INFLUENCE OF NEAR-ELECTRODE EFFECTS ON THE MECHANISMS OF GENERATING THE CHARGED PARTICLE BEAMS AND PLASMA FLUXES IN A PLASMA FOCUS DISCHARGE

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The systems of "Plasma Focus" -Type (PF) are known as the intense sources of various radiations among which the charged particle beams and the high power plasma fluxes occupy a noticeable place. Along with a purely-fundamental interest to the studies in this field, an optimization of such radiation can be of importance for a whole number of practical applications, for those, in particular, related to the surface treatment, simulation of astrophysical processes etc. A characteristic feature of the PF-systems with flat geometry of electrodes (Filippov's type) is the presence of large operating surfaces in the discharge system elements (electrodes, insulator). As shown previously, one can actively control the operating discharge conditions by changing the anode configuration [1], and the processes of working gas sorption and desorption provide an essential effect on the scenario of physical PF-discharge process developments [2]. The production of new experimental data on the near-electrode process effects on the PF-discharge development is a goal of a given study.

The experiments were done at two facilities of the same type (PF-3, W_{max}=2.8 MJ, and PFE, W_{max}=180 kJ) which noticeably differ from each other, first of all, by the stored energies in the power supply sources. This has allowed one to essentially - expand the range of experimental condition respective to the discharge current level, pressure and to the type of a working gas and to perform the studies using various modifications of the central anode part configurations (various anode insertion). The principal experimental circuit-diagram is shown in Fig.1. The main differences in the experimental conditions (along with the discharge system dimensions) are the following: PF-3 - facility, W=500 kJ, central anode insertion has a deepening of a cone-like configuration, the distance between the anode plane and the plane of registering the plasma flux, L, is 40 cm; the PFE-facility, W=50 kJ, its central anode insertion has a flat configuration (copper, tantalum), L=30 cm. For studying the dynamics of plasma fluxes a speedy photography of a plasma current sheath (PCS) at the stage of its conversion to the axis, slit scanning of a plasma flux image at a considerable distance from the dense pinch region, at the slit orientation along the system axis, as well as in parallel to the anode plane, and the detectors of light radiation were used. The last ones are collimators collecting the light radiation from a narrow discharge chamber region (with averaging over the chamber diameter). The collected light is applied to the light guide entrance and, then, to the photocathode of a photomultiplier. The spatial resolution of a few millimeters is attained by the careful collimation that allows one to measure an average plasma flux rate, V_{av}, at the known path length. An instant of the emergence of the signal related with the light guide luminosity under an effect of hard X-ray radiation and/or with the working gas ionization by soft X-ray radiation of PF at the stage of a maximal PCS compression at the axis was used as a bench mark for counting the time. The usage of two light probes, spread at the distance $\Delta l \ll L$, allows one to determine an "instantaneous" velocity, V_{in}, at the point of observation. Usually, the measurement of the time differences in the signals from two light probes, spread at the distance Δl = 3 cm, when L = 30-40 cm, was used for determining the instantaneous velocity.

A comparative analysis of the results of studying the parameters of plasma flux generated in a PF-discharge under of the PCS-collapse at the system axis - made at two facilities - has shown that an average plasma flux rate at the path length of 30-40 cm in optimal discharges attains an approximately - the same magnitude (~10^7cm/s) in spite of a considerable difference in the power supply and in the masses of the used gases (Ar, Ne, D_2). An example of oscillograms from light detectors is given in Fig.2.

A given circumstance shows the hydrodynamical mechanism of the flux generation, related with the current sheath compression rate towards the axis, not with the thermal plasma expansion of the compressed pinch. As known, at the optimally - matched parameters of the power supply source, gas pressure and of the discharge system geometry, the PCS - compression rate at the instant of a collapse at the system axis attains a few units times 10^7cm/s. In our experiments it has been confirmed that such a compression rate takes place independently of a gas variety and a discharge current magnitude (given statement is not spread to the so-called operating conditions with a "current sheath runaway" [3], when a fast collapse of the discharge current occurs without mass compression). At the same time, a specific feature of the PF-system is a non-cylindrical PCS-configuration at the stage of compression. This results in the cumulative effect of the plasma expulsion from the compression zone under which the radial PCS-compression rate is transformed into the longitudinal plasma flux velocity which usually exceeds the compression rate, dependent on the profile of a converging PCS. An analysis of the plasma blob configuration confirms the proposed assumption: transversal flux dimensions are 7-10 cm at the distance of about 40 cm from the anode, hence the transversal plasma ion velocity (provided by the very thermal blob expansion) is almost by the order of magnitude lower than the longitudinal velocity. The photograph of a slit scanning for the plasma blob image produced at PF-3 in the neon discharge, at the slit orientation parallel to the anode plane, is given in Fig.3.

Thus it becomes evident that the plasma flux parameters should essentially depend on the converging PCS-profile which, in its turn, can be effectively controlled, changing the central anode insertion profile and a variety of working gas [1]. The experimental facilities used in a given study were optimized for various operating condition those of PF-3 are characterized by the production of a dense extended pinch, being a high source of soft X-ray radiation [4], meanwhile the PFE-conditions are somewhat opposite to it, they are characterized by the "runaway" of a current sheath. This difference in the operating conditions is noticeably manifested in the experiments on the study of cumulative plasma fluxes.

A high repetition of the results characterizes the PF-3-facility. Its main specific feature is the proximity of an average flux velocity at the path length to the radial PCS-compression rate and to the instantaneous velocity at the point of observation, $(0.5\text{-}1.5)10^7$ cm/s. The observed experimental spread can be related with differences in the compression rates and in the PCS-profile configurations, as well as with different condition for the blob motion along the path length (blob deceleration under interaction with a background plasma and with a neutral gas). In the experiments at PFE-facility (optimized for conditions with a "low" current sheath) an average plasma flux velocity is usually lower - $(0.3\text{-}0.5)10^7$ cm/s. However, the velocities $\geq 10^7$ cm/s observed in this case in a number of discharges (at the lower energy contribution into the discharge by the order of magnitude and with a heavier gas, argon) are, as we believe, the direct evidence of a cumulative plasma flux generation mechanism. It is characteristics that such discharges are usually considered to be "failing" from the viewpoint of developing the conditions with the current sheath “runaway”: probably the dense pinch production occurs simultaneously with a reduction in the accelerated particle beam yield.

At the same time, the very system with flat anode turn out to be preferable for generation of ion and electron beams. In this case the beam parameters are noticeably affected by thermophysical, absorption and by other properties of the anode. The studies realized at PFE on the beam parameter optimization have shown that the best results are attained with a flat tantalum insertion. The dynamics of near-electrode processes in this case results in a more effective discharge current contraction at the chamber axis. As a result in the discharges with the tantalum insertion the hard X-ray intensity rises, and the absorption property use a tantalum anode allows one to produce considerable neutron yields after preliminary anode saturation with deuterium [2]. In this case, argon is used as the main working gas that alleviates the achievement of matching between the discharge chamber and the power supply source and allows one to optimize the total PCS-dynamics. The study of the dynamics of a working gas composition and its effect on the subsequent discharge (discharge “prehistory”) were done with the mass spectrometer MX-7304 in the process of a attaining the conditions with the X-ray and neutron radiation generation (chamber “training”) and under conditions of their intense generation. It has been shown that an intense adsorption of deuterium at its puffing into the discharge chamber is observed, when the Ta-insertion is used. In that experimental run, in the subsequent operation with argon, a small amount of deuterium was registered in the working gas composition (at the level of a few percent). At the same time, as noted above, a rather intense neutron radiation is registered in the discharges, that is explained by us by accelerating processes upon the central anode insertion surface: neutron radiation emerges under interaction of the deuterons accelerated in the near-anode zone with the deuterium absorbed in the cathode part of the discharge chamber [2]. Implementation of the cathode unit with a replaceable central limiter (position 7 in Fig.1) has shown that the accelerated deuterons have a rather wide angular distribution: neutron radiation retained at a rather high level, when the central part of the cathode limiter, 12.5 cm in diameter, is replaced by a new one, not-saturated with deuterium. At the same time, the neutron radiation is practically not registered, when the tantalum anode insertion is replaced by a copper one. An insignificant presence of deuterium, observed in this case in the discharge chamber, is probably related with its desorption from the insulator surface. In spite of a relatively - low neutron yield (~10^8 n) in comparison with the yield produced in the traditional discharges with pure deuterium (~10^9-10^{10} n), this technique of neutron generation can have a number of the advantages related with an opportunity to produce considerably higher fluences (cathode of the system is a neutron source, in its direct vicinity one can place the samples for irradiation).

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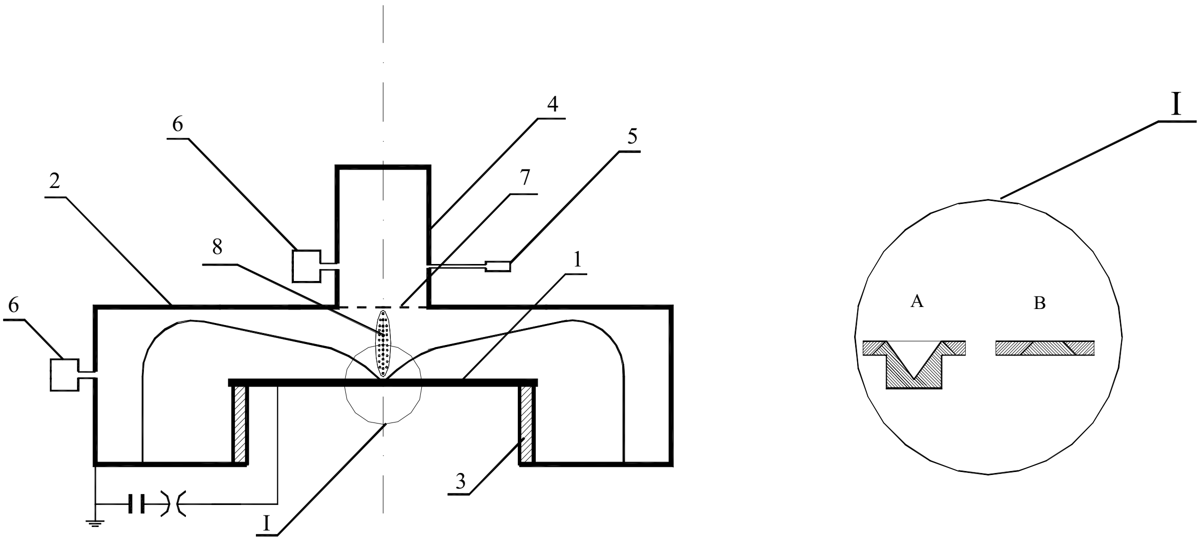

Fig. 1. *Principal circuit-diagram of the experiment.*
1 - anode; 2 - cathode; 3 - insulator; 4 - cylindrical extension on the vacuum chamber (drift tube); 5 - light detector; 6 - streak-camera; 7 - replaceable central limiter; 8 - plasma jet; A - anode insertion with a deepening of a cone-like configuration; B - flat anode

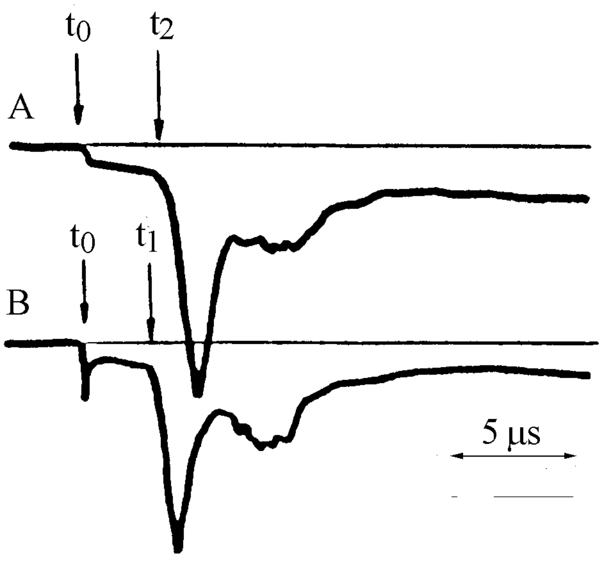

Fig. 2. *Oscillograms from light detectors:*
A - L = 41 cm, B - L = 38 cm;
t_0 is an instant of pinch phase (an instant of plasma jet generation). PF-3 facility, Ne 1 Torr,
V_{av} = 1.3 10^7 cm/s, V_{in} = 8 10^6 cm/s.

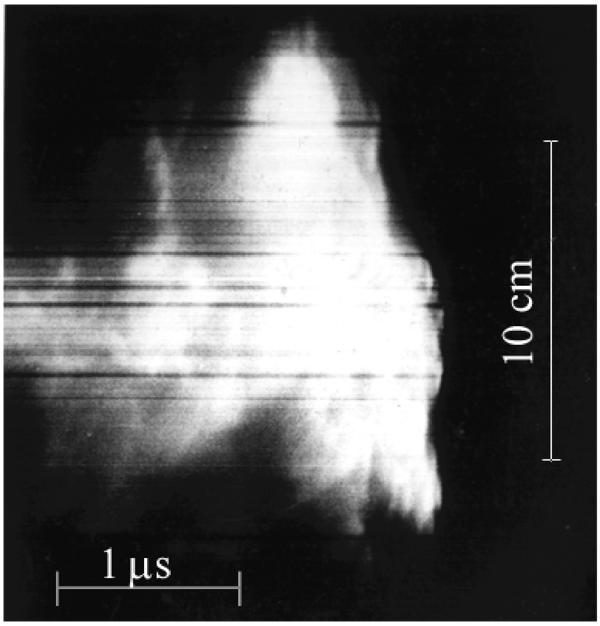

Fig. 3. *Slit scanning of a plasma flux image at L = 38 cm. PF-3 facility, Ne 1 Torr, slit orientation is parallel to the anode plane.*