FORMATION AND DYNAMICS OF THE CURRENT SHEATH IN A METALL-PUFF Z-PINCH IN A MICROSECOND IMPLOSION REGIME

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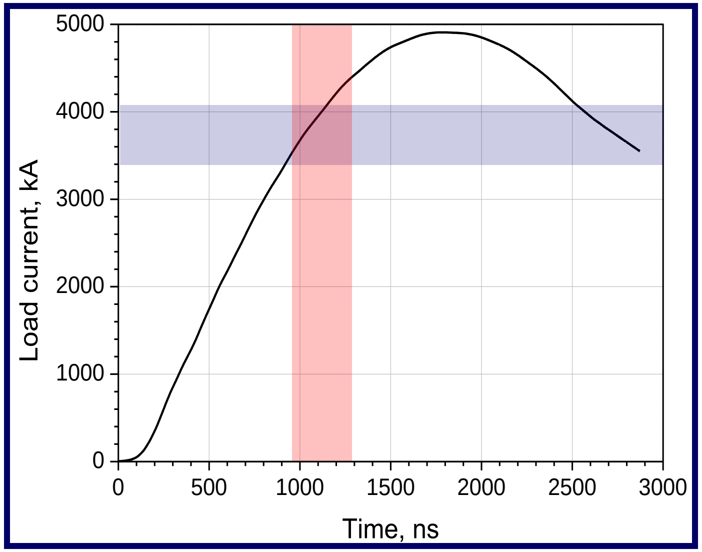
CURRENT SHEATH AND MHD INSTABILITIES

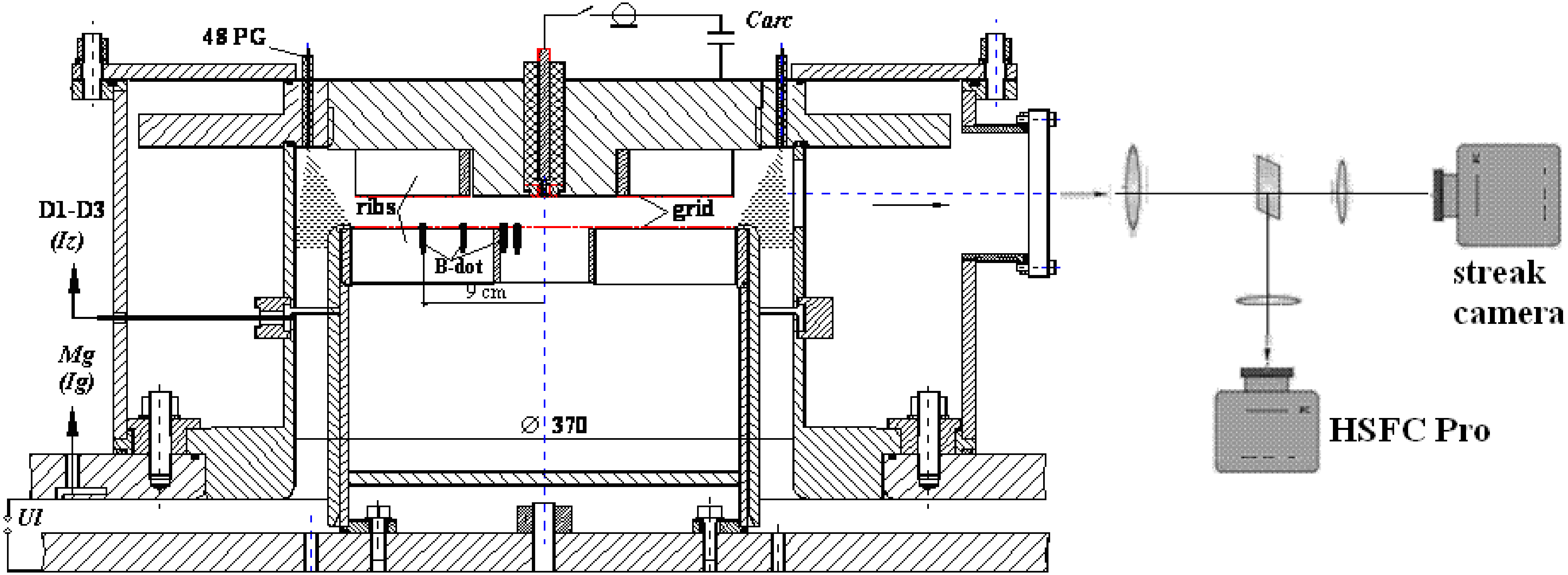
On the GIT-12 generator, experiments were conducted on implosion in the microsecond regime of metal-puffs (MP) at a current amplitude of ~ 3 MA. In this range of parameters, MHD instabilities are possible that arise during the compression of the metal-puff material to the axis, especially at the initial stage of formation of the current sheath at large radii with a reduced density of the substance. To eliminate the causes of the most significant Rayleigh-Taylor instabilities at this stage, the formation of a uniform, well-conducting current sheath (CS) can be especially important. This poster presentation is about the results of a study of the formation and dynamics of the current sheath in a Z-pinch shell formed by an arc discharge plasma in pairs of aluminum vaporized from electrodes.

GENERATOR GIT-12



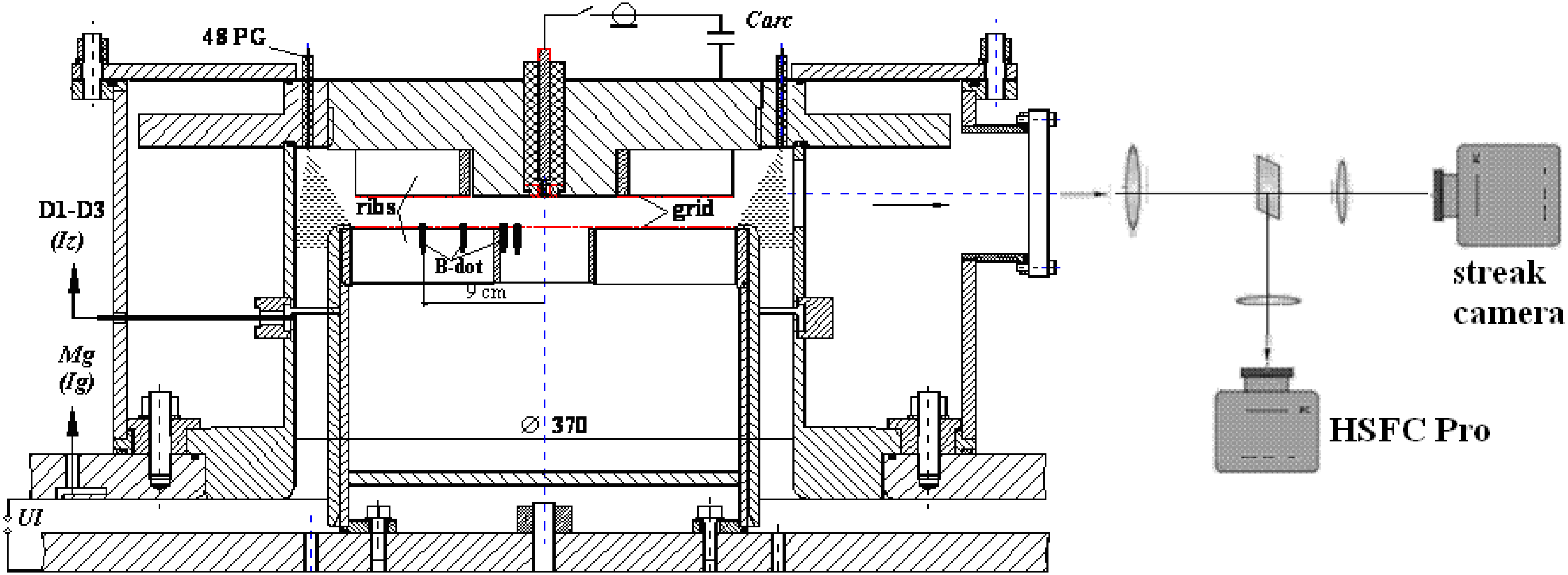
- **IHCE SB RAS, Tomsk**
- **Charging voltage – 50 kV**
- **Stored energy – 2.6 MJ**
- **Operation with POS: 2.5 MA, 250 ns, 20 kA/ns**
- **Operation w/o POS: 4.7 MA, 1.7 ms, 3 kA/ns**
- **In these experiments: mode without the POS was used.**

EXPERIMENTAL LOAD



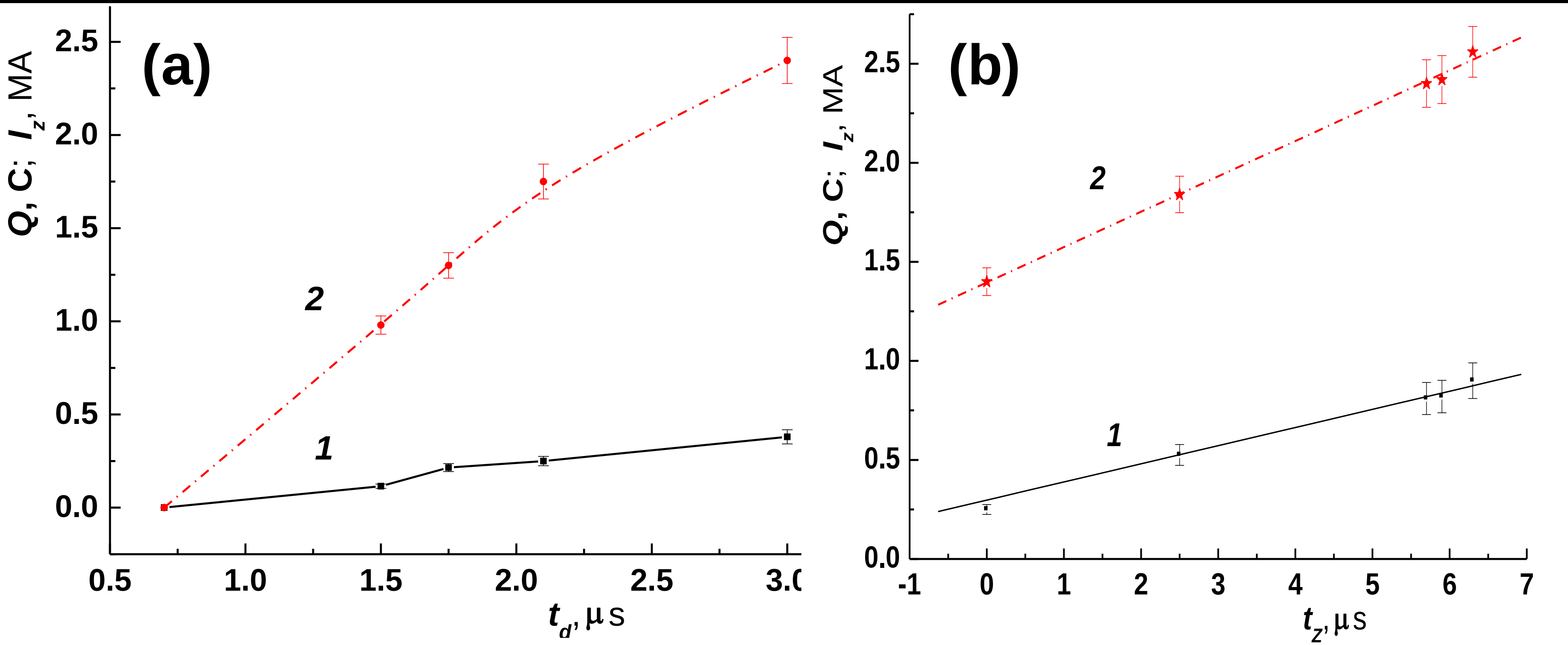
The load unit of the GIT-12 generator is shown schematically. In this configuration, an Al metallic jet of diameter 0.4 cm was surrounded by a cylindrical plasma shell of diameter 35 cm (48 PG). The Al metal-puff was formed by a plasma stream injected by a vacuum arc discharge with aluminum electrodes (U_{arc} = 25 or 35 kV, I_{arc} ~ 100, 130 kA, with a rise time of ~ 8 μs). In the plasma source, a vacuum arc operated between a grounded Al anode and an Al rod cathode 0.4 cm in diameter. The electrodes were separated by a polyethylene insulator. The outer plasma shell was formed by 48 plasma guns arranged in a circle of diameter 35 cm. The guns operated 1.8 μs before the onset of the GIT-12 current, and this made it possible to form an azimuthally symmetric current sheath at a diameter of 32–35 cm.

DIAGNOSTIC SETUP

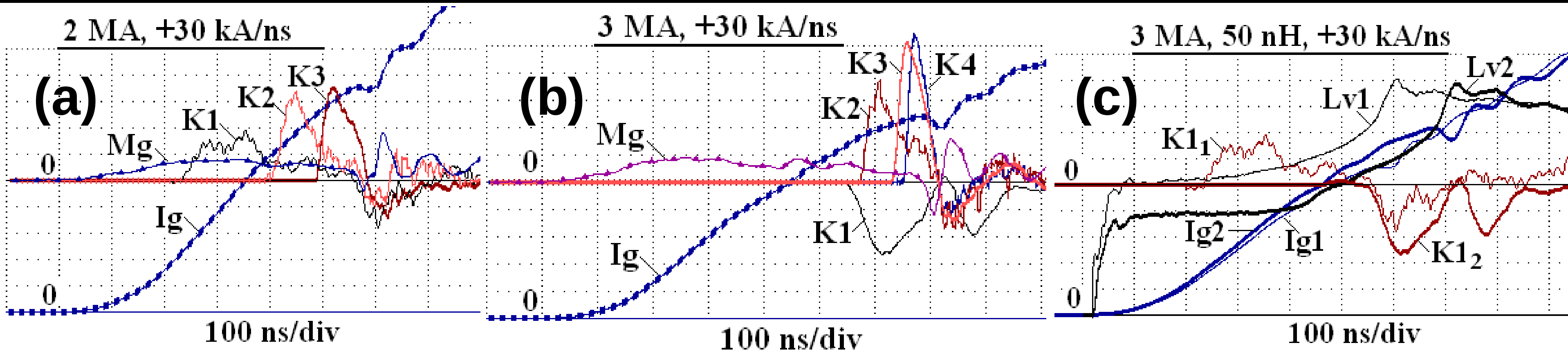


- Inductive grooves were used to measure the shape and amplitude of the current pulse (I_g, I_z and sensors D1-D3 located symmetrically in azimuth through 120°).
- The voltage divider recorded the voltage at the assembly electrode of the GIT-12 central unit.
- To determine the characteristics of the CS used magnetic probes (B-dot). The probes were installed inside the holes in the grid covering the end of the inner cathode electrode at radii of 2, 3, 6, and 9 cm.
- To record the motion of the shell in the optical range, the streak camera and a 4-frame HSFC-Pro camera with exposure time of 3 ns and with an interval between frames of 20 to 60 ns were used.

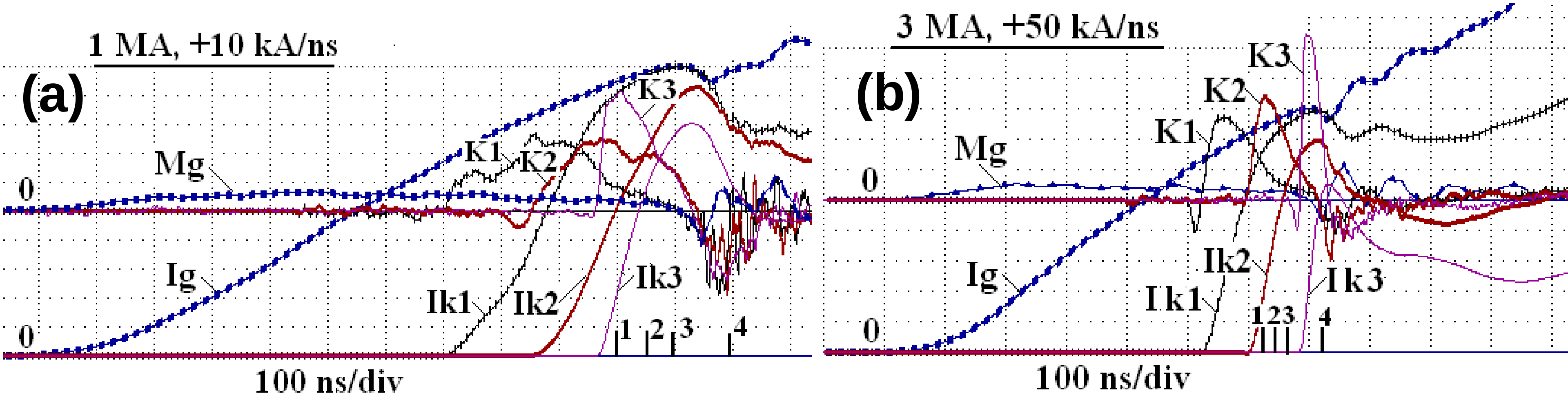
SWITCHING CHARACTERISTICS



The characteristics of the generator were determined when only 48 PG were turned (a) on and MP was working together with 48 PG (b). The outer plasma shell formed by 48 PG at t_d = 1.8 μs switches the current with an amplitude of Ig ~ 1.4 MA (charge Qc ~ 0.21 C, estimated linear mass ~ 5 μg/cm) at the conduction stage. For MP with an outer plasma shell at t_d = 1.8 μs, the switching characteristics for U_{arc} = 25 kV and the main delay of arc plasma injection t_z = 6±0.2 μs are as follows: current amplitude $I_g \cong$ 2.4±0.1 MA, switched charge $Q_c \cong$ 0.85±0.05 C. (1 – charge, 2 – current).

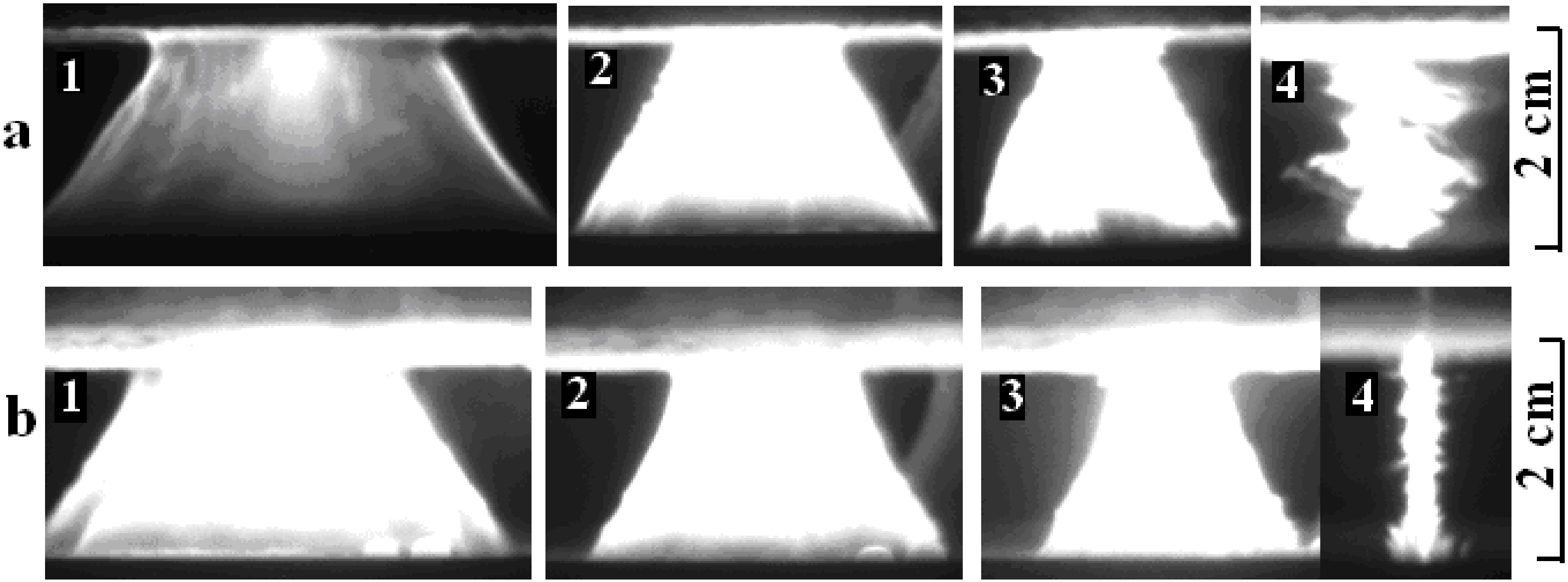


- **Figure shows the signals from B-dot (waveforms K1-K4) and inductive grooves (waveforms Mg) for the regime without 48 PG – (a) and with switching on 48 PG – (b), as well as a comparison of the calculated inductance values of the load unit $L_v(t) = \int UI(t)dt/I_g(t)$ for option (a) (L_{v1}, I_{g1}) and (b) (L_{v2}, I_{g2}) - graphs (c). The initial inductance of the load node without 48 PG exceeds the initial inductance with the connection of 48 PG by ~ 6.5 nH. It can be seen that the signals from the K1 sensor at a diameter of 18 cm in both regimes are recorded at different time instants, but with equal and corresponding to this diameter inductance load unit $L_{v1} = L_{v2} \cong 26.5$ nH.**
- **The use of an outer plasma shell changes the dynamics of the CS. The CS speed is close to constant and amounts to 25-30 cm/μs. The CS thickness decreases from ~ 3.5 cm (K1) to ~ 1.5 cm (K3) with an increase in the average current density in the CS from ~ 10 kA/cm² (K1) to ~ 50 kA/cm² (K3). The value of the speed of motion of the luminous boundary of the shell, determined by optical measurements by the HSFC-Pro camera at radii of 3-1 cm, is 25±5 cm/μs and, as a rule, is slightly lower than the average speed in the area between the K3-K4 sensors at radii 3-2 cm.**



To determine the effect of the initial current growth rate on the dynamics of the CS, shots were fired at the charging voltage of the GIT-12 generator U_0 = 20 kV (U_g = 240 kV), i.e. dI_g/dt reduced by ~ 2.5 times. In figure shows the results of an experiment with the same conditions for t_d = 1.8 μs, t_z = 6.2 μs, and U_{arc} = 25 kV for generator voltages U_0 = 20 kV (a) and U_0 = 50 kV (b). A decrease in voltage by a factor of 2.5 led to a decrease in the current amplitude by a factor of ~ 2.1, an increase in implosion time by a factor of ~ 1.8, while Q_c ~ $I_c t_c$ remained virtually unchanged (a drop of ~ 14%). The CS thickness with a decrease in dI_g/dt by 2.5 times changed slightly – ~ 4.5 cm at a radius of 9 cm and ~ 2.1 cm by 3 cm with a decrease in the average current density by ~ 2.5 times (~ 4 kA/cm² – K1 and ~ 20 kA/cm² – K3).

EFFECT OF THE INITIAL CURRENT GROWTH RATE ON THE CS DYNAMICS



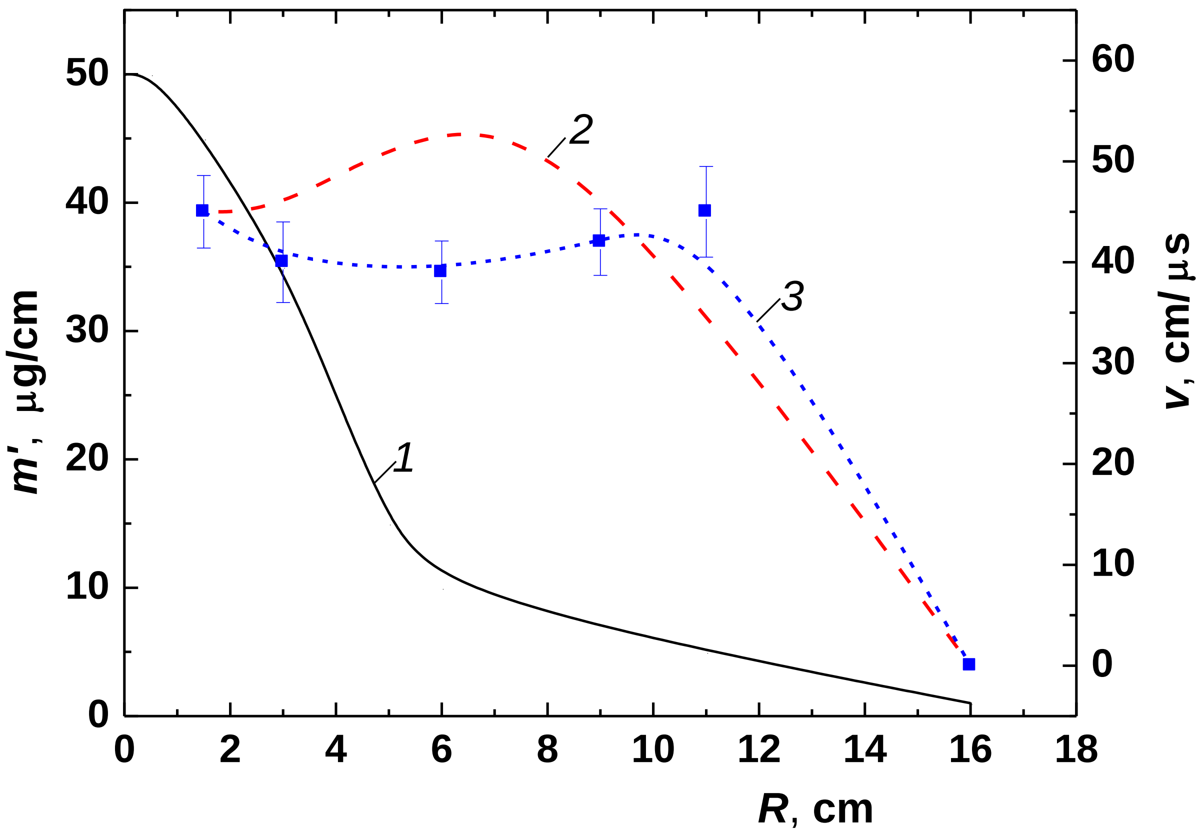
Frames with HSFC-Pro show stable metal-puff compression in both cases

CURRENT SHEATH DYNAMICS

In all implosion regimes of a metal-puff, measurements with B-dot magnetic probes indicate the formation of a CS already at the initial stage, the thickness of which decreases when moving toward the center, and the average current density in the CS increases and amounts to tens of kA/cm^2. Such high current densities can only be ensured by the presence of a high concentration of cathode plasma created by cathode spots. In this case, electron emission is carried out from the front of a dense cathode plasma. In CS, additional ionization of the liner material by this electron beam can take place.

According to the B-dot data, the CS velocity is (25-30) cm/μs, which significantly exceeds the speed of sound in a plasma even for an electron temperature of 100 eV. As a result, a shock wave is formed with a jump in density and temperature. It is possible that it is the motion of the denser front of the shock wave that is captured by the HSFC-Pro camera. The CS moving toward the center can form a denser electrode plasma on the surface of the cathode with increasing current density. When it expands into the interelectrode gap, the emission boundary can shift from the electrode to the plasma with a part of the current screened in B-dot.

CURRENT SHEATH DYNAMICS



Change in the linear mass of the metal-puff (graph 1), formed by an arc discharge with aluminum electrodes, during implosion from an initial radius of 16 cm, graph 2 is the estimated speed of the magnetic piston, graph 3 is the CS speed averaged over 10 shots. The delay of the beginning of the current of the Ig generator from the beginning of the arc current I_{arc} is t_z = 6.2 μs, U_{arc} = 25 kV.

Figure illustrates the change (raking) of the linear mass of a metal-puff (MP+48 PG) when moving toward the axis of the system. The density gradient growing toward the center allows the use of the snow plow stabilization mechanism with the suppression of large-scale Rayleigh-Taylor instabilities.

CONCLUSION

- **The experiments showed that in the microsecond implosion regime, a change in the average radius of the current shell, determined from the inductance of the compressing liner $L_z(t) = \int (V_z(t)dt)/I_z(t)$, is consistent with the dynamics of the average radius of the current sheath by signals with B-dot**
- **The width of the current sheath decreases as it moves toward the axis from ~ (3-4) cm at a radius of 9 cm to ~ 1.5 cm at radii of 3 and 2 cm with an increase in the average current density from ~ 10 kA/cm^2 to ~ 50 kA/cm^2**
- **In the final stage of implosion with a diameter of ~ 6 cm, the outer boundary of the Z-pinch shell, recorded by optical measurements, corresponds to the leading edge of signals with B-dot at radii of 3 and 2 cm**
- **With a decrease in the current growth rate by 2.5 times, the structure of the current sheath practically does not change, energy characteristics associated with the energy supplied to the liner fall. The investigated metal-puff provides shock compression of the substance without the development of large-scale instabilities in the microsecond implosion regime**