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Study on the Elaboration of High-Current Drivers Aimed at the Inertial Fusion Energy

Yu.Bakshaev, A.Bartov, P.Blinov, A.Chernenko, K.Chukbar, S.Dan'ko, G.Dolgachev, L.Dubas, F.Fedotkin, Yu.Kalinin, A.Kingsep, A.Korelskiy, V.Korolev, D.Maslennikov, V.Mizhiritsky, A.Shashkov, V.Smirnov, G.Ustroev

Russian Research Centre "Kurchatov Institute", 123182, Moscow, Russia

I. A series of experiments was carried out on S-300 facility aimed at the investigation of the short piece of co-axial magnetically self-insulated transporting line (MITL), at the linear current density on the inner electrode surface up to 0.5 MA/mm. Electrode's plasma behavior simulation code NRINCH [1] validation was done by measured plasma parameters comparison. The scheme of the experiment is shown in Fig.1. Two parallel plane electrodes 1 cm in length served as outer anode, a gap between them was varied from 8 to 12 mm. Stainless steel pipes in diameter of 1-1.2 mm and with wall thickness of 0.1÷0.2 mm were used as a central cathode.

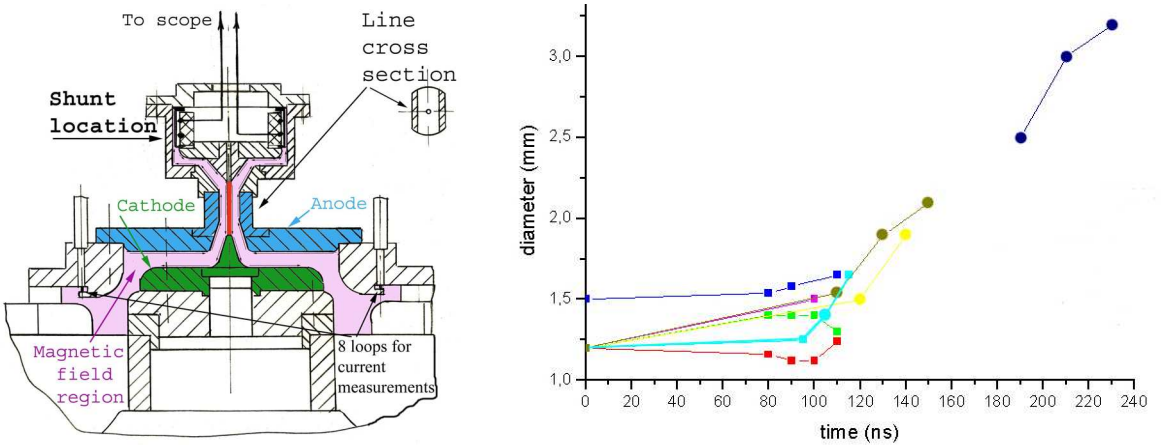

Fig.1. Left - the scheme of experiment. Right –cathode plasma diameter derived from the shadow and Schlieren images. Lines of proper color join points from the same shot together.

Input and output MITL current was measured by loops and low-inductive shunt, correspondingly. It ranges from 1 to 1.8 MA with characteristic rise-time 160÷200 ns.

Collected laser probing data (Fig.1, right) show that up to 240 ns from the current beginning dense plasma (N_e~$5\cdot10^{17}$ cm^{-3}) expands no more than to 3.2 mm in diameter. After maximum of current, 200-220 ns from its beginning, dense plasma sharply accelerates up to 1–$2\cdot10^6$ cm/s. Usually, this moment is correlated with the input and output

current divergence. Soft x-ray plasma images are like the visual light pictures at the appropriate moments. Pipe cathode compression was seen at the middle part of the discharge, that coincides with numerical simulation fairly good (Fig.2).

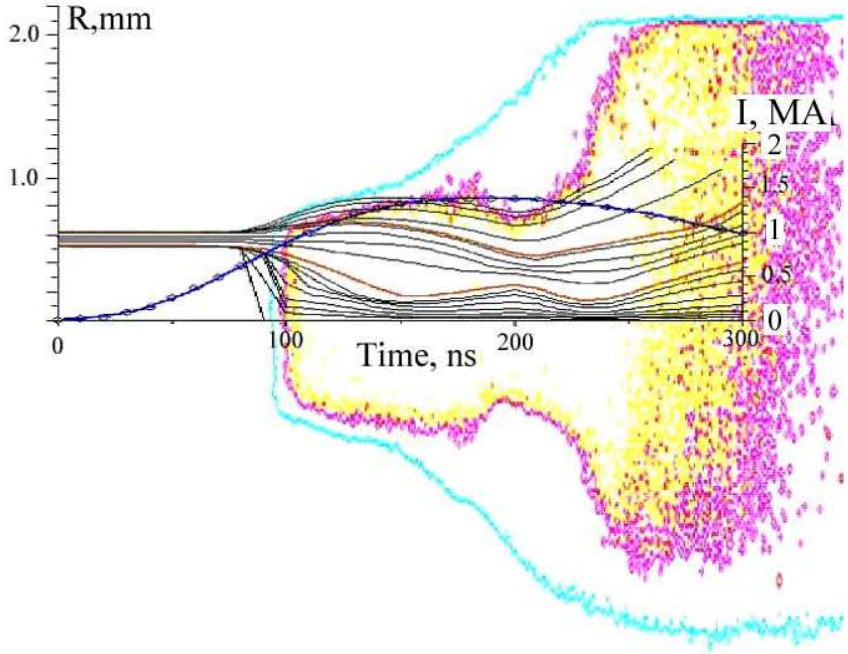

Fig.2. Superposition of the darkening isolevel lines of the visual light chronogram (sky blue-violet-yellow in the ascending order) with calculated curves (black and brown solid lines). Full blue curve is an electrical current.

Thus:

- Input and output electrical currents coincide reasonably well up to 220-260 ns. It was found that at this stage of MITL operation the plasma originating after the electrode surface explosion don't short-circuit MITL gap.
- Electrode explosion process and created plasma dynamics agree well with the one-dimensional MGD numerical simulation predictions. The code NPINCH takes into account both metal state and plasma state equation.
- Except dense plasma magneto-hydro-dynamics simulation model, the EMGD effects may play a part in. In particular, they reveal themselves in the fast instability of the plasma layer that can be considered as a reason of the short-circuiting MITL at 220-260 ns. This statement should be proved in the next investigation.

II. "Baikal" – project looks ahead to superpower pulsed generator creation (~10 MV, ~50 MA, ~150 ns) as a driver for inertial confinement fusion. This is a report about the experiments with the Plasma Opening Switch (POS) [2], which is specially designed as a module of the final stage of pulse sharpening for the "Baikal" prototype. The features are:

1. Electrical current prepulse transferring (~40 microseconds, ~80% of the whole charge).

2. The prevention of reclosure of POS during the performance at the low-inductive load with rising-in-time impedance – imitator of the real liner.

3. Axial plasma motion suppression and designing of minimum length POS.

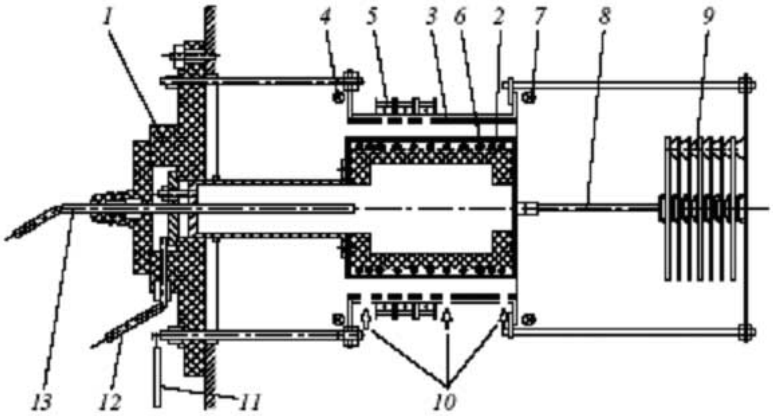

Fig.3. <u>POS-module scheme</u>. 1- insulator, 2- POS anode, 3- cathode, 4,7-input and output Rogowsky current monitors, 5- plasma guns, 6-extrinsic magnetic field solenoidal coil, 8- inductive load, 9-separating switch, 10-ion detectors, 11- plasma gun power supply, 12- high voltage supply, 13- solenoidal coil power supply.

1. Being in erosion regime, in order to transfer long prepulse and, hence, large electrical charge, the programming plasma filling of the POS gap is proposed. It is due to the additional plasma injection at the initial phase of erosion to sustain plasma concentration at the level of 10^{15} cm^{-3}. This proposal realization is reflected in Fig.4: threefold plasma injection increases transferred charge in three times; POS operation instant is shifted up to the required 40 μs.

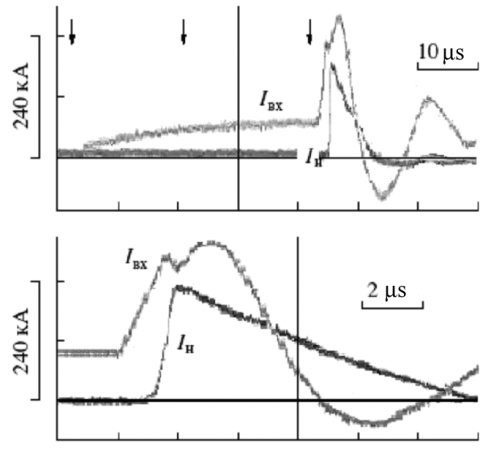

Fig.4. <u>Electrical current traces</u>. I_{in}, I_{out}-input current and inductive load current (120 kA/division). The moments of guns operation are indicated by arrows. The separated switch is closed. B_z=0,6 T. Beneath – the fragment of the whole trace in another time scale.

2. To prevent an undesired POS reclosure with plasma the extrinsic magnetic field is applied and the separating closing switch has been proposed to be placed between the POS and the load. The separating switch assists in obtaining the wide magnetically insulated vacuum gap in the POS to keep high voltage and to transfer the energy to the load. The extrinsic magnetic field effect at the capacitive load performance is illustrated in Fig.5. This is a synthetic workload of the real liner-load. One can see that the second POS reclosure comes in ~ 1 μs after POS actuation, now that 20% of magnetic energy is transferred to the load.

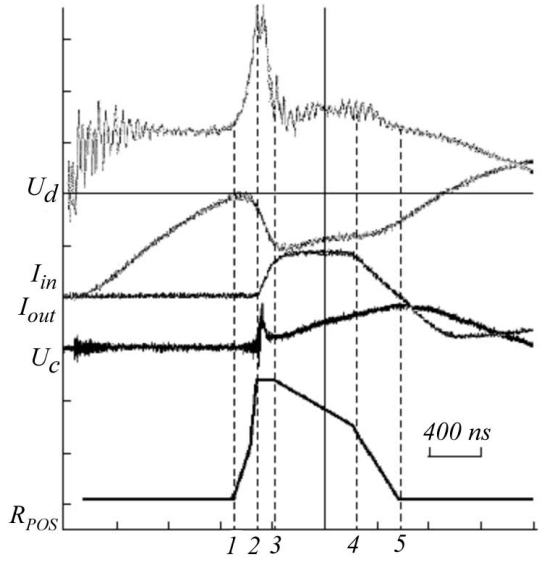

Fig.5. <u>Energy transfer to the synthetic work-load</u>. U_d –input divider voltage 15 kV/div; I_{in}, I_{out}-input POS current and load current 60 kA/div;, U_C- load voltage; R_{POS}- POS impedance 0.5 Ω/div. Instances: 1- current abruption beginning; 2 -separated switch breakdown and capacitor charging beginning (the spike on the oscillogram U_C is an inductive voltage); 3- energy transfer from the inductive storage finishing and energy transfer from the capacitive storage beginning; 4- load current transition to the oscillatory conditions; 5-POS reclosure and the load capacitor discharge beginning.

3. Axial plasma motion is suppressed by the extrinsic axial magnetic field application that redirects this axial drift to the azimuthal one. In such a way longitudinal electric field induced by the specific charge of the drifting electrons disappears. It is just this field affect plasma axial motion. The evidence of the axial motion limitation is ion current distribution measurements that show only belt ion flow existence near the middle ion detector. Moreover, convincing evidence is the particles treatment of the electrodes, shown in the Fig.6. The length of this signature is equal to ~10 cm.

Fig.6. At the left- stainless steel anode; at the right- carbon-carbon cathode of the POS is shown. The belt erosion region by electron and ion bombardment correspondingly is seen.

[1]. S. I. Tkachenko et al. High Temperature, **39**(5), 728 (2001); Int. J. Thermophys, **23**, 1359 (2002).

[2]. A.Altukhov, P.I.Blinov, G.I.Dolgachev et al. Instruments and Experimental Techniques ISSN 0020-4412, 2005, №4.