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Study of Tungsten Wire Array Implosions on Qiang-Guang 1 Facility

T.P. Peng, R.K. Xu, Z.H.Li, J.L.Yang, Z.P. Xu, C. Guo, and S.L. Jiang

Institute of Nuclear Physics and Chemistry, P.O.Box 919–212, Mianyang 621900, China

Abstract: Tungsten wire array implosions were investigated experimentally on Qiang-Guang 1 facility employing an X-ray power meter (XRPM), a time-resolved one-dimensional (1D) X-ray imaging system and a pinhole camera. The research was focused on the X-ray radiation characteristics of tungsten wire array driven at a current level of 1.5MA. The wire array used in the experiment was in 8mm diameter and 20mm length comprising 32 5μm-diameter tungsten wires. The experimental results give X-ray yield up to 36.6 kJ. Estimation gave the decreasing rate of X-ray emission of about 6.4×10^6 cm/s. It also shows that the peak time of X-ray radiation was prior to the time when plasmas were compressed into the on-axis region.

Keyword: Z pinches, multi-wire array, X-ray radiation characterics, plasma

1 Introduction

Z pinches are very efficient for producing X-ray. At present, many Z-pinch devices have achieved >10% conversion of stored electrical energy into X-ray.[1-3] The Qiang-Guang I facility (QG-1) located at Institute of Northwest Nuclear Technology can store up to 260 kJ electricity energy, 80 kJ can be delivered into a pinch load. It can be used to investigate Z-pinch implosion process in the case of light loads, such as the process of plasma formation and merging, plasma instability and its influence on the implosion, spatial structure and characteristics of X-ray radiation, etc.. For searching a way to achieve high X-ray power and conversion coefficient of electric energy to X-ray energy, investigation the X-ray radiation characteristics of tungsten wire array was carried out on QG-1 facility in 2003.

2 Experimental setup

Theoretical analysis[4] and 1D calculations show that QG-I can drive a Z-pinch load mass from 30μg/cm to 150μg/cm at a current level of 1.5MA. It means that the array load consisting of 10 to 50 tungsten wires with wire diameter of 5 μm can be used. On the other hand, Deemey's research[5] shows that the X-ray power is closely related to the gap of adjacent wires. According to the analysis above, the three kinds of loads studied in the experiment comprise 32 5μm-diameter tungsten wires with geometry of 6mm, 8mm and 10mm, respectively. The initial length of the wire array is 2cm. Temporal distribution of the X-ray radiation power were recorded employing an X-ray power meter (XRPM). A detector, which didn't view the pinch load to avoid the background lights from infrared to ultraviolet rays, was used to record the fluorescence emitted by an X-ray sensitive scintillator. The factors determining time resolution of < 3 ns and a flat energy response are described in Ref.[6]. Radial distribution of X-ray power as a function of time was recorded by a 1D X-ray imaging system.[7] A pinhole camera was used to record image of time-integrated X-rays.

3 Experimental results and discussion

Time-integrated pinhole images are shown in Fig.1. The experimental measured axis length was about 1.6 mm, as a fraction of near-anode area was obstructed from viewing. There are three individual pinholes covered with 3 μm Al filters, without any filters, and with 0.73 μm C8H8 add 0.1 μm Al filter, respectively, i.e., images of photon energy of > 1 keV in the first pinhole, including visible light in the second, and < 1 keV in the third were obtained. Fig.1 shows that the plasmas were compressed with a better axial uniformity. The emission region was in a radial scale of 1.5 mm to 2 mm as the middle images show. X-ray photon energy of sub-keV or higher was mostly located in a sub-mm radial region seen from the other two images. In other words, the X-ray radiation with higher photon energy mostly came from the pinch center around which the X-ray emission has lower photon energy. In addition, there was no noticeable difference in the final X-ray radiation distribution for different loads.

Under the same condition, the XRPM has the same sensitivity to effectively compare the variation of the X-ray radiation between different loads. Typical X-ray pulse, i.e., X-ray radiation power as a function of time, is shown in Fig.2 together with corresponding load current. The rise time and peak value of load current are 62 ns and 1.54 MA, respectively. The rise time of X-ray pulse and pulse duration (FWHM) are 15 ns and 21 ns, respectively. The time of maximum X-ray power was at 5 ns after the time of peak current value. The X-ray power and yield are 0.91 TW and 33.4 kJ, respectively.

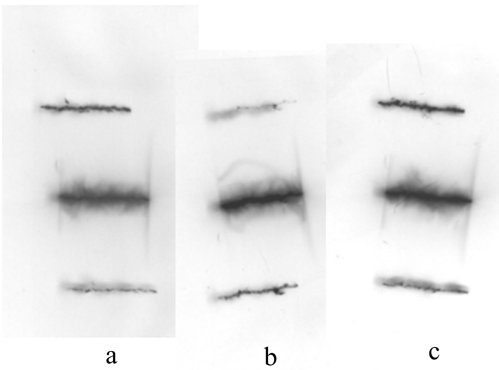

Fig.1 Time-integrated pinhole images with 50μm spatial resolution for three kinds of loads with different array diameters. a): D=8mm; b) D=10mm; c) D=6mm

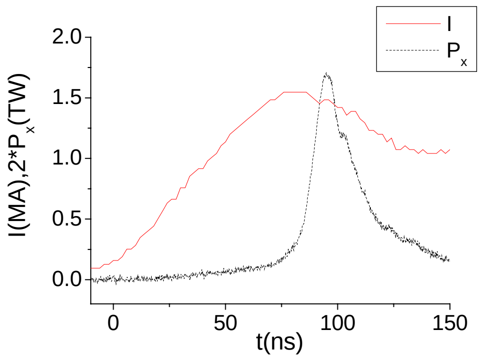

Fig.2 Typical X-ray power waveform obtained by XRPM together with current waveform in shot 03197. The load with a diameter of 8mm consists of 32 tungsten wires with wire diameter 5μm.

Experimental data, i.e., X-ray power and X-ray yield obtained by XRPM, of the same two pinch loads have a fluctuation because of the instability. However, on the whole, the fluctuation is smaller compared to the fluctuation between different pinch loads as shown in Fig.3 and Fig.4. It indicates, by the way, that the loads prepared in our experiments were well controlled in their quality to a certain extent. Attributed to the well-fabricated wire array, the results definitely show that the array with diameter of 8 mm was of the highest X-ray power and yield than the others.

Radial distribution of X-ray radiation power as a function of time was measured by the 1D X-ray spatial-temporal imaging system with axial and radial fields of view of 2.2 mm and 5.9 mm, respectively. The two typical images obtained in shots 03197 and 03195 for different loads of diameter10mm and 5mm are given in Fig.5 and Fig.6. It is shown that the initial time of X-ray radiation on axis was prior to that of near-axis region in Fig.5. The region of X-ray radiation first extended to 1.4 mm and lasted about 15ns, and then gradually decreased at a rate of 6.4×10^{6}cm/s. Same as Fig.5, Fig.6 also indicates that the X-ray radiation started from the axis and lasted about 15 ns first reaching quickly a maximum radial size, then gradually decreased.

The streak images of X-ray radiation distribution as shown in Fig.5 and Fig.6 lead to the following points:

1) A fraction of plasmas reaches to the axis at a relatively earlier time, the remaining part of the plasmas gradually fills the whole region, then stagnated with X-ray burst. No plasmas-shell was observed in this experiment. It may be attributed to the relatively large gap between adjacent wires, as has been confirmed by previous researches that the plasmas breaking away from adjacent wires are not well merged.

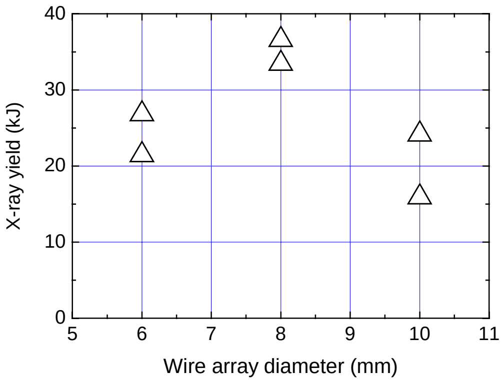

Fig.3 Comparison of X-ray yield as a function of diameter of wire arrays for all six shots

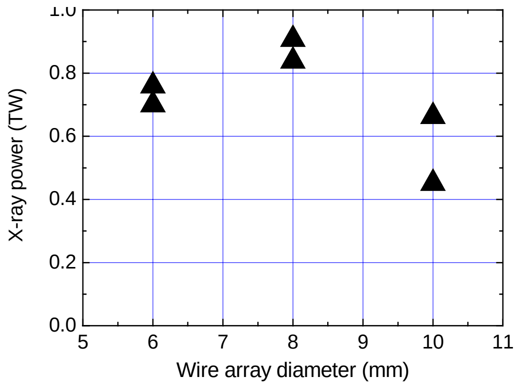

Fig.4 Comparison of X-ray power as a function of diameter of wire arrays for all six shots

2) The plasmas are distributed in a radial region of 1.4 mm to 1.5 mm for some time corresponding to the scanning images, as the X-ray radiation only comes from the implosion. It means that the convergence ratio r_0/r_1, where r_0 was initial radius of wire array and r_1 was radius of the plasmas, was from 5 to 7 for loads of 8 mm and 10 mm diameter at this stage. It's relatively small comparing to the results of experiments conducted on Angara-5-1 facility. As well know that a higher r_0/r_1 means a higher temperature and a shorter X-ray pulse duration, that's the reason for the relatively wider pulse duration as shown in Fig.2.

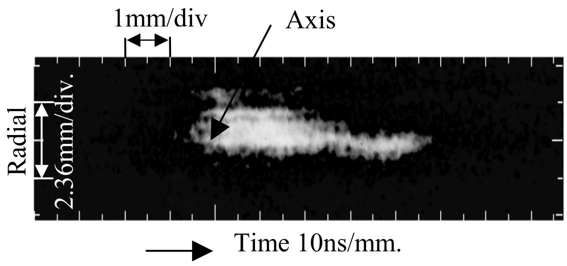

Fig.5 Radial X-ray radiation distribution in shot 3197 with a spatial resolution of 0.15mm

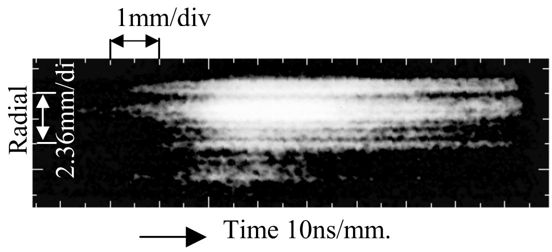

Fig.6 Radial X-ray radiation distribution in shot 3195 with a spatial resolution of 0.15mm

3) The strong X-ray emission in a steady radial region lasted about 15ns. According to the brightness of the scanning images, the radially-integrated X-ray radiation intensity gradually decreased with the decreasing X-ray radiation region. It indicates that the strongest X-ray radiation was prior to the stagnation of plasma. A qualitative explanation for this phenomenon is that there exists a equilibrium of outward plasma pressure with the inward magnetic pressure on the boundary as shown in Fig.5, i.e., when internal energy of plasmas and its outward pressure gradually increased with the plasmas pouring into the boundary in the leading edge of load current, the magnetic pressure increased synchronously, that results in a balance and a steady boundary for a few nanoseconds at this stage. On the other hand, the plasmas will deliver its energy in the form of X-ray

radiation in the rear edge of the current waveform, which causes a decrease of plasma temperature. While the pinch force also decreased with the decreasing of load current, the balance was kept and lasted for a while. When the balance was broken, the pinch force was dominant, which resulted in the decrease of plasmas distribution. Further investigation of this process by means of laser probing with temporal and spatial resolution is under consideration.

4 Conclusion

1) Experiments with different kinds of loads was successfully performed on QG-I facility. Maximum X-ray yield was 36.6 kJ for an optimized load with a diameter of 8 mm, consisting of 36 wires with a wire diameter of 5μm.

2) The most intensive X-ray radiation period corresponds to the steady radial region in which the X-ray radiation sustains for a more or less long time, and then its intensity gradually decreases with the reducing of X-ray radiation region.

5 References

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