DIAGNOSTICS OF A THICK FIBER CORONA OF A MA Z-PINCH

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A great interest of general Z-pinch investigation is focused on the suppression of the instabilities and the X-ray emission. In the contribution [1,2] a relatively stable channel around the rod, with an inner layer in solid phase and a high energy monochromatic non-thermal (wavelength 17-20 nm) burst of soft VUV radiation in the axial direction, were reported from a small 500-J-energy Z-pinch device.

In this paper the experimental investigation is being performed at the 8–module pulse power generator S–300. The S–300 installation with an output impedance of 0.15 Ω provides a current of 2 – 3 MA, with a rise time of 100 ns on a load, and the total energy transferred to the vacuum concentrator was 100 kJ [3,4]. For the measurement of the plasma parameters are used various X-ray diagnostics: an array of semiconductor detectors with a 1-ns resolution in the radial direction toward the axes; vacuum X-ray diodes with mylar and Al foils in the radial and in the axial directions, three optical framing cameras with 3-ns of exposure time in the radial direction, a mica crystal X-ray spectrograph for 1-10 keV; obscure chambers as well as a optical streak camera in the radial direction with the slit aligned parallel and perpendicular to the pinch axes.

In this contribution, the parameters of the plasma corona and of the radiation of high energy z-pinch are studied in a situation, when the inner layer of the carbon rods and Cu fibers are in the solid phase for testing the possibility of non-thermal pumping of inverse population of levels, for a recombination scheme of lasing of higher z-elements.

A corona formed around the carbon rod of 0.5 mm diameter was stable with an invariable diameter during the first 60 ns. Then the explosion of the corona was observed with a mean velocity of $3x10^4$ ms^{-1}. The framing camera pictures imagined the corona column with symmetrical instabilities of small (neck) and big (node) diameter. The boundary of the column was blurred and may be interpreted as the escaping of plasma from the corona during the 3 ns of the exposure time. The X-ray images, with 3-ns exposure time and sharp boundaries, have a toroidal form at the nodes, similar to these described in [5].

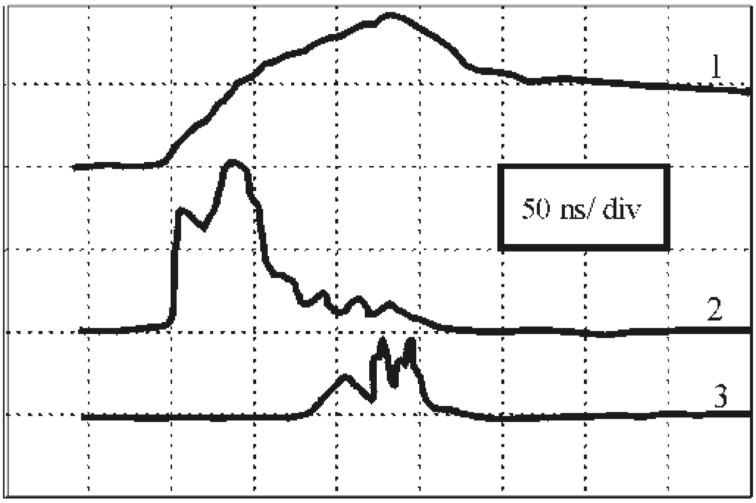
A corona formed around the carbon rod of 6 mm diameter was stable without evidence of instabilities and with a relatively constant diameter of 8 mm in both the visible and the X-ray pictures, during 120 ns. Later the corona expanded with a mean velocity of $3x10^4$ ms^{-1}. At the time ~200 ns the regular toroidal ring around the expanding corona was detected by the framing camera. An emission of soft X-ray started 20-50ns after the increase of the current and reached its maximum at the same moment as the current maximum. The FWHM of this soft X-ray was 120-140 ns. The ratio of emitted intensity in the radial direction was ten times higher than in the axial position, directly proportional to the emitting surface. The power of the emission in soft X-ray was evaluated as 100 GW. Filter applications enabled the determination of 10 – 100 eV interval of radiated energy.

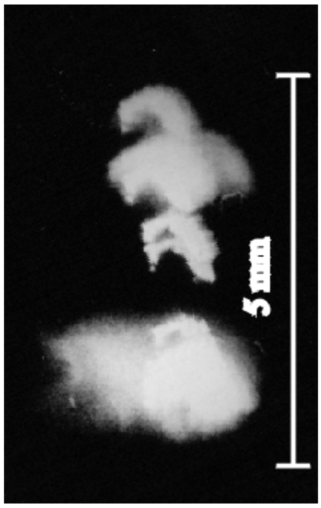
The diagnostics of both diameters of carbon rod, by the obscure chamber, did not demonstrate the existence of hot spots, which are typical for thin fiber experiments, as well as the spectrograph photographs did not demonstrate the presence of a line of a few kV-energy radiation.

The diagnostics of the copper fibers with a diameter of 75 and 110 μm and a length of 5-8 mm at a maximum of the current of 1.3-2.7 MA, showed another behavior. The velocity of the enhancement of the corona radius (of $1\text{-}2x10^4$ ms^{-1}) was estimated from the streak camera pictures during the first 150 ns after the current began. The soft X-ray radiation was detected by a vacuum diode with 2 foils, each of 1.5 μm mylar $C_{10}H_8O_4$ and 60 nm of Al. This radiation began 100-120 ns after the start of the current, it had 2-3 local maxima with a FWHM of 20-30 ns, a total duration of ~50 ns and a total energy of tens of J. For an integral X-ray exposure, an obscure chamber with a pinhole of 100 μm and with 2 foils (each 12 μm of mylar and 100 nm of Al) was used. In the pictures of the obscure chamber, the interesting structures, helical or like the part of a spiral and rings of 0.5-1.5 mm diameter, were imagined. The dimensions of these structures varied between 0.1-0.4 mm. Some rings are covered by a cloud of exploding plasma. In the spectra obtained by the spectrometer were detected lines of Cu K and L shell of 0.14-1 nm.

In Fig.1 the oscillogram of the current, voltage and signal of the vacuum-diode is presented. In Fig.2, the structures emitted X-ray with an energy higher than 0.7 keV, are imagined by the obscure chamber with 100 μm pinhole with foils (24 μm of mylar $C_{10}H_8O_4$

and 120 nm Al). In Fig.3 the spectra of lines and a continuum of energy higher than 0.7 keV are shown for a shot with the current maximum of 2.7 MA. All figures belong to the same shot No. 22059801.





Shot No. 22059801 I_{max} = 2,7 MA Cu Φ 110μm

Fig. 1: Oscillogram: trace 1 – current, 2 – voltage, 3 – vacuum diode X-ray signal

Fig. 2: Obscure chamber picture - time integral

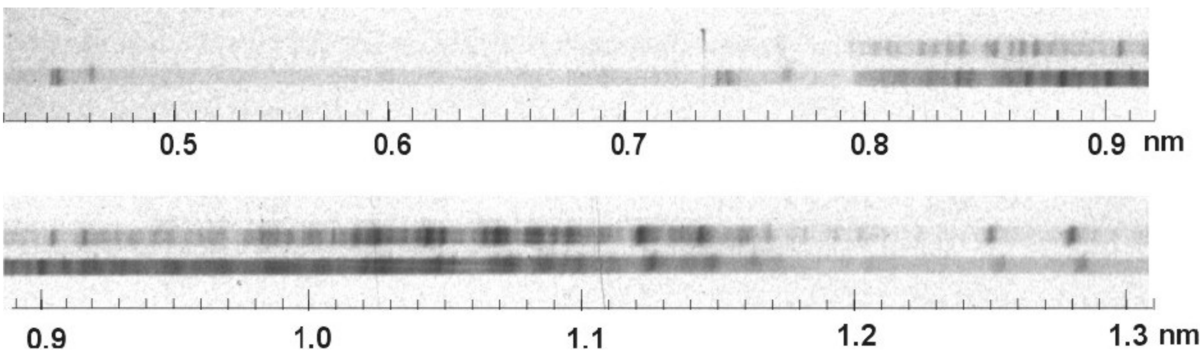


Fig. 3: Spectrum of the X-ray emission

In the spectrum, the lines of the Cu K and L shell were detected. The K shell He-like Cu lines of 0.1478 and 0.1485 nm are imagined in the third and fifth order, the L shell Cu XX-XXII lines are imagined in the interval 0.8-1.3 nm. From the absolute intensities the number of He -like Cu ions of $2x10^{16}$ with a whole energy of ~20 J were estimated. The energy emitted from L-shell may be a few hundreds of J. The number of He–like Cu ions is equal to 0.1%, the number of ions emitting L-shell lines is equal to 1% of the atoms of the copper fiber. It is not clear in this moment, if these high-energy lines are emitted from the rings or from the exploding clouds.

The reason for helical and toroidal current tube formation could be a radial explosion of the plasma from the plasma corona across the azimuthal magnetic field. In situation when the non-homogeneous plasma is moving perpendicular to the magnetic lines, the conditions for dynamo effect may be fulfilled. A non-thermal radiation could be generated by electric field induced by variation of the inductance of the helical magnetic fields and acceleration of the electrons in the helical tubes to energies sufficient for ionization of K and L shell Cu lines. This phenomenon could be used for generation of harder X-rays and for an X-ray laser pumping.

Acknowledgements

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