PECULIARITIES OF SELF-SUSTAINED DISCHARGE IN CLOSED ELECTRON DRIFT ACCELERATOR BASED ON PERMANENT MAGNETS

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PACS: 52.75.-d

INTRODUCTION

Investigation of accelerators with closed electron drift is a subject of extensive research [1]. However, for their half-century history these accelerators were mostly used for propulsion. That's why majority of investigations was directed to achieving maximum possible velocities of plasma flux and attaining gas economy of accelerator.

In the last years the interest to treatment of surfaces of hard materials by plasma fluxes with moderate energies has grown up very much [2]. Those are used in a number of electronic and optical devices. Plasma flux modifies the surface prior to deposition of functional coatings onto it, and improves their adhesion, strength, electrical and chemical properties. Such tendency has led to changes in a number of requirements to the accelerators. The first place was taken by homogeneity of surface treatment, absence of incandescent elements in the system, servicing simplicity. It, in turn, led to the necessity of reconsidering a set of statements used in design of accelerators. Besides, switching to new operation regimes surely influences dynamics of discharge glowing in the systems of such kind.

In experiments described in [3,4] it is shown that it is reasonable to inlet working gas not through the accelerator cathode or anode (classic option), but immediately into vacuum chamber. In that case cleaning rate increases approximately twice, and working pressure shifts towards the range of higher values. For this reason, in modernized configuration of accelerator exactly such system of gas inlet was used.

Described accelerator provides high surface cleaning rates at a level of 1 nm/s in narrow pressure range near $9 \cdot 10^{-4}$ Torr. At pressures higher than $1,2 \cdot 10^{-3}$ Torr cleaning is replaced by deposition.

Obviously, clarifying physical nature of such behavior of accelerator is a base for its further modernization.

In the present work peculiarities of self-sustained discharge in crossed ExH field on permanent magnets with closed electron drift are studied. The cases of discharge glowing onto closely placed conductive and dielectric collectors are researched, as well as that onto remote metal collector. Dependencies of discharge current on pressure in the system for various conditions of discharge glowing are presented.

RESULTS OF EXPERIMENTS

The experiments were conducted at setup described in [3] in configuration described in [4]. Width of accelerator channel is 1 cm. Since the system was intended for technological purposes, for making it simpler and cheaper its single-stage version with the use of permanent magnets was developed. The same reason served as a base for rejection of forced space charge compensation of ion beam. The accelerator cathode was grounded, and constant voltage of 900 V value was supplied to the anode. Argon is used as plasma forming gas.

As it was shown by previous investigations, two factors may lead to described behavior of accelerator. The first of those is, that floating potential of target placed at 6-50 cm distance from the accelerator increases very much in pressure range above 10^{-3} Torr. The potential increases from 300 up to 800 V. It surely results in retarding ion beam and lowering sputtering coefficient. At second, in that pressure range arch-shaped luminescence occurs at front side of accelerator, and at further pressure growth this luminescence fills the whole vacuum chamber volume. It gives evidence to ignition of stray discharge, which results in intensive sputtering of accelerator jaws and structural elements of vacuum chamber.

With an aim mentioned above it should be determined, what is the origin – stray discharge ignition leads to the beam decompensation, or vice versa, the beam decompensation results in stray discharge ignition.

Let us consider at first stray discharge. As it was shown by more detailed researches, actually three types of stray discharge exist. This subdivision is due to magnetic field structure near metal pole of magnetic core. Fig. 1 exhibits schematically the cross section of accelerator channel with polepieces. Magnetic field lines may be closed between them on two directions – A and B. There also exists separatrix C – magnetic field line going to the infinity. Main discharge is glowing in «O» zone.

The ways of suppression of stray discharges in the devices with crossed fields are well known. For that purpose one should install metal shield under floating potential near the surface, which the discharge is glowing onto, or to cover the surface by dielectric. In our case the first stray discharge was suppressed by metal shield, and the second and the third ones were suppressed by dielectrics. By subsequent adding of those elements, it is easy to determine thresholds of discharge ignitions and their relative contributions to the discharge current.

The lowest ignition threshold (in pressure) is possessed by the first stray discharge (about $7 \cdot 10^{-4}$ Torr). It glows in zone I (see Fig.1). Current value for this discharge is of same order of magnitude, as that for main discharge (see Fig.2). Magnetic field value near the surface of polepieces at C line is about 150 Oe. It complicates coming of electrons from zone I to zone II. For that reason threshold of second stray discharge ignition appears to be somewhat higher ($1\text{-}1,2 \cdot 10^{-3}$ Torr).

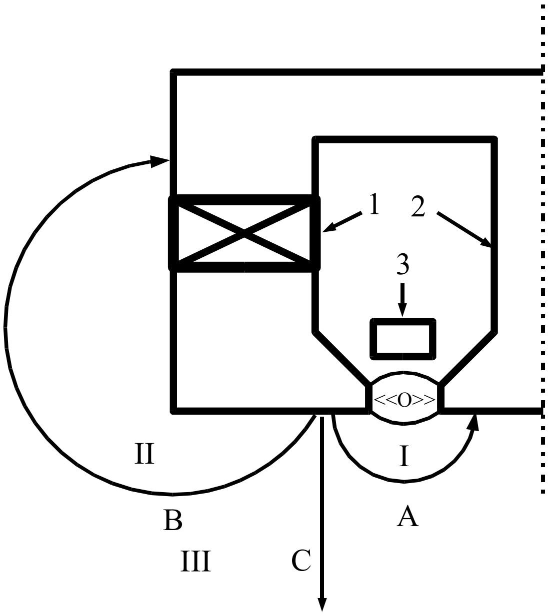

Fig.1. The Scheme of accelerator cross section with magnetic field structure and zones of stray discharges: 1- permanent magnets, 2- magnetic circuit, 3- anode; A, B, C – magnetic field lines; I, II, III- zones of stray discharge glowing

Its cathode is represented by zone of polepieces placed behind separatrix C. Contribution of this discharge to the whole discharge current is small – about 10%. Finally, at pressure $1{,}4\text{-}1{,}6\cdot 10^{-3}$ Torr the third stray discharge is ignited with cathode represented by the discharge chamber walls. Current of this discharge depends essentially on distance between the target and the accelerator, which in turn defines the cathode square for this discharge. Its contribution to overall discharge current may vary from 10 up to 80%. It is easy to see that ignition thresholds for all these discharges are close enough, or even overlapped. It is due to fact that in mentioned pressure range floating potential grows up rapidly.

Fig.3 shows the dependencies of metal target floating potential. Curve 1 corresponds to conditions, when no steps are taken for suppression of stray discharges. Curve 2 corresponds to conditions, when all stray discharges are suppressed. In both cases in pressure range above $8\text{-}10\cdot 10^{-4}$ Torr rapid growth of floating potential is observed. It gives evidence to fact that the origin of processes occurring in this pressure range consists in the growth of space potential. On one hand, it results in ion beam deceleration, and on the other hand– to ignition of stray discharges. Draw an attention that floating potential for pressure range $1\text{-}9\cdot 10^{-4}$ Torr is somewhat less, if arch-shaped discharge exists. It gives evidence to fact that this discharge partially supplies electrons to ion beam zone. Basically, there is nothing strange, if ion beam leaves the accelerator in decompensated state. It is put in the nature of accelerator with anode layer [4]. More surprising is fact that in pressure range below 10^{-3} Torr partial compensation takes place. Arch-shaped discharge supplies just a portion of electrons to the beam. It is currently unknown, where the rest portion of electrons is taken from. Studying this issue

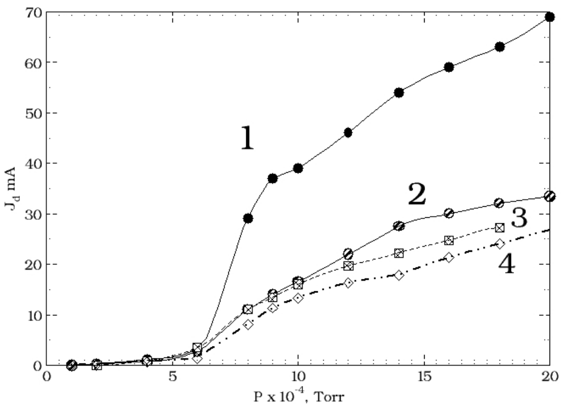

Fig.2. Dependencies of discharge current on pressure: 1- stray discharges are not suppressed; 2- the first stray discharge is suppressed; 3- the first and the second stray discharges are suppressed; 4- all stray discharges are suppressed

requires additional investigation.

Let us consider the nature of stray discharge ignition. Purely hypothetically, one can assume that glow discharge is ignited in the volume. However, simple calculations show that for existing cathode material and working gas pressure range the distance between anode and cathode should be a few meters, what is unreal. Another possibility is self-sustained arch-shaped discharge in crossed magnetic and electric fields. Indeed, magnetic field strength at front side of accelerator is high enough and, as shown by estimations, is able to provide about ten turns of electrons before its coming to cathode. For verification of this assumption main discharge was turned off. Auxiliary electrode was installed near accelerator front side in arch-shaped discharge zone, and potential of about 1000 V was applied to that electrode. This verification has shown that arch-shaped discharge is not self-sustained one.

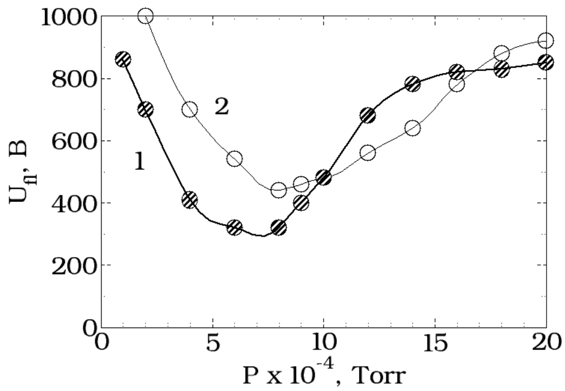

Fig. 3. Dependencies of target floating potential on pressure in the system. Curve 1 corresponds to conditions, when no steps are taken for stray discharge suppression. Curve 2 corresponds to conditions, when all stray discharges are suppressed

Finally, the possibility of non-self-sustained discharge ignition exists in this region. It is readily to understand its nature, if we recall classic equation for breakdown in the gas $\gamma(e^{\alpha d}-1)\geq 1$, where γ is coefficient of secondary ion-electron emission from the cathode, α is electron multiplication coefficient in a gas, d is effective distance between electrodes. Usually γ value is $10^{-2} – 10^{-3}$. It requires large values for $e^{\alpha d}$ about 100-1000. Such necessity disappears when we have non-self-sustained discharge. Let us imagine model task, in which quasi-neutral plasma flux flows into the gap between two plates with potential difference applied to them. If electric field strength is high enough, and electron free path is small enough, it is not difficult to reach $e^{\alpha d}$ values at a level of 2-5 instead of hundred or thousand. In this case we get the discharge current growth by factor of 3-6, which exactly is observed in the experiment.

CONCLUSIONS

Thus, in the present proceeding it is shown that:

1. Non-monotonous character of cleaning rate dependence on pressure for single-stage AAL is determined, first of all, by the growth of space charge potential in high pressure range. Although sputtering of accelerator channel walls is present, this effect is second-order one.

2. Besides main discharge, which glows in zone of maximum magnetic field, three more non-self-sustained discharges are present in the system, that distort the discharge characteristics. Presence of those discharges results in undesirable sputtering of technological surfaces of device and unreasonable increase of consumed power.

ACKNOWLEDGEMENTS

This work is supported by STCU grant #1596.

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