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STUDIES OF DYNAMICS AND STRUCTURE OF CURRENT SHEATH ON PLASMA FOCUS FACILITY PF-3

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One of attractive features of the plasma focus (PF) systems is a strong dependence of a radiation yield on a pinch current. In particular, summarizing the experimental data obtained on various PF facilities at power supply energy, W, from several kJ up to hundreds, gives the neutron scaling (by different estimations) $N \sim I^{3.3 \div 5}$. However, at transition to the experiments with large ($W \geq 1$ MJ) machines the "saturation" of neutrons yield that at the level $\sim 10^{11}$-10^{12} neutrons/pulse is observed. The possible reason of that may be a shunting of the pinch current by the residual plasma on the periphery of the discharge. The measurements of the current distribution performed earlier [1] have shown that the part of the discharge current may remain nearby the insulator, forming closed loops, and do not participate in the compression process. The aim of this work was the studies of the current distribution and the plasma-current sheath (PCS) dynamics on the Filippov-type PF-3 facility.

The absolutely calibrated magnetic probes [2] have been designed for the measurements of the PCS parameters. The probes consist of two small coils (300-900 μm in diameter), wound in the different directions and packed in the common screen from thin (less than the skin-depth) NbTi-foil. It provided obtaining two signals with different polarity that allowed to pick out unequivocally a "magnetic" component of the signal on the background of electromagnetic noise. Last circumstance gets the special importance at measurements close to the axis. In this case the destruction of the probe usually takes place and symmetry of the signals is the basic criterion of the obtained results reliability. Each probe measures a derivative of an azimuthal magnetic field in a point of the probe arrangement. For obtaining the value of the current the numerical integration of the probe signal was applied in the assumption of symmetry of the current-carrying plasma relative to the facility axis. The measurements with simultaneous use of three probes located at radii r = 460 mm (R1), r =160 mm (R2) and r = 20 mm (R3) from the system axis were carried out. The experiments were performed at the power supply energy W = 290 kJ with argon and neon as working gases at the pressure of 1.5 Torr. The scheme of the experiments is shown on Fig. 1.

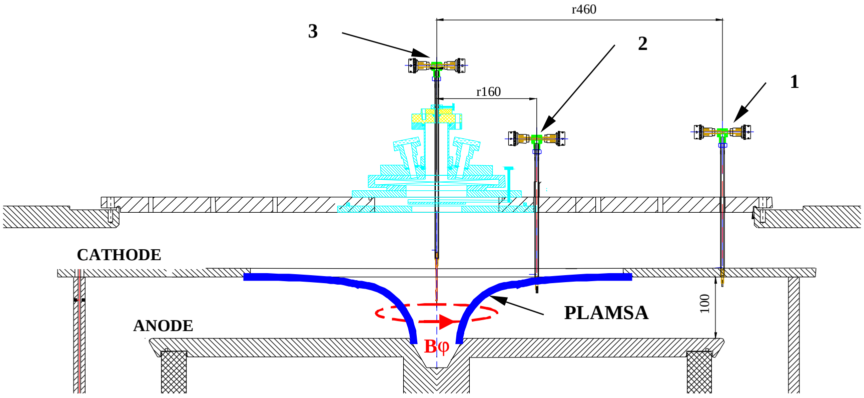

Fig. 1. The configuration of probes arrangement in the PF-3 chamber. 1, 2, 3 **-** probes for the magnetic field measurements located at radii 460 mm, 160 mm and 20 mm correspondingly.

The axis probe was located at the distance 10-20 mm above the anode plane. In a combination with a conic insert in the center of anode (see Fig. 1) it provided the probe protection from a premature breakdown from the high-voltage anode to the probe. Usually such breakdown occurred through some hundreds nanoseconds after PCS passage. It allowed to register the signal, corresponding to current flowing close to the axis. For checking the probe position towards the pinch and symmetry of plasma sheath convergence photographing of the final stages of compression with the help of 4-frame cameras was used.

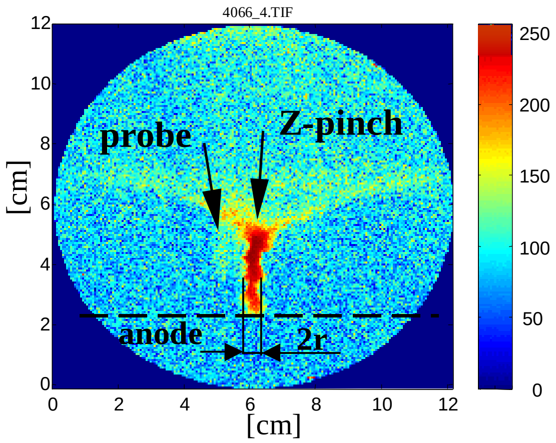

Fig. 2. The optic frame image of the pinch and the probe. Time exposition of the frame is 12 ns.

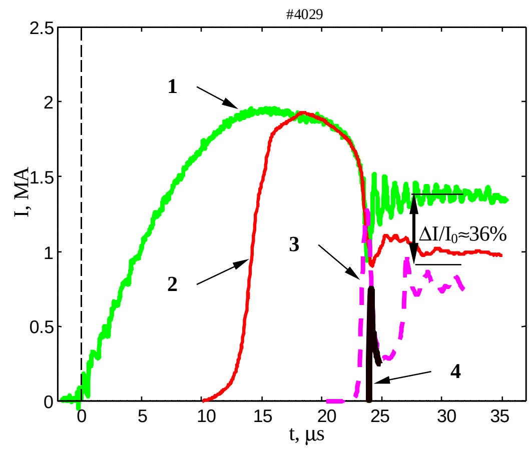

Fig. 3. The results of current measurements at the discharge in argon: 1 - total current; 2, 3, 4, - the currents measured by probes at radii r=460 mm, r=160 mm and r=20 mm accordingly.

In Fig. 2 the pinch image at the stage of the maximal compression is presented. It is important that the pinch does not “bind" to the probe and forms at the system axis. Fig. 3 shows the results of the current measurements at the discharge in argon. It is obtained that in the process of the PCS compression to the axis the current derivative increases from $\approx 0.9 \cdot 10^{12}$ A/s (at r=460 mm) up to $\approx 3 \cdot 10^{12}$ A/s (at r=160 mm). At the final stage of the PCS compression (at r=20 mm) current derivative reaches $\approx 1.5 \cdot 10^{13}$ A/s. The reduction of the plasma skin-depth from (6±1) cm at r=460 mm up to (3±1) cm inside the radius < 160 mm is simultaneously observed. At the final stage of compression (inside the zone with r=20 mm) the skin-depth can be less than 1 cm.

The experiments in argon have shown a good efficiency of the current transferring to the axis. The amplitude of the current registered by the probes R1 and R2 corresponds to the total discharge current and the probe signals trace well the dynamics of the current decreasing caused by the sharp increase of the discharge loop inductance as a result of plasma sheath compression to the axis. Inside zone with r = 20 mm the maximal measured current attained is 0.8 MA, that makes up approximately 88 % from the total current. After "peculiarity" current decrease inside the zones with r = 460 mm, r = 160 mm and r = 20 mm is registered in comparison with the total discharge current. Especially brightly this decrease is expressed on the signals from the probes close to the axis. Obviously, it is caused by secondary breakdown with the formation of the shunting current sheaths both in the area between the probes R1 and R2 and in the area close to the discharge system insulator. Then the current registered by the probe R2 grows up to the value close to that measured by the probe R1. It is testified about shunting plasma sheath arrival to the place of the probe R2 disposition. However the part of the current continues to flow nearby the insulator. Unfortunately, we could not check the further evolution of the current near the axis because of axial probe R3 destruction. But such late moments of the time do not to exert influence on the processes in the dense pinch at the stage of its maximal compression. It is much more essential that, at the discharge in argon, it is possible to collect a significant part of the total discharge current to the axis at the moment of the dense pinch formation. Also it is necessary to take into account the fact that the probe R3 is located at height of 10-20 mm above the anode surface. Because of non-cylindrical character of PCS the non-simultaneous compression along the axis takes place. The sheath comes to the area of the probe R3 position after "peculiarity" on the total current derivative when the part of the current can be transferred in the shunting channels. Thus, it is possible to assume that the higher values of the current - close to the total current in the discharge circuit - can be attained in the pinch.

Another situation is observed in the experiments with neon. At r=460 mm only ≈75 % (≈1.3 MA) from the total current is registered at the moment of its maximum value (Fig.4a).

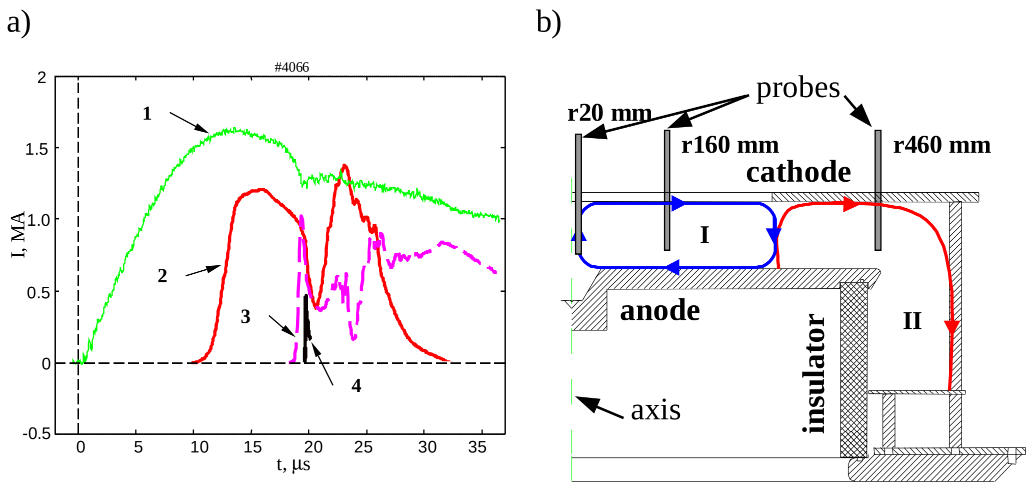

Fig. 4. The results of current measurements at the discharge with neon (a) and the scheme of the closed current loops formation (b). 1 - total current measured by Rogowsky coil; 2,3,4 - the currents measured by the probes at radii 460 mm, 160 mm and 20 mm accordingly.

It means that part of the current does not leave the area of the insulator from the very beginning. After pinching, as well as in the experiments with argon, the current decrease inside the radii r = 460 mm and r = 160 mm is observed. Then the current inside r = 460 mm starts to grow and reaches about the total current through ≈2.5 μs. At the same time the current inside r = 160 mm continues to fall, and then accrues up to value, greater than registered by the probe R1, and, sometimes, more than the total discharge current. The similar result has been received at the measurements with the little Rogowsky coils, built in one of the rods of the return conductor. This can be explained if we assume that the probes R1 and R2 register the currents in the different current loops (Fig. 4b).

Thus, it is shown, that the efficiency of the current transfer to the axis essentially depends on the discharge conditions. Under certain conditions the significant part of the current can remain at the insulator area and does not participate in the pinch formation. The knowledge of the current flowing directly through the pinch is the necessary condition at the analysis of the observable scaling laws.

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