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EXPERIMENTS WITH THE TINY NANOSECOND OUTPUT DEVICE ON THE S-300 HIGH-CURRENT GENERATOR

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On the S-300 pulsed power generator (4.5 MA, 70 ns, 0.15 Ohm), within the frames of ICF program based on fast high-current Z-pinches, experiments are being carried out studying promising schemes of output units. In particular, a device similar to the plasma flow switch is being investigated aimed at sharpening the pulse. In the experiments with such a device, by means of variation the geometry of the inner electrode of a co-axial, as well as the acceleration of a cascade of plasma "washers", the switching of the current up to 750 kA has been obtained, with the rise time ~ 5…7 ns and subsequent decrease being in accordance with that of the net current (~ 100 ns). Thereby the opportunity of switching of much more amount of energy onto the load has been demonstrated compared to our preliminary experiments (2.5 MA/2.5 ns). Soft X-ray radiation from the cavity was recorded by means of vacuum diodes with a nickel cathode and especially selected filters. The radiative temperature of the cavity walls estimated from the ratio of diode signals was close to 50 eV.

1. INTRODUCTION

Fast compression of high-current Z-pinches is under consideration as a possible approach to electric energy conversion into X-ray pulse at the energy scale of dozens of megajoules aimed at the inertial confinement fusion (ICF) as well as experimental study of the extreme state of matter. Nowadays, the typical load of the pulsed power machine of megaampere range is based on the array of wires of the micrometer thickness. Scientific cooperation including TRINITI, Kurchatov institute, Efremov institute, and VNIITF develops the "Baikal" project [1,2] in which an inductive storage has to be used which in the case of successive transformation procedure could produce an electric pulse with parameters adequate for ICF. Unfortunately, one of the shortcomings of such schemes is the X-ray radiation into the solid angle equal to 4π that results in the reduction of energy density and, consequently, the equivalent temperature since the radiation fills the whole volume of the output unit. As a result, the experiments with a Hohlraum are available now only on the level of "Z"-machine at "Sandia" laboratories [3]. The goal of ICF experiments in Kurchatov institute is to study some new kinds of tiny output units those could provide the Hohlraum experiments at the current generation of high-current machines.

2. NANOSECOND PLASMA FLOW SWITCH

We investigated especial output devices similar to the plasma flow switch but operating in the nanosecond range of pulse duration. The plasma bridge between the inner and outer cylinders was accelerated along the axis by means of the current pulse of generator. The scheme of our output device has been shown in Fig. 1. Accelerated plasma bridge moves along the inner coaxial cylinder. When it is flying through the break of the inner cylinder, the circuit becomes to be broken, as a result, the magnetic flux enters the central cavity where the load is situated. The 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…3.0 MA. We used the accelerated foils produced of different materials, to wit, metallic foils as thick as 5–10 μm, mylar films of 2…5 μm, nitro-cellulose films with thickness <1 μm, and aluminum-coated mylar films of 1.2…1.5 μm. The homogeneity of breakdown of foils and the velocity of their sliding along the inner electrode were recorded by means of both frame and streak ICT photographs in visible range. The maximal velocity of sliding recorded was up to 10^8 cm/s. The better results of the

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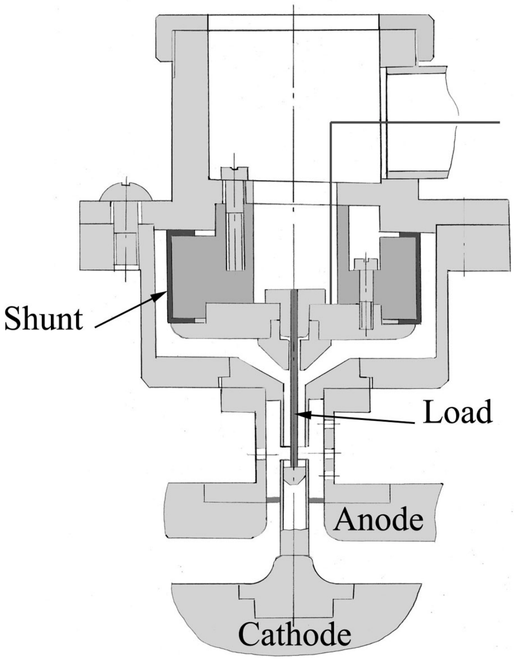

Fig.1. The sketch of output device

current series were achieved by using plastic “washers” of 1.2…1.5 μm thickness coated by very thin aluminum layer. As loads in the first experiments we used metallic wires or tubes with the diameter of 0.5…2 mm. The moment of current switching on the load and the current amplitude were determined by means of the shunt measurements. The shunt (see Fig.1) was made of steel foil as thin as it was necessary to provide the time resolution $\Delta\tau<2$ ns. As our simulations show, heating of this shunting foil does not distort essentially the signal up to the moment of maximal current amplitude. The current rise time on the load varied from 2.5 ns up to 10 ns.

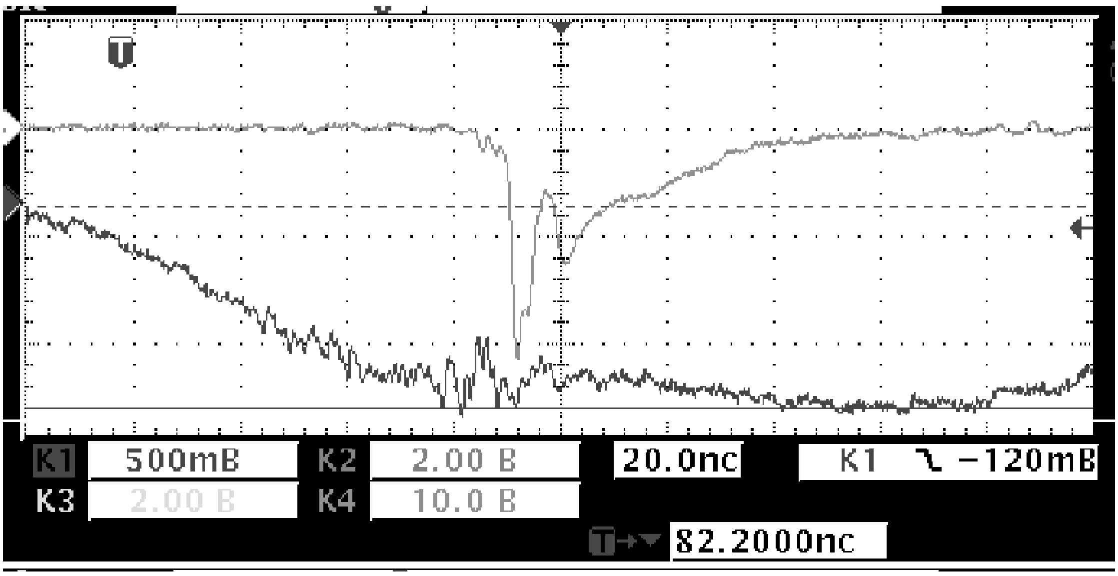

Fig. 2. Traces of the current on a load (top) and total current (bottom)

The current amplitude was up to 2.5 MA. Heretofore, such a switching rate (10^{15} A/s) has been achieved only in our experiments. In Fig. 2, on can see the oscilloscope traces of both input current and current switched onto the metallic tube of 1.5 mm in diameter that served as a load. Nowadays, we operate with new loads, namely, wire arrays of the small diameter (~2 mm) set up in the cavity of the inner electrode.

3. SIMULATIONS

We have carried out a series of simulations of the dynamics of plasma “washer” on the base of single-fluid, two-temperature MHD code with the effects of radiation transfer and Electron Magnetohydrodynamics (EMHD, see [4]) included. At first sight, EMHD effects should be immaterial in this problem since the typical space scale of both plasma washer and Z-pinch are at least one order of magnitude more than c/ω_{pi}. However, our simulations result in the important role of EMHD. Not only quantitative results, even scenarios in pure MHD and Hall MHD (EMHD) turn out to be different. We believe, this effect is conditioned by the generation, in the process of the plasma bridge acceleration, space scales much less than the basic scale of the problem, especially in the regions close to the electrodes. Simulations show an essential dependence of the acceleration and consequent switching upon the initial plasma temperature, to wit, the “warm” plasma bridge (~8…10 eV) is preferable from the standpoint of its stability and efficiency of switching.

4. CASCADE SYSTEM OF FOILS

To form less diffusive outer boundary of our plasma bridge, we have used the system of double “washers”, to wit, two mylar foils, each one being of 1.5 μm thickness, with 1…2 mm gap between them. Besides, to prevent from breaking the plasma bridge near the inner electrode resulting in the formation of parasitic plasma opening switch, we used a conical inner electrode with a diameter growing in the direction of the plasma bridge motion.

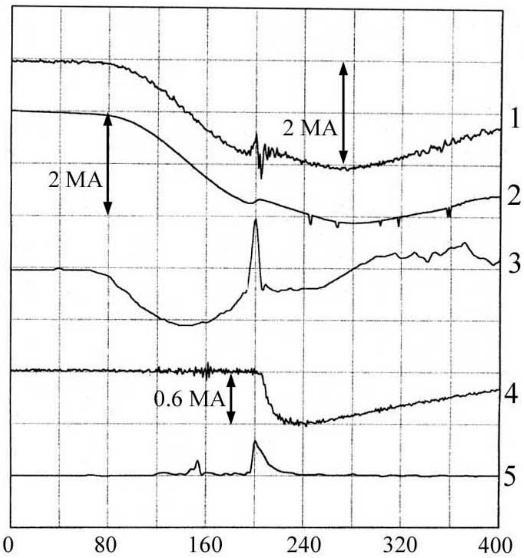

Figure 3. Oscilloscopic traces corresponding to the cascade scheme experiment

An example of oscilloscopic traces is shown in Fig.3. Here the trace 1 presents the net current *I* obtained by the analogous integration of the signals from the diagnostic loops, 2 – the same current *I* integrated numerically, 3 – the signal dI/dt, trace 4 – the value of I_L, where I_L is the current on the load, trace 5 – the soft X-ray signal recorded just from the spatial region of switching (see the gap in Fig.1). The first pike on this curve corresponds to the impact of two foils and the second one – to the moment of switching. As one can see, the switched current value in this shot was ~750 kA/5 ns, and the time scale of subsequent current decrease was the same as that of the net current, unlike the extreme regime shown in Fig.2. As a load, an array of 8 to 16 tungsten wires was used with the diameter of 5 to 6 μm collected in the array with the radius of 1 mm.

Except of registration of the electric signals, we recorded the soft X-ray radiation (SXR) of both compressed Z-pinch and the solid walls of the Hohlraum, in the range of $h\nu \geq 50$ eV. These measurements were carried out by means of the vacuum X-ray diodes (XRD) with the *Ni* photo-cathodes, supplied by mylar filters with the mass thickness = 0, 0.34 mg/cm^2, and 0.67 mg/cm^2. SXR pulse recorded from the load served as the witness of switching. SXR signal of the pinch recorded from its edge, if supposed to be nearly Planckian, may be used to obtain the following estimates: $T \cong 140$ eV, $E_{h\nu} \approx 20$ J, and the efficient radiating cross-section area $S \cong 2\cdot10^{-5}$ cm^2. To some extent, these results remain indefinite since we cannot resolve the hot spots of Z-pinch. We believe the temperature of cavity walls to be more reliable. The geometry and layout of output device and diagnostics allowed XRD “to see” only the inner surface of the cavity while the straightforward radiation of the load being screened. The temperature of the inner wall thus determined was in the range of 38-48 eV, in some shots, it turned out to be as high as ~ 50 eV.

5. SUMMARY

1. Scientific cooperation including TRINITI and Kurchatov institute develops the “Baikal” project aimed at constructing the pulsed power machine of new generation. Nowadays, experiments in Kurchatov institute are being carried out supporting this program, in particular, those with special output units at S-300 high-current generator.

2. The switching rate as high as 10^{15} A/s = (2.5 MA)/(2.5 ns) has been achieved by using nanosecond plasma flow switch, and the quasi-steady regime of a tiny wire-array implosion, corresponding to the current and switching time level (750 kA)/(5 ns) with the typical time of subsequent damping ~ 100 ns.

3. The radiative temperature of the inner wall of a microscopic Hohlraum has been recorded as high as ~50 eV.

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