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DIAGNOSTICS OF PULSED PLASMA IN THE ACCELERATOR IPU-30

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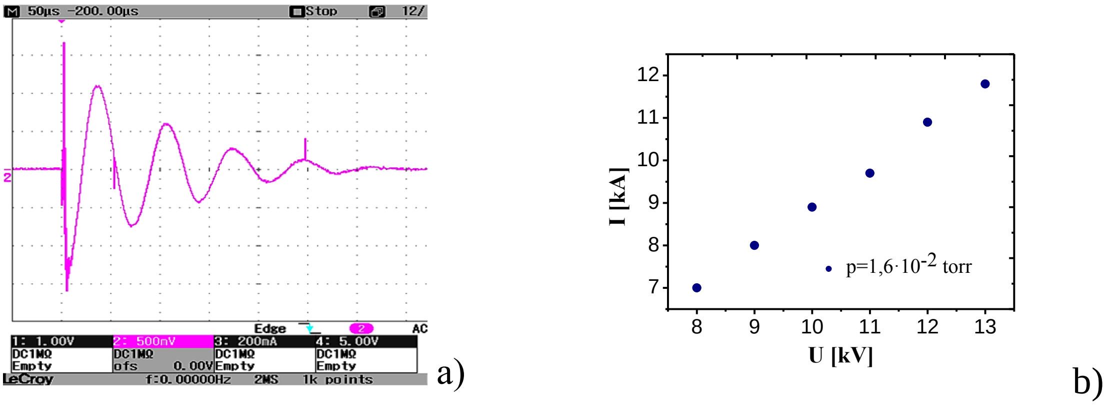
The experimental setup of IPU-30 assembled in the IETP consists of pulsed plasma accelerator, a plasma duct with a length of 1 m, grounding and protection systems, a control panel and diagnostic equipment. The plasma accelerator is powered by the capacitor bank with a total capacity of 100 μF. The operating voltage varies in the range of 5-14 kV. The schematic diagram and operating principle of the experimental setup are described in detail in references /1, 2/.

In this work, the discharge current was measured by using Rogowski belt. The belt of 400 coils is closed to the resistor R = 12 Ohm. The voltage drop in the resistance is measured by the digital oscillograph LeCroy 354A. One example of oscillograms obtained from the belt is shown in Fig. 1a. Figure 1b shows the dependence of the discharge current on the discharge voltage.



a)

b)

Figure 1. a) The oscillogram of the discharge current, b) the dependence of the discharge current on the discharge voltage

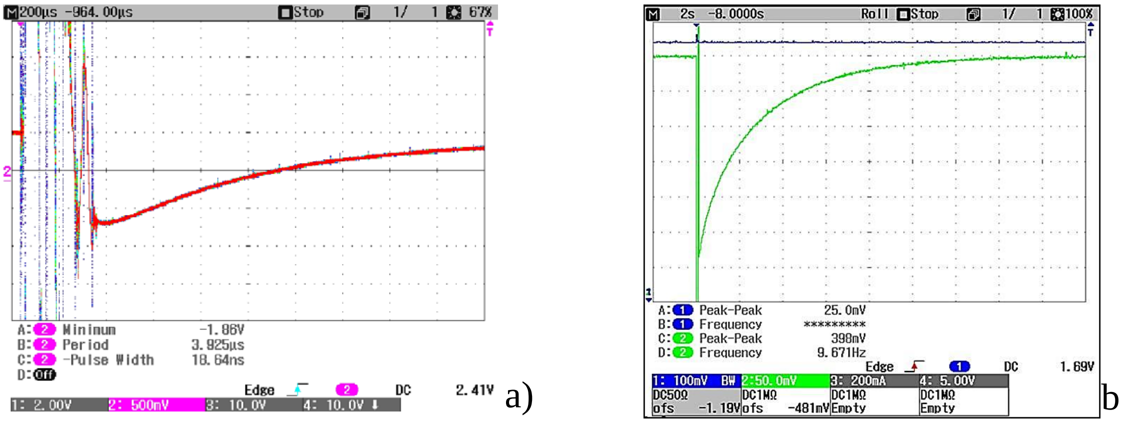
The dependence (Fig. 1b) shows, that when the discharge voltage increases, the electric field between the electrodes increases, which leads to an increase in the ionization process, thereby improving the conductivity of the plasma.

In thermonuclear reactors, the energy density of the plasma flow to the wall after the breakdown of the plasma pinch is several MJ/m^2 /3/. In those conditions the study of the interaction of plasma with protective materials is one of the most urgent problems in thermonuclear research. A wire calorimeter was used to study the energy density of the pulsed plasma flow in the IPU-30. The wire calorimeter is a dielectric frame on which tungsten wires with a diameter of 100 μm are stretched at the same distance of 5 mm. The surface area of the wire is not large, so the wire calorimeter has a high thermal response when interacting with the plasma /2/. In the experiments for the measurement, the wire calorimeter was placed on the path of the plasma flow and covered the entire transverse area of the outer electrode. When a pulsed plasma passes through calorimeter, it gives it energy, the heat is absorbed by the wires, as the result of which, the wires heat up.

The energy density of the plasma flow was calculated by equation 1:

$$Q = \frac{c\rho {S_{\Pi}}^2}{\alpha\rho_0} \cdot \Delta R. \qquad (1)$$

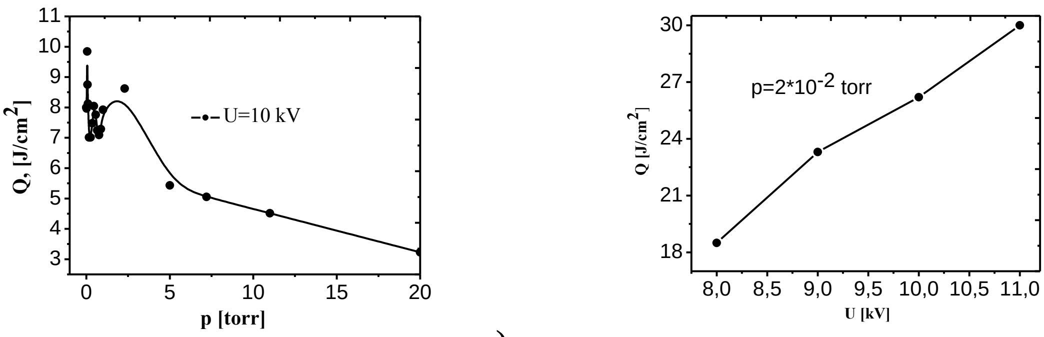
To measure the change in the resistance of the wire calorimeter, it was connected through a shunt to the oscilloscope. In the measurements, we recorded the voltage drop at the shunt of 86 Ohm, the value of which determines the change in the resistance of the wire calorimeter. One of the examples of the oscillograms of the voltage drop on the shunt resistance is shown in Fig. 2. The oscillogram from the calorimeter was divided into two ranges. Range 1 corresponds to Fig. 2a, and range 2 corresponds to Fig. 2b. In Fig. 2a, when the time scale on the oscilloscope is set to 200 μs, one can see the appearance of the oscillation on the curve. The total width of the oscillations corresponds to the lifetime of the pulsed plasma. The difference between Fig. 2b and Fig. 2a, when the time scale on the oscilloscope is set to be long enough, is 2 seconds.



a) b)

Figure 2. The oscillograms obtained from a wire calorimeter

In the range 2, the wire calorimeter operates as a thermal detector, that is, the change in the voltage drop across the shunt resistance occurs only due to the heating of the wires by the plasma flow. And in the range of 1 there are other effects. In our statements, the appearance of oscillation is due to the redistribution of charges in wires. Based on oscillograms, the energy densities of the pulsed plasma were calculated depending on the gas pressure and the discharge voltage. The results are shown in Fig. 3a and 3b.

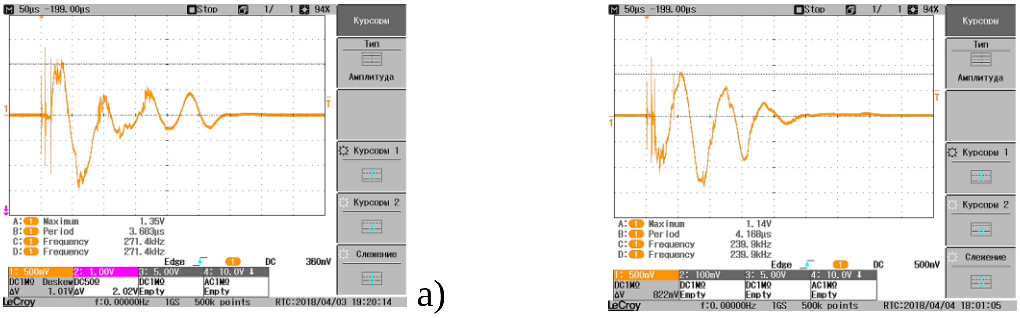


a) b)

Figure 3. Dependences of the energy density of a pulsed plasma a) on the gas pressure and b) on the discharge voltage

The dependence of the energy density of the plasma flow on the gas pressure (Fig. 3a) shows that as the gas pressure increases, the energy density of the plasma flow first increases, then at a certain value of the gas pressure reaches a maximum and decreases with further growth. This behavior of the curve is explained in accordance with Paschen's law. Fig. 3b shows that as the discharge voltage increases, the energy density of the pulsed plasma increases, due to an increase in the ionization energy of the gas.

One interesting phenomenon, the appearance of non-stationary magnetic fields in a pulsed plasma also requires its study. In this work a magnetic probe was used to measure the magnetic field in a pulsed plasma. A magnetic probe consists of 15 coils. The area of the coil section is $7*10^{-6}$ m^2. For measurement, the magnetic probe is connected to the oscilloscope through an integrating circuit. The integration time of the signal is 25 μs. Some of the examples of the oscillograms obtained from the magnetic probe are shown in Fig. 4.



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A: 1 Maximum       1.35V
B: 1 Period        3.683µs
C: 1 Frequency     271.4kHz
D: 1 Frequency     271.4kHz
                    Edge  1  DC    360mV
1: 500mV  2: 1.00V  3: 5.00V  4: 10.0V
DC1MΩ Deskew DC50Ω  DC1MΩ     AC1MΩ
ΔV   1.01V ΔV  2.02V Empty    Empty
LeCroy  f:0.00000Hz  1GS  500k points  RTC:2018/04/03 19:20:14
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a)

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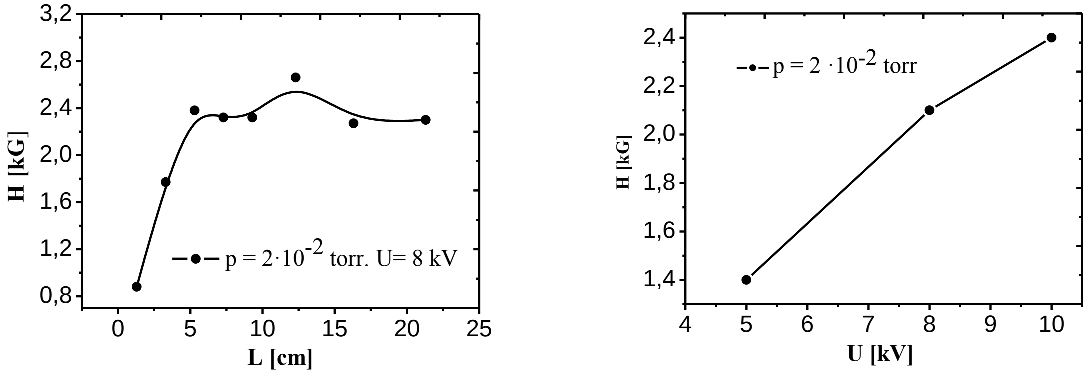
A: 1 Maximum       1.14V
B: 1 Period        4.168µs
C: 1 Frequency     239.9kHz
D: 1 Frequency     239.9kHz
                    Edge  1  DC    500mV
1: 500mV  2: 100mV  3: 5.00V  4: 10.0V
DC1MΩ     DC1MΩ     DC1MΩ     AC1MΩ
ΔV  822mV Empty     Empty     Empty
LeCroy  f:0.00000Hz  1GS  500k points  RTC:2018/04/04 18:01:05
```

b)

Figure 4. The oscillograms obtained from the magnetic probe:
U = 11 kV, p = $2*10^{-2}$ torr, a) magnetic probe in horizontal position, b) magnetic probe in a horizontal position inverted for 180°

To ensure that the magnetic probe is operating correctly, the magnetic probe is located at a fixed distance but in two different positions of the coil. In the first position, the axis of the probe coil was vertically aligned with the electrodes in the interelectrode space, and in the second position, the probe coil was turned upright 180° as in the first position. In this case, we should receive the same signals from the magnetic probe, but the inverse phases, which we obtained in the experiment, are shown in Fig. 4a and 4b.

On the basis of these oscillograms, the values of the magnetic field of the plasma were calculated from the distance in the interelectrode space from the beginning of the end of the outer electrode, Fig. 5a, and from the value of the discharge voltage, Fig. 5b.



a) b)

Figure 5. a) The dependence of the magnetic field of the plasma on the interelectrode distance from the beginning of the end of the outer electrode, b) the dependence of the magnitude of the magnetic field of the plasma on the discharge voltage

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References

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