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On the current layer in the run-down phase of the plasma focus discharge

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Abstract. In the experiments with the 3 kJ plasma focus device in the Sofia University are measured the basic characteristics, namely the discharge current, the current derivative, the soft X-ray and the hard X-ray emission from the plasma. By a set of magnetic probes the velocity of the current sheath during the run-down axial phase is determined. In the last two thirds of the axial phase the current layer velocity is a constant.

1. Introduction

Despite the considerable period of study of the plasma focus (PF) discharge, there is still an interest towards this phenomenon due to the unresolved problems of the discharge dynamics and the resources for different applications of the PF machines.

In the Faculty of Physics at the University of Sofia a Mather's type dense plasma focus device (DPF) is in regular operation for about one and a half years.

The aim of this work is to present the results of the measurements of basic discharge characteristics of this discharge with an emphasis of the current layer during the axial phase.

It is well known that the evolution of the PF discharge consists of several phases: breakdown, axial run-down (in the Mather type PF systems), radial compression, pinch phase followed by expanding and a decay of the hot plasma column. After the breakdown and current lift-off from the insulator, a run-down phase takes place. The current sheath observed in this stage is a strong ionizing shock wave, driven by $(\vec{j} \times \vec{B}_\vartheta)$ force (a magnetic piston). Here as usual $\vec{j}$ is the current density and $\vec{B}_\vartheta$ is the induced magnetic field. This current sheath propagates into the neutral gas, scooping up a part of the mass it encounters and ionizing the particles.

One of the conditions for an efficient high energy density pinch is that the plasma layer should be thin, axially symmetrical and uniform, moving with high snow-plow efficiency. Therefore efforts to find the best conditions during this stage are necessary both for an efficient work of the existing devises and for construction of new ones. The variable parameters are geometry of the PF system, type and pressure of the filling gas, charging voltage, etc.

There are several experimental and theoretical works, considering the axial run-down phase [1 - 4]. Although that in principle the existing models describe satisfactory the effects observed, still there are some questions. For example in the work [5] it was shown that the current sheath structure is not homogeneous. It consists of two zones: a first layer with a steep density gradient and a second one associated with the plasma-magnetic field interface. It is not yet clear whether this division exists only in the beginning of the axial phase.

2. Experimental device

The condenser bank has capacitance of 20 μF, with the maximal voltage of 40 kV. The insulator is a quartz tube (2.6 mm in diameter, 30 mm length) the main switch is a vacuum spark gap. The anode is a copper tube with 20 mm diameter and 145 mm length, the cathode consists of 6 copper rods (8 mm diameter, 160 mm length) mounted in the massive cathode bottom on a circle with a radius 35 mm.

A procedure for optimizing the discharge conditions was carried out, changing the charging voltage and the gas pressure. So far the experiments were conducted in air and the nominal pressure is in the range 1.0 ÷ 1.7 mBar. The voltage operating range is chosen to be 15 ÷ 18 kV. We are monitoring the discharge current, (Rogowski belt) the current derivative (pick-up coil), the soft X-ray (PIN diodes) and the hard X-ray emission (scintillator probe) from the plasma. Thermo-luminescent dosimeters (TLD) were used to measure the full X-ray dose in the stainless steel chamber of our DPF and to control the radiation outside the device.

A set of magnetic probes inserted between the anode and one of the cathode rods allow us to determine the velocity of the current sheath, during the run-down phase.

Figure 1 shows schematically the PF electrodes and the set of magnetic probes. Each probe is formed by a twenty-turn, 2 mm diameter coil. The distance between the probes is 1 cm. The probes shown by one color are connected in series. So we have 4 “channels” of probes each one with 4 cm distance between the separate coils. A Pyrex tube with 5 mm external diameter serves as a container of the probes.

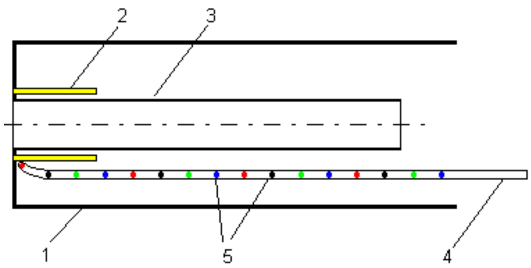

Figure 1. Scheme of the PF electrodes and the Pyrex tube with the set of magnetic probes. 1 – cathode, 2 – insulator, 3 – anode, 4 – Pyrex tube, 5 – probe coils

The data of all of the detectors mentioned above have been recorded by two 4 channel oscilloscopes (TDS 3034C, TDS 2004B).

3. Results and discussions

3.1. Basic measurements

The data, received by the diagnostic tools in the first several hundred shots fired so far, reveal the typical peculiarities known from the literature. The oscilloscope pictures give the moment of the initial breakdown of the gas, followed in a few microseconds by the occurrence of a pinch. A correlation between the observed one or more peaks of soft and hard X-rays and the peculiarities of the dI/dt signal is established, the latter corresponding to the same number of pinches with the same mutual distance in time. Figure 2 presents oscilloscope traces of discharge current, soft and hard X-ray signals.

As it was stated above the optimization of the run-down phase of a specific plasma focus system is necessary in order to obtain high yield of radiation in the pinch phase. Thus the experimental study of this period is required. For this purpose monitoring of the light of the moving layer or magnetic probe measurements are used. An advanced method is visualizing the layer by the Schlieren technique [5].

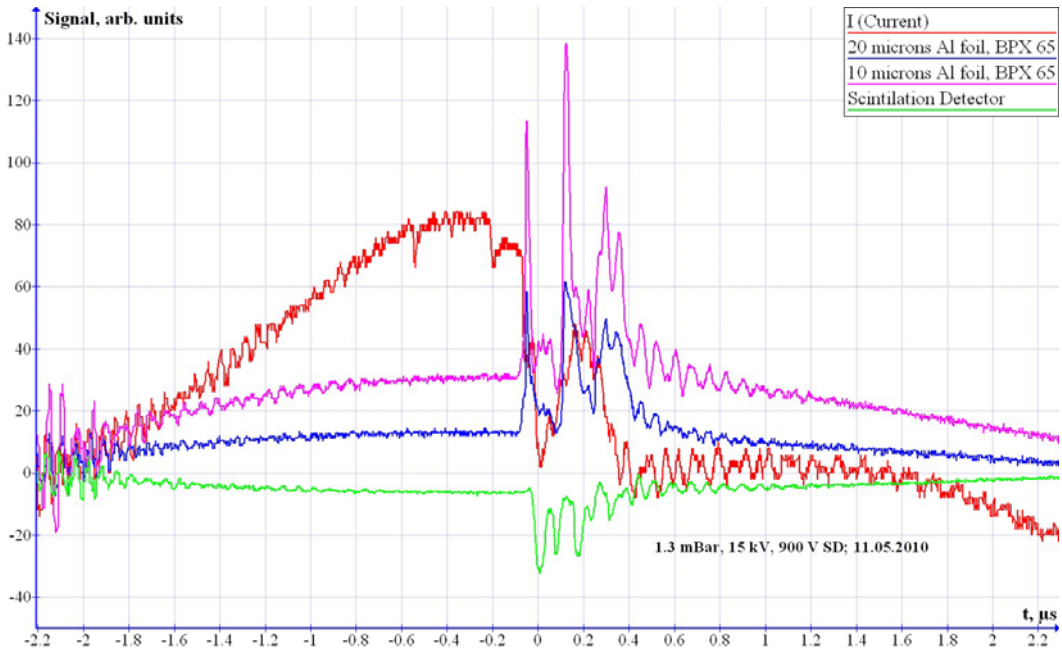

Figure 2. Basic measurements

3.2. Magnetic probe measurements

As it was already mentioned in this work we use a set of magnetic probes shown on figure 1. As output of the set are 4 channels, consisting of connected probes with a distance of 4 cm between the coils.

Figure 3 presents the experimental results derived with this system of probes. Using such system of probes we can determine the velocity and the acceleration of the current sheet as well as it's evolution during the run-down phase in a single shot. It is seen that in the frame of one probe "channel" the intensity of the peaks increases (see for example the behaviour of the red curve). This is due to the current density distribution of the layer [7].

The sharp dips appearing simultaneously for all four channels near 2.8th and 3.2nd microsecond time moments correspond to the electromagnetic signals from the pinch. It is seen also that there are signals from the probes in the second half period of the discharge current too although that no pinch in this case is observed.

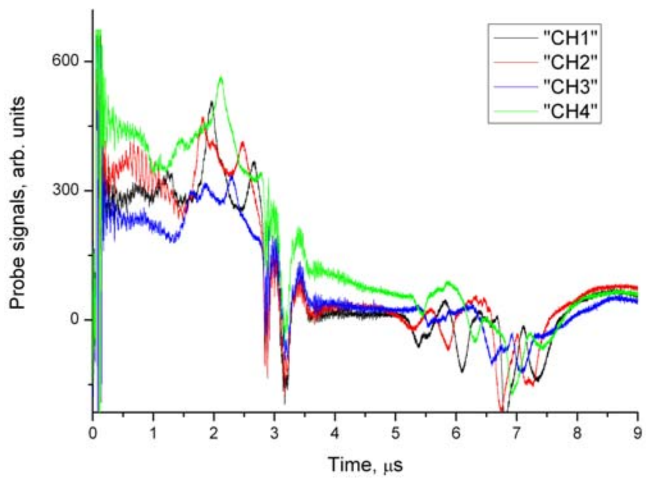

Figure 3. Signals from the magnetic probe system for single shot.

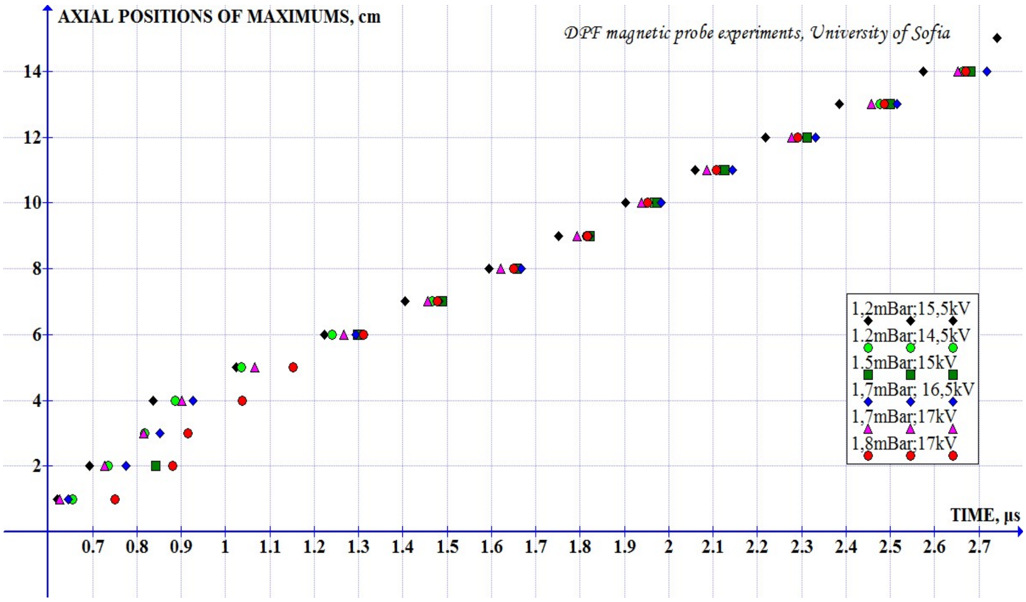

Figure 4. Axial positions of the maximums of the signal of magnetic probe set.

Figure 4 shows the axial positions of the probe peak maximums versus the time scale of the discharge evolution. The points at the (start) beginning of the acceleration phase are determined with a considerable error. Nevertheless after about 1 microsecond from the beginning of the discharge equilibrium of the forces, controlling the current layer is established. It seems that the driving magnetic piston is balanced by the resistance of the compressed gas. That leads to constant velocity of the current layer. I our case between the 1st and 2.8th µs the layer velocity is constant. The values of the velocity of the current sheath were derived by processing of the data of a number of shots fired at different conditions. Before this time interval according to figure 3 from 700 ns to 1 µs the layer is moving faster. Quite interesting is the period before 700 ns but it is impossible to say something for this time interval with the present probe set. For the purpose a radial set of probes has to be used [8,9]. Subtle details in the behavior of the current sheath can be obtained by a model, however this model should be complete enough in order to describe adequately the operation of the specific device (see for example [3]). Naturally constructing such a model is not a trivial task. In the study [9] Bruzzone et al propose a simple model for the same lift-off stage that is intermediate between the breakdown and the axial phase the PF discharge.

4. Summary

Besides the data for discharge current, current derivative, Soft and hard X-ray, we present values of the velocity of the current sheath in the axial run-down phase. The data, derived from a series of shots at conditions: gas pressure 1 ÷ 2 mbar, charging voltage 14 ÷ 17 kV shows that between 1st and 2.8th µs the current sheet has almost equal constant velocity in range of 5 ÷ 6.7 cm/µs.

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