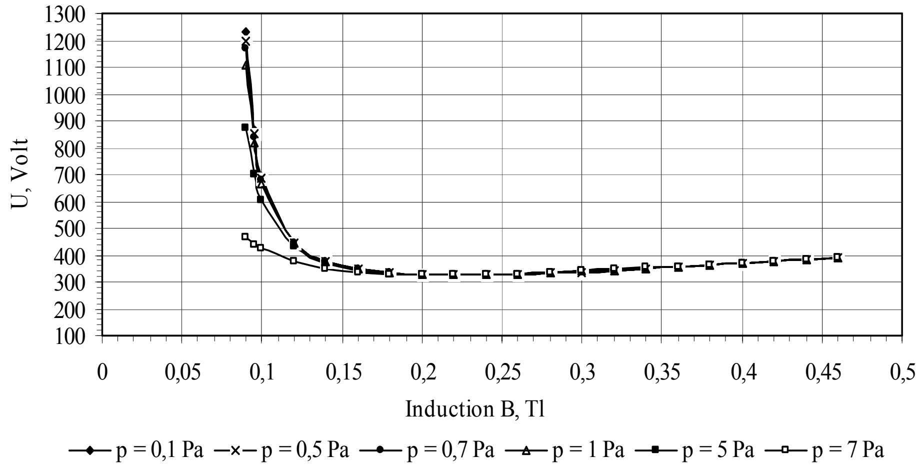

Fig. 2. Rated dependences U_{ign}=$f(pdB_\perp/p)$, where d=0,95 mm

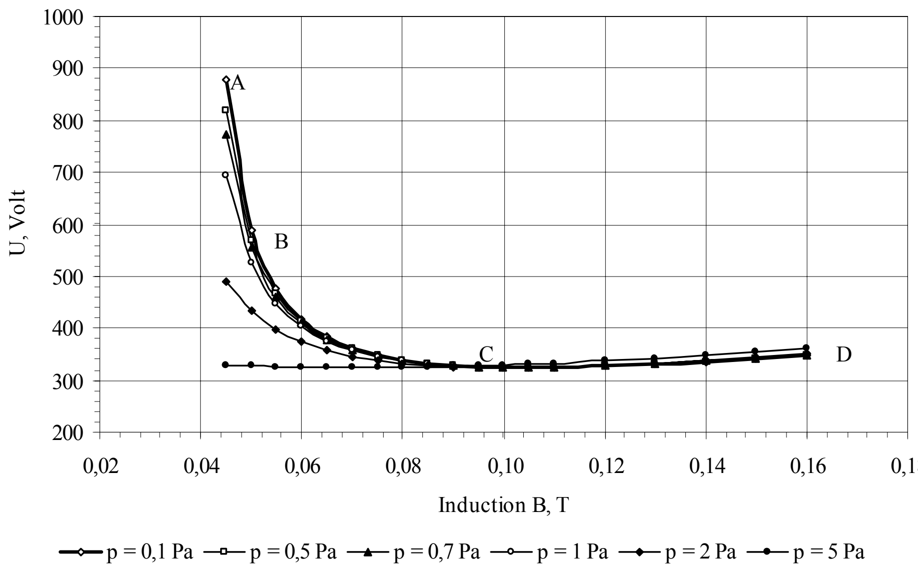

Fig. 3. Rated dependencies U_{ign}=$f(pdB_\perp/p)$, where d=2 mm

the breakdown steepness doesn't vary greatly in the range of measured pressure from 0,1 up to 1 Pa. The gas pressure increase up to 5 Pa and the magnet field induction increase up to ~0,2 Tl bring about the superposition of curves. All the further $B_\perp$ – field increase, the ignition potential starts to increase slowly in all the range of gas pressure.

We can explain the considerable decrease of discharge ignition potential in the presence of magnetic field like this. In the crest (on the left of $U_{\min}$) the path bend is insignificant, as the altitude of electron h_e cy-cloid is bigger than the inter-electrode distance *d*. Consequently, the average path of an electron λ_e till its encounter this time does not go along the E-field, as it goes along the cycloid. The relocation Z_e of the electron along the electric field at that is less than λ_e, and the energy, gathered by the electron between its en-counters, is λ_e/Z_e times less.

As a result the length of the path from cathode to anode, and ionization section increase, and this leads to the decrease of the punch voltage.

From the condition that an electrode gathers its band-gap energy on the cycloid altitude of $eEh_e=eU_i$ it is easy to understand that the $B_\perp$ increase results in the ignition potential rise, as, when the magnetic field induction increases, the altitude goes down, and to amount to the band-gap energy it is necessary to augment the electric field strength.

A schematic diagram of functional dependences is shown in Fig. 3.

As we perform the calculations of the punch voltage within the bounds of equivalent pressure theory, whose working out was based on a large quantity of facts and theory, to make a clear explanation of U_{ign} rise in the left branch we can make use of some data from [8].

When the inter-electrode distance enlarges, provided that the product *pd* and $B_\perp$ – const., remains constant, the equivalent pressure goes up. In that case the increase in d means the decrease in the pressure p, and it brings the increase in ignition U_{ign}.

5. Conclusion

In conclusion we want to emphasize that:

1. To some extend this work can enlarge the experimental data of breakdown process, and digitally alterable inter-electrode distance in the ring plural cell system of Penning's type.
2. It is justified to consider the set of experimental and analytical work results to be useful in elaboration of this sort of magma oscillators.
3. It is significant to note that in 28 discharge cells adjoined to each other and enclosed into a circle, transverse field is recurrent, all the cells run free, and the discharge is balanced. Hence, there is the possibility to enlarge the size of the emitting plasma ring oscillator with n_i number of discharge cells with the general construction principles observance.

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