33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, O-5.001 (2006)

Study on fast Z-pinches at the S-300 machine aimed at the IFE

A. Chernenko, S. Anan'ev, Yu. Bakshaev, A. Bartov, P. Blinov, K. Chukbar, S. Dan'ko,
Yu. Kalinin, E. Kazakov, A. Kingsep, V. Korolev, V. Mizhiritsky, A. Shashkov, V. Smirnov
Russian Research Center "Kurchatov Institute", Moscow, Russia

On the S-300 pulsed power machine at the Kurchatov Institute, some experimental activity is devoted to the prospects of Inertial Fusion Energy (IFE) program. Experiments are gone on aimed at the energy transfer into the high-current tiny wire array with the typical radius $R \approx 1$ mm, as well as study of its dynamics and analysis of the tiny Hohlraum heating. The results of experiments, devoted to the study of operation of magnetically self-insulated transporting line (MITL), by the linear current flow density on the inner electrode surface up to $j \approx 0.7$ MA/mm are also presented. The specific parameters of this current-carrying line correspond to those of the conceptual project of IFE reactor based on the fast Z-pinch [1, 2].

An investigation of output devices similar to the plasma flow switch but operating in the nanosecond range of pulse duration was carried out [3]. The plasma bridge between the inner and outer cylinders is accelerated along the axis by means of the current pulse of generator (FIG.1-A). When it is flying through the break of the inner cylinder, the circuit breaks, as a result, the magnetic flux enters the central cavity where the load is situated.

Our plasma bridge was created by means of the current-driven explosion of a thin foil in very beginning of the current pulse. Diameters of inner and outer cylinders were equal to 4 and 10 mm, respectively. The break of inner cylinder was varied between 1 to 2.6 mm. The diameter and length of central cavity were equal to 3.6 mm and 10 mm, respectively. The maximal current value was close to 2.5 MA. The better results were achieved by using plastic "washers" of 1.2–1.5 μm thickness coated by very thin layer of aluminum. The velocity of the foil sliding along the inner electrode (up to 10^8 cm/s) was recorded by means of the streak ICT photographs in visible range. As loads, we used the arrays of 8–16 tungsten (5 μm) wires situated at r = 1 mm. An extreme switching rate (10^{15} A/s) has been achieved in our experiments. Heretofore, this result remains to be unique one; unfortunately, its reproducibility is low enough. To form less diffusive outer boundary of our plasma bridge, we have used the system of two colliding mylar foils, each one being of 1.5 μm thickness, with 1–2 mm gap between them. As a result, the reproducible switching was achieved on the level ~ 750 kA/5 ns, and the rate of the current decrease was the same as that of the net current (~ 100 ns), unlike the extreme regime. The soft X-ray radiation (SXR) of the solid walls of Hohlraum was recorded in the range of $h\nu \geq 50$ eV by means of two vacuum X-ray diodes (XRD) with the *Ni* photo-cathodes, supplied by the mylar filters with the mass thickness 0.34 and 0.67 mg/cm^2. They were situated at the distances 2.3 m from the output unit in the radial direction. The geometry and layout of output device allowed XRD "to see" only the inner surface of the cavity while the straightforward radiation of the load was screened (see FIG. 1-B). The SXR signals corresponded to the black body radiation at the temperatures in the range of 38–50 eV. We can explain this result on the base of theory of strongly magnetized Hohlraum with the self-consistent penetration of both magnetic field and thermal wave into the cavity wall.

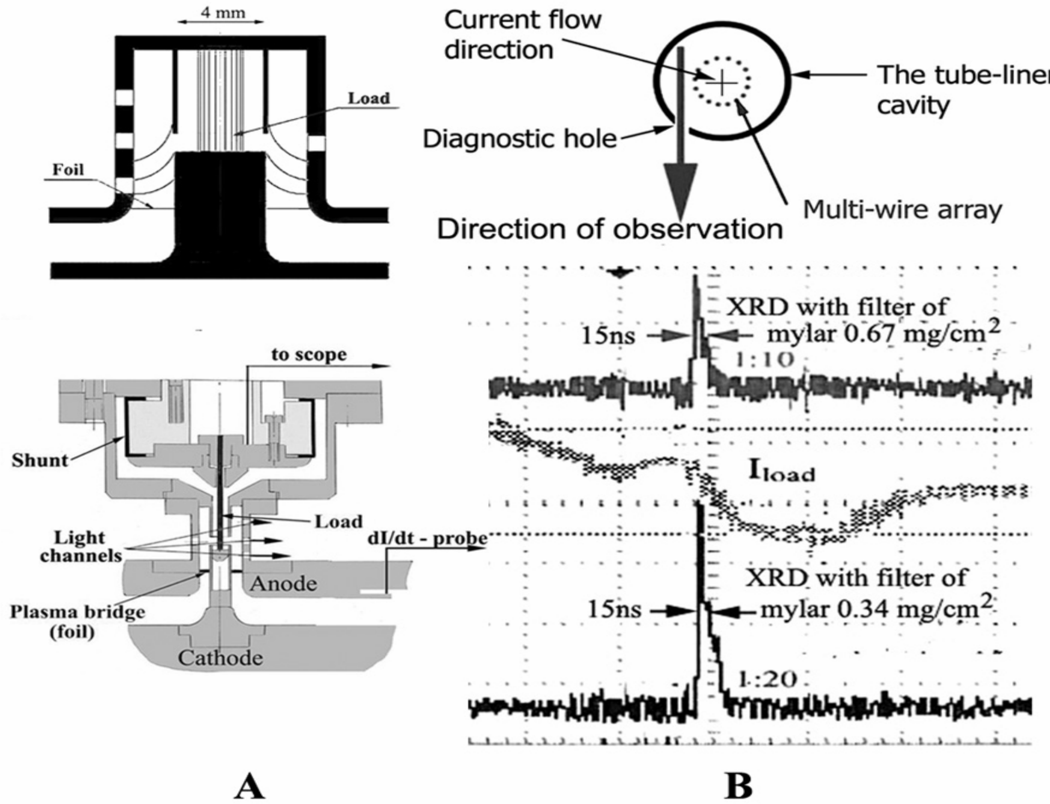

Fig. 1. A – Principal and experimental schemes of the plasma flow switch output device; B – wall temperature measurements on the base of SXR signals

Output unit with geometry presented in Fig. 2 was used in the research of MITL with linear current flow density up to j ≈ 0.7 MA/mm. The inner negative electrode of MITL was situated symmetrically. In most experiments, the inner electrode made of stainless steel or nickel tubes with the outer diameter 0.75 or 1.2 mm and the wall thickness 100 or 200 μm were used as cathodes. MITL section (Fig.2) was joined to the output unit (OU) of the S-300 generator. The current on the input to OU and the output current of MITL were recorded by the magnetic loops and low-inductance shunt, respectively. Extra details increased essentially the OU inductance; as a result, the output current pulsed of the machine was broadened and decreased in the amplitude. In these experiments, the current at the OU input varied in the range of 1-1.8 MA with the typical risetime ~ 160-200 ns. The most representative experimental results on the plasma dynamics in the MITL inter-electrode gap were obtained by means of the ICT chronography in visible range and by the multi-frame laser probing as well. The 4-frame pictures of the vacuum gap were taken in both VUV and SXR range with the 10 ns exposure by means of the open ICT with MCP cathodes.

In our conditions, the minimal electron density was of the order of $N_e \approx 6{\cdot}10^{17}$ - $1.2{\cdot}10^{18}$ cm^{-3}. As both shadow and Schlieren pictures show, the dense plasma flying away from the central electrode is looking like rather perfect cylindrical formations with the sharp boundaries (the density decreases by one order of magnitude on the scale 0.2-0.4 mm).

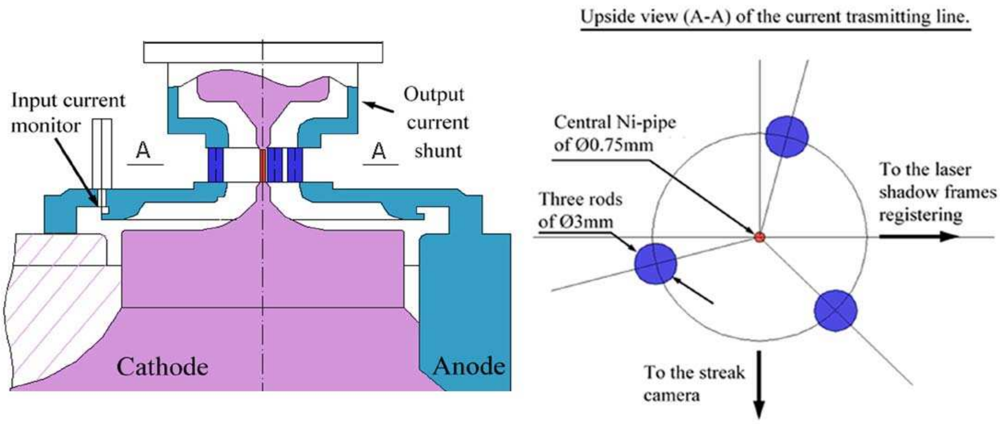

Fig. 2. Scheme of the MITL experiment with a shunt.

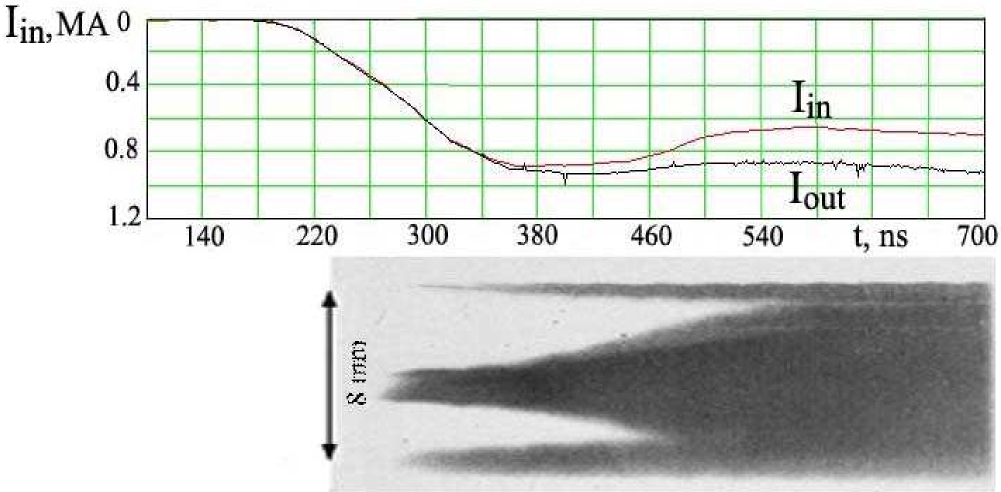

Fig. 3. Top: oscillograms of the input (I_{in}) and output (I_{out}). Bottom: chronogram of the plasma expansion in the MITL model (the negative).

The laser probing was carried out by using the second harmonics of YAG:Nd laser (λ = 0.532 μm). The laser diagnostics allowed obtaining 5-frame shadow photographs with the exposure 300 ps and the inter-frame interval 10 ns or 3-frame Schlieren photographs with the inter-frame interval 20 ns. The calculations show that, by our wavelength, if one takes into account the typical space scale of plasma formation (< 1 mm), the ion density on the boundary of shadow may be estimated as $6{\cdot}10^{18}$ cm^{-3}. To record plasmas of smaller densities, 3-frame Schlieren photography was used in the experiments.

The generalized data of laser probing measurements demonstrate that, up to the point 240 ns, the dense plasma with the electron density not less than $5{\cdot}10^{17}$ cm^{-3} expands along the diameter of the system not more than up to 3.2 mm, by the initial diameter of the central electrode ~ 1-1.2 mm (see Fig.3). The cathode luminescence starts at ~ 70-100 ns after the current start, and the inhomogeneity of this luminescence is obvious enough. A region of bright luminescence is clearly visible that corresponds to the high-density plasma kern (probably optically dense in the visible range), and the halo with smaller luminosity probably corresponding to the plasma with smaller density. The transversal size of the region of most bright luminosity, after slight broadening while explosion, then does not broaden during 100-120 ns, moreover, it turns out to be compressed when the current is close to its maximum (see Fig.3). After the current maximum, some at 200-220 ns from its start, the sharp increase of the dense plasma expansion happens; its velocity reaches $1–2{\cdot}10^{6}$ cm/s.

At the moment of the input and output current divergence (Fig.3, top), the magnetic insulation becomes violated in the circuit part OU–MITL. The ICT photographs in the SXR range seem (Fig.4). the development of some instability may be observed that manifests itself just at the moment of reconnection, besides, it is very similar to the EMHD instability.

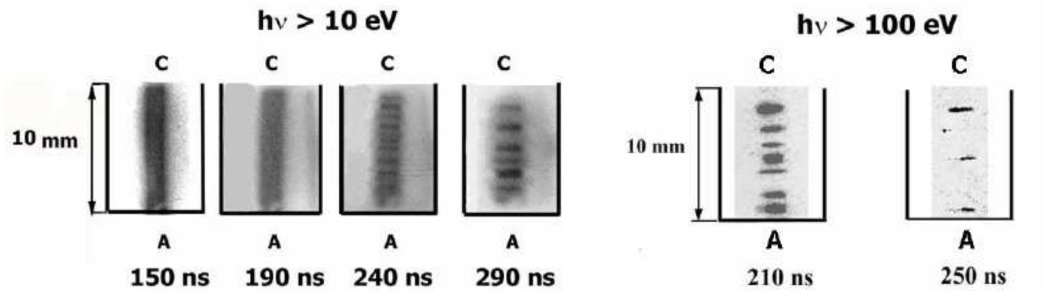

Fig. 4. ICT photographs of the plasma surrounding the central electrode in the SXR range.

The temporal behavior of both input and output current in the MITL section is identical up to 220-260 ns. At this stage, it has been found that the plasma formed as a result of electrodes surface explosion, did not reconnect the MITL gap. The process of electrodes explosion and subsequent dense plasma dynamics fairly corresponds to the predictions of numerical simulations based on the 1-D MHD NPINCH [4] code taking into account EOS for metals and plasmas.

The work was supported by the Russian Foundation for Basic Research, grants 05-02-17339 and 05-02-08061-ofi-e, and by the contracts # 346778 and 449961 “Sandia Laboratories – Kurchatov Institute”.

1. C.L. Olson and Z-pinch IFE Team // Proc. 15-th Int. Conf. on High-Power Particle Beams, 2004, D.V. Efremov Institute, Saint-Petersburg, 2005, P. 681.
2. Yu. Bakshaev, A. Bartov, P. Blinov, et al. // Plasma Phys. Reports, 2006, V.22, #12 (in press).
3. Yu.L. Bakshaev, A.V. Bartov, P.I. Blinov, et al, *Plasma Phys. Reports*, 30, 2004, 318-329.
4. N.A. Bobrova, S.V. Bulanov, P.V. Sasorov, *Plasma Phys. Peports*, 22, 387 (1996).