*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-1.133 (2005)*

Diagnosis of Wire-Array Implosions Using X-ray Frame Camera

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1. Introduction

Great progresses have been made recently in investigation of Z-pinch implosions. Using cylindrical tungsten wire arrays as a load, implode by a current of 20MA, an intense x-ray pulse was obtained with power up to 200TW and energy of nearly 2MJ[1]. It's the most intense soft x-ray source ever obtained in laboratories. In view of the lower cost than laser-driven ICF, such a progress brought forward great interest in Z pinches all over the world. Abundant researches, both experimental and theoretical ones included, have been carried out in accelerators of different current levels. Some physical models, such as models of "snowplough" and of "thin-shell", were established to describe the implosion process, assuming that the plasma from the wires forms a uniform shell and then the MHD instabilities are dominant. But in some experiments[2], no uniform plasma shell was found. Moreover, some phenomena observed in these experiments cannot get reasonable explanations from such physical models. Further researches are necessary to gain more understanding of the dynamic imploding process. This paper is description of some results of experiments performed in the facilities of Angara-5-1 (located at *Troitsk Institute for Innovation and Thermonuclear Researches, Russia)* and QiangGuang-1 (located at *Institute of Northwest Nuclear Technology, China*), including some experimental results of plasma formation and the fast evolution process of plasma radiation during the stage of inward acceleration and some analysis to these phenomena. Results show that it is more consistent with the model of "radial plasma shower" than other ones.

2. Generator and experimental diagnosis

The Angara-5-1 generator consisting of eight modules can provide load current of about 2.5~3.5MA with a rise time of 60ns. X-ray power level is up to 4TW. The QiangGuang-1 generator has only one module, and load current of 1.5MA with a rise time of 80ns can be provided. X-ray power level is about 1TW.

Single tungsten wire array and tungsten nested wire array were performed in our experiments, as listed in Table 1. Some diagnostic equipments including ns X-ray Multiframe Camera (1.5ns, 0.2~10keV), ps X-ray Multiframe Camera (80ps, 0.2~10keV), probing laser (with a wavelength of 266nm) and x-ray power meter are used.

Table 1 Liner Parameter

Liner	Height of wire-array mm	Diameter of wire-array mm	Diameter of wire μm	Number of wires	Mass per unit length μg/cm	Notes
Single array	15	12	5,6	40,48,60	118~327	On Angara-5-1
	20	8	4,5,6	32	77~174	On Qiangguang-1
Nested wire array	15	12/6	5, 6	40+20	227~327	On Angara-5-1

3. Early stage of implosion

Nanosecond X-ray Multiframe Camera is mainly used to record the spatial distribution of x-ray radiation at an interval of several nanoseconds. The earliest photograph obtained at the Angara-5-1 facility, at the moment 124ns before x-ray peak (near to current start with a value of +2ns), is shown in Fig.1 for the single array consisting of 60 tungsten wires with wire diameter of 5µm. Obviously five current channels can be seen from the graph, and the luminance of these channels is not uniform both in the axial direction and in the azimuthal direction. It shows that the current didn't flow uniformly through the load.

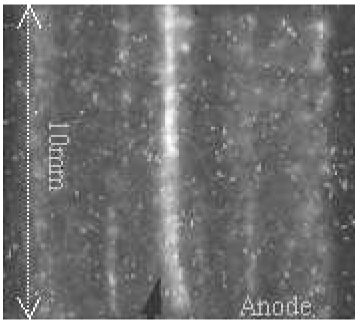


Figure 1. X-ray Frame Image of Single Tungsten Wire Array

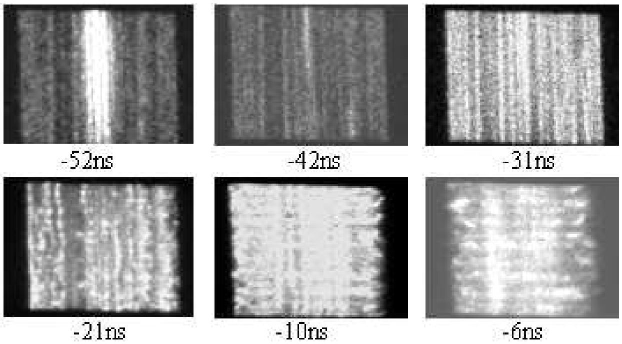


Figure 2. X-ray Multiframe Image of Nested Tungsten Wire Array

Figure 2 is for the nested array, in which the outer array consists of 40 tungsten wires and the inner array consists of 20 tungsten wires, with wire diameter of 6µm. Images show that the wires luminant uniformly till 31ns(i.e. -31ns) before x-ray peak and at the moment of -21ns plasma in some area started to implode. Plasma formation in the outer array prolonged to the moment of -10ns, i.e., nearly 90% of the total time of the implosion. It's noticeable that at this moment (-10ns) the inner array started to radiate uniformly at its initial position. Apparently that plasma of the inner array formed much later than that of the outer ones. Till the moment of -6ns, when the outer plasma had started to implode integrally, the inner ones still stay at its initial

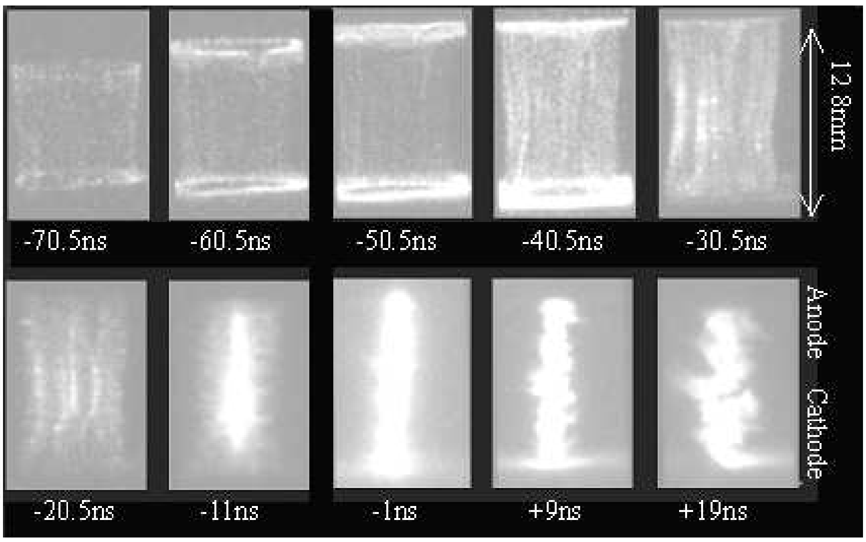


Figure 3. X-ray Multiframe Image of Single Tungsten Wire Array

position and radiate uniformly. During the process of plasma formation no plasma expanded outward due to the existence of magnetic field. In addition the plasma that formed earlier moved inward under the control of the magnetic field and, as a result, a portion of plasma reached pinch axis much earlier. This phenomenon is more remarkable for single array. Thus it is difficult to form a uniform plasma shell for load of wire array. In experiments performed on QiangGuang-1 generator, when during the stage of plasma formation, x-ray radiation was found first appear in the middle area of the array, then in the area near cathode and near anode as the "ring" drift to both sides at a rate of 2.4×10^7cm/s (near cathode) and 5×10^6cm/s (near anode), respectively (Fig.3). Radiation of the rings comes from the interaction of the electrode-jet plasma with plasma of the load. No similar phenomena were observed in experiments on other generators. It may be related to the structure of the electrodes and to the load parameters.

4. Stagnation and radiation stage

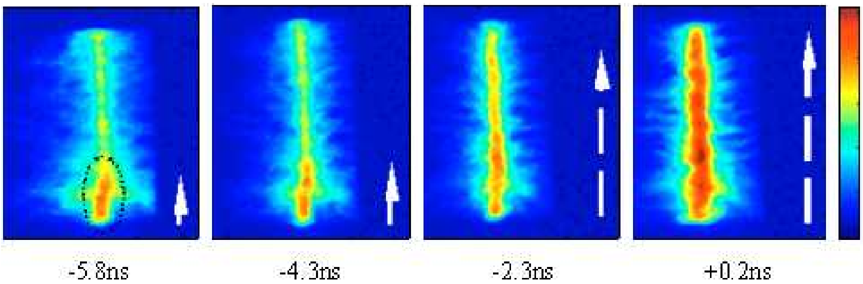
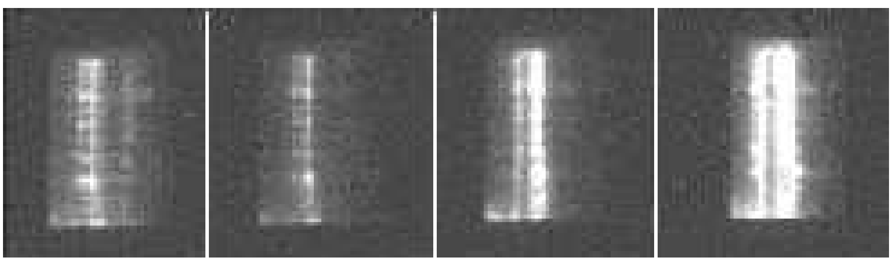


Figure 4 Evolution of hot region for single array consists of 60 wires

Photographs obtained by ps Multiframe Camera on Angara-5-1 show that the x-ray radiation process is asynchronous along the axis during stage of stagnation. For single array the hot spots start on the cathode and extend to the anode in 6ns, similar to the "chain effect" in gas-puff experiments. For nested array the hot spots also start on the cathode, but extend to anode in less than 2ns. But in experiments performed on QiangGuang-1, the hot spots start in the area between the electrodes and extend to both sides beyond 20ns. The asynchronism characteristic of axial x-ray emission directly exerts an influence on the x-ray power and FWHM of x-ray pulse. The better asynchronism results in the higher x-ray power and the smaller FWHM.



-9.4ns -7.9ns -5.9ns -3.4ns

Figure 5 Evolution of double radiation region

Double plasma region was observed for single array experiments on Angara-5-1. Figure 5 shows the evolution of the double plasma region from –9.4ns to –3.4ns before the first x-ray peak. Seen from these images that there is only one axial radiation region at -9.4ns, and at -5.9ns this region evolved into two separate regions. It was also observed by ns Multiframe Camera fit orthogonal to ps Multiframe Camera except for the different space interval. Explanation for this phenomenon needs further investigations. Rate of r0/r1, where r0 stands for initial radius of array and r1 stands for minimum radius, distinctly decreased, from which we can infer that the kinetic energy decreased with magnitude more than 30%, but there is no noticeable dispersion of total x-ray energy compared with other shots of the same kind of load. It indicates that the kinetic energy is not the only source of x-ray radiation. In addition, radiation intensity varies without spatial displacement for these hot spots after the peak of x-ray pulse.

5. Conclusion

In experiments performed on different generators series of ps and ns photographs, which reveal the plasma evolution during every stage of the implosion, were obtained. Prolonged plasma formation, fast evolution of central radiation region and double plasma region were observed. These results are of great importance for further optimization in the design of load and electrode structure.

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