STUDIES OF PLASMA COMPRESSION IN DENSE Z-PINCH NECK

Yu.L. Bakshaev, P.I. Blinov, A.S. Chernenko, K.V. Chukbar, S.A. Dan'ko, E.M. Gordeev, **V.D. Korolev**, S.F. Medovschikov, V.I. Mizhiritskii, S.L. Nedoseev, E.A. Smirnova and V.I. Tumanov

Russian Research Center "Kurchatov Institute" 123182, Moscow, Russia
Troitsk Institute Innovative and Fusion Research 142092, Troitsk, Russia

Abstract

Investigation of profiled dense Z-pinches compression was carried out on the 8-module pulsed power S-300 generator (4 MA, 700 kV, 60 ns). As a load the agar-agar fibre with carbon filling of 3-5 mm in diameter with the preformed neck of 0.4-2 mm in diameter were used. The initial density of loads ranged from 0.005 to 1 g/cm^3. The plasma parameters were measured by vacuum X-ray diodes, X-ray framing cameras, crystal Roentgen spectrographs, optical streak camera, integrated pinhole camera and visible light frames. It was found that plasma electron density and temperature in the neck region depend on the its initial diameter and profile. The Local Plasma Formations (LPF) with $(0.3\text{-}1)\cdot 10^{22}$ cm^{-3} electron density, 1-1.5 keV temperature and the minimal size of 40-70 μm were observed in the region of the preformed neck.

LPF's emitted x-ray radiation with a power level of $0.5\cdot 10^{10}$ W in the 1-2 keV quantum energy range and the irradiated energy was about 10-50 Joules. The LPF's creation moment corresponded closely to the current maximum and the X-rays pulsed duration comes to less than 10 ns.

1. Introduction

The aim of our experiments is to investigate the self-focusing effect in Z-pinches in order to create the compact hot dense plasma with extreme parameters (density, temperature) to realize the proposal, published in [1,2]. In these works it was suggested to initiate thermonuclear burn wave by the Z-pinch compression that would cause the high-temperature plasma to propagate along the pinch. One can expect the theoretically predicted ignition of D-T mixture compressed from the initial diameter of about a centimetre to the micron cross-size neck by passing through the Z-pinch plasma 10 MA current.

In this paper are presented the experimental results obtained at the 8-module pulsed power S-300 generator (0.15 Ohm, I = 4 MA, t = 100 ns) [3] on the compression study of carbon fibres with initial density of 0.1 g/cm^3 and preliminary formed neck.

2. Experimental results

The experimental investigations of plasma compression in the Z-pinch neck region were carried out on the pulsed power S-300 generator, at currents up to 3 MA with a rise time of 100 ns. The initial plasma was produced by an electrical breakdown of profiled carbon filled agar-agar fibres with density of 0.05-1 g/cm^3. The best matching with the load at the level of incident energy wave of 70 kJ transmitted to the vacuum concentrator unit occurs for the fibres diameter of 3-5 mm and their length of 7-10 mm. The neck diameter and its mass per unit lenghth being varied between 0,5-2 mm and 0.1-0.5 mg/cm accordingly. Various X-ray diagnostics were used for plasma parameters measurements: X-ray framing cameras with 5 ns exposure time, X-ray pinhole cameras, fast response detectors with filters and crystal Roentgen spectrographs. In addition, optical radial streak photographs with the slit aligned perpendicular to the pinch axis and framing cameras were used.

It was established that plasma formation essentially depends on the initial density and radius of the neck. At the initial fibre density lower than 0.05 g/cm^3 the plasma corona was formed with the diameter exceeding that of the neck diameter [4]. Chaotically arising bright spots were observed in the space occupied by the rare plasma (the corona). At increasing the initial fibre density up to 0,1 g/cm^3 the time integrated pinhole camera and X-ray frame camera pictures show the plasma formation in preliminary made neck [see Fig. 1]. The mean compression velocity as determined from X-ray frame camera pictures proved to be $5{\cdot}10^6$m/s. The highest compression for the initial neck diameter of 1 mm corresponded to the moment of current maximum. Fig. 2 shows optical radial streak image in the fibre neck of 1 mm initial diameter. The bright region with cross - size dimension of 0.5 mm exists during first 100 ns. The continuous expansion of emission comes at least 100 ns after the current start. It must be noted that the expansion of bright region is observed on soft X-ray frames. The picture of expansion were taken at about 135 ns after the current start. From time-integrated pinhole camera pictures follows that as a result of compression the plasma formation occurs with the least diameter dimension of 40 - 70 μm as observed behind 10 - 20 μm thick mylar filter (Fig. 1b). Approximatly the same dimension values of the hot plasma were obtained in spectroscopic measurements from the width of X-ray penumbra behind the edge of the horisontal slit. The compression was accompanied by the soft X-ray radiation pulses (Fig. 3). The moment of the hot plasma appearance determined by soft X-ray radiation burst behind the 10 μm thick mylar filter corresponds to the current's maximum. It should be noted that the VUV-diode with 10 μm mylar filter is most sensitive to 2 keV X-ray radiation. The hot plasma life-time measured by the half intensity of soft X-ray decay is less than 5 ns, while the radiation power for > 1 keV quanta exceeds $5{\cdot}10^9$ W and the total irradiated energy is to be 20-50 J.

In some experiments in which a diagnostic admixture of KCl was used, the luminous region length of helium-like chlorine radiation measured by a spectrograph proved to be 100-150 μm with its diameter of 200 μm. At the same time measured diameter for helium-like potassium is in one and a half times less. The electron density and temperature, calculated from the spectral lines intensity ratio of hydrogen-like and helium-like ions, proved to be: n_e = $(0.3\text{-}1.)\cdot10^{22}$ cm^{-3} , T_e = (0.8-1.5) keV. In Fig. 4, the third order reflection of the observed spectrum for chlorine and potassium is presented.The line broadening measurement analysis shows that there is a significant difference between the ion and electron temperatures. The observed effect is characteristic for fast Z-pinch, compressed by the magnetic field of megaampere current range.

The plasma parameters at the initial density of 0.1 g/cm^3 were essentially depended on the neck profile. The highest parameters were obtained when the load neck was like two truncated cones with their tops directed towards to each other and the cone angle not exceeded 90°. By increasing the initial load density up to 1 g/cm^3 the plasma parameters decreased and became lower than for the density of 0.1 g/cm^3.

3. Conclusion

The experiments carried out on the S-300 generator show that at Z-pinch current increase from 1 MA [5] to 3 MA the effect of deep neck development is remained. The hot dense plasma with typical cross-size dimension of 40 - 70 μm was formed in the region of a preliminary made neck as a result of electrical breakdown of carbon filled agar-agar fibres. The highest plasma parameters $n_e = 10^{22} cm^{-3}$, T_e = 1-1.5 kev, were obtained by using fibres of 0,1 g/cm^3 density. The hot plasma life-time proved to be 5 ns. The power and full energy of soft X-ray radiation in the range of quanta energy hν>1 kev proved to be $5 \cdot 10^9$ W and 20-50 J, correspordingly. If we take for granted that almost all the Z-pinch current flows through the neck region, then it comes out that for the smallest measured neck diameter of 40-70 μm which at the same time corresponds to the space resolution of used diagnostics, the magnetic pressure $H^2/8\pi$ round the neck would be about two orders of magnitude higher than the kinetic pressure ($n_eT_e + n_iT_i$). Therefore it may be thought that the plasma compression might still be going on to the lower values of neck diameters. The upper mentioned difference between the magnetic and kinetic pressure is not well understood. This question needs further experimental and theoretical studies.

Acknowledgements

This work was supported by Russian Foundation for Basic Research (grant 96-02-19534).

References

[1] Yan'kov V.V.: Phys. Plasmy (Sov.) **17**, 521, 1991.
[2] Vikhrev V.V. and Ivanov V.V.: Sov. Phys. Dokl. **30**(6), p.492, June 1985.
[3] Chernenko A.S.et al.: *Proc.of Beams 96*, Prague, Vol.**1**, p.154, 1996.
[4] Bakshaev Yu.L., et al.: *Proc. of 18th Symposium on Plasma Physics and Technology*, Prague, p.50, June 17-20, 1997.
[5] Gordeev E. M.et al.: *Proc.of Beams*, San Diego,Vol.1,p.167, 1994.

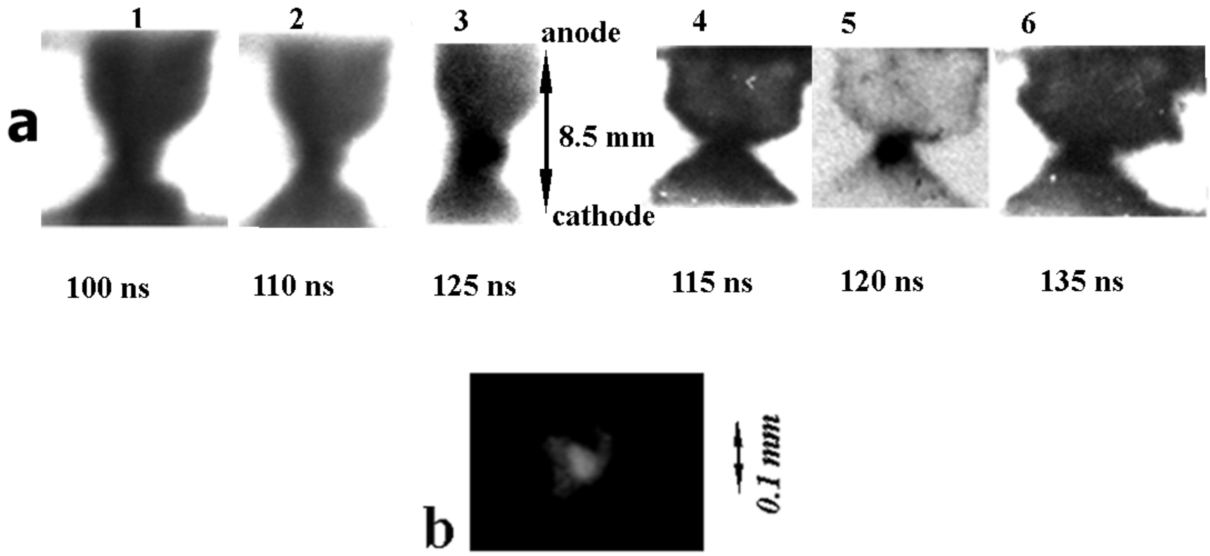

Fig. 1. a) Optical(1,2,3) and VUV-soft X-ray (4,5,6) frame-camera pictures for carbom filled agar-agar fibres of 0.1 g/cm^3 density with a neck region of less than 1 mm diameter; b) Pinhole-camera picture (12 μm mylar) of carbon filled agar-agar fiber of 0.1 g/cm^3 density and with the initial neck diameter < 1mm.

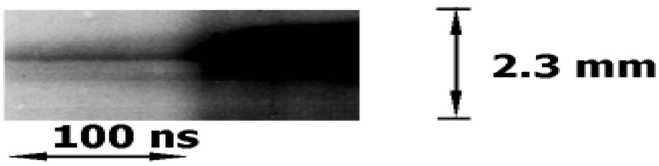

Fig. 2. The radial optical streak photography of a fibre neck.

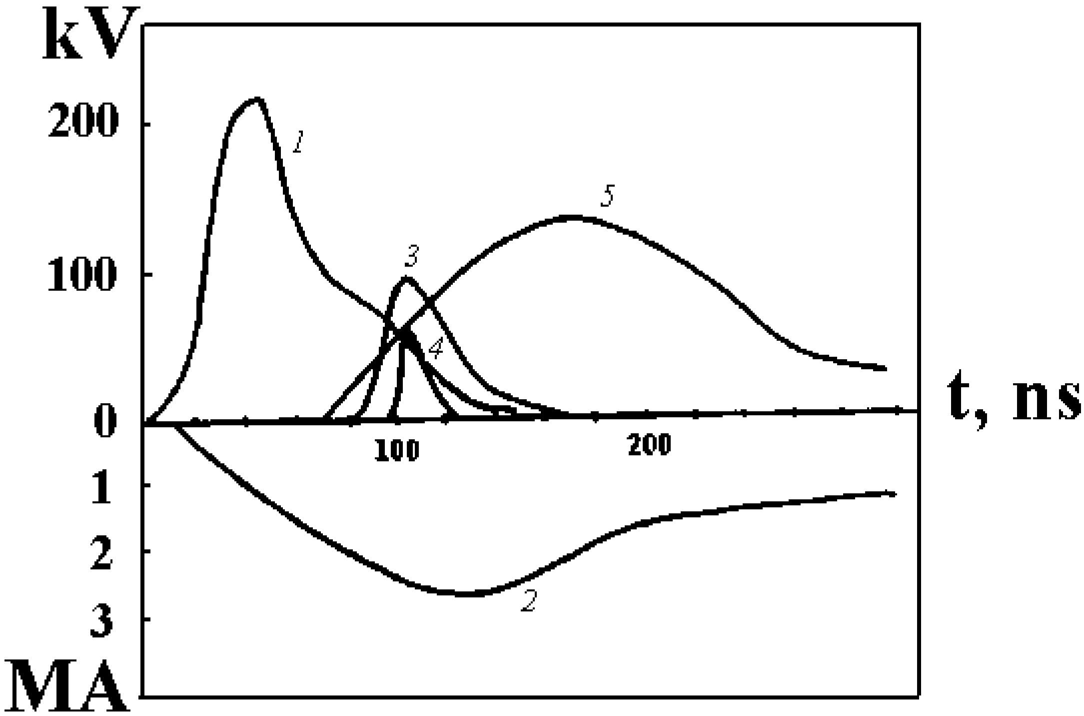

Fig. 3. Voltage (1), current (2) oscillographic traces and soft X-ray radiation signals obtained with 5µm mylar filter (3), 10µm mylar filter (4) and no filter at all (5).(The Z-pinch load - a carbon filled agar-agar fibre of 0.1 g/cm^3 density and with neck diameter < 1 mm).

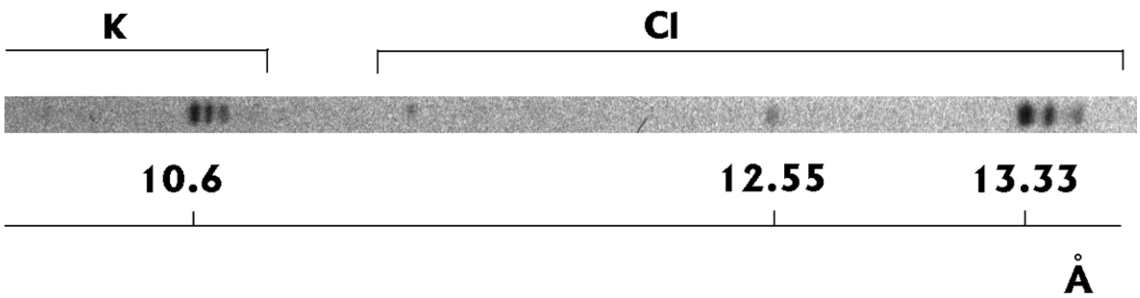

Fig. 4. The third reflection of [H]-and [He]-like chlorine and potassium ions spectrum in the Z-pinch constriction (negative).