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Tungsten Wire Number Dependence of the Implosion Dynamics at the Z Accelerator.

Shortened title: Wire number dependence of z-pinches

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Abstract. We report results of the experimental campaign which studied the initiation, implosion dynamics and radiation yield of tungsten wire arrays as a function of the wire number. An optimization study of the x-ray emitted peak power, rise time and FWHM was effectuated by varying the wire number while keeping the total array mass constant and equal to ~ 5.8mg. The driver utilized is the ~20-MA Z accelerator in its usual short pulse mode of 100ns. We studied single arrays of 20-mm diameter and 1-cm height. The smaller wire number studied was 30 and the largest 600. It appears that 600 is the highest achievable wire number with present day's technology. Radial and axial diagnostics were utilized including crystal monochromatic x-ray backlighter. An optimum wire number of ~370 was observed which is very close to the routinely utilized 300 for the ICF program in Sandia.

INTRODUCTION

The 20-mm diameter, 10-mm high, 300-wire, ~5.8-mg total mass, W wire array is widely used with the Z-accelerator in Sandia National Laboratory and is considered the radiation source of choice for Inertial Confinement Fusion (ICF) research. It is a design that was developed to optimize radiated power based on array height and mass only. Over the years, a number of experiments have been conducted which indicate that the radiated x-ray wire array power should also be optimized based on both wire number and total array mass. In particular, experimental results show that higher number wire arrays provide higher powers for broadband emission and k-line radiation. Similarly, arrays lighter than 5.8mg, which give faster ~80-ns implosion times, yield higher peak radiated x-ray power and faster rise times. These observations suggest that the mass and wire number of the 300-tungsten wire array are not optimized for maximum peak power. To this end, a systematic, controlled

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experimental campaign was undertaken to investigate the effect of wire number only keeping the array mass the same and at the assumed optimum of ~ 5.8 mg.

Wire numbers ranged from 30 to 600, corresponding to wire diameters between 35.85μ and 8.01μ, and inter-wire gaps of 2.09mm down to 0.104mm were studied. A similar mass optimization of the array at constant, optimum, wire number is also needed and is advisable to follow the present investigation.

The first Al array wire number optimization experiments were performed by T. Sanford [1] with the short, 35ns, mode of Saturn accelerator. A critical inter-wire gap (IWG) of ~ 1.3mm was measured, below which the radiated x-ray power output increased dramatically while the x-ray rise time remained approximately the same.

More recent wire number scan experiments by Coverdale *et al.,* [2] again with the Saturn accelerator but in a longer pulse mode (time to pinch 165ns) show similar behavior of the Al arrays. In addition to exhibiting a critical IWG (Inter-Wire Gap) like the previous work, these experimental results also revealed an optimum gap of (~ 0.7mm), below which the output power appears to decrease while the rise time increases.

In our W wire number scan experiments we varied only the wire number and kept all the other load parameters strictly the same, that is the total mass, the array diameter, the height, the gap between the wire array edge and the return current can as well as the final coaxial MITL (Magnetically Insulated Transmission Line) gap. We made a special effort to extend the measurements to as small an IWG as technically possible which turned out to be 0.104mm. Our results clearly demonstrate in addition to the critical IWG at ~0.3 mm, an optimum IWG of 0.17 mm which is approximately 4 times smaller than that observed in aluminum.

EXPERIMENTAL ARRANGEMENT

The experiments presented in this paper were performed with the Z accelerator, which can drive up to 20MA current within ~100ns through a wire array load. We fired 17 shots, all with approximately the same 5.8-mgr mass. Despite the fact that the total cross sectional area of the arrays remained the same, and consequently the total load initial inductance and resistance, the current per wire unavoidably did not. Therefore our results may be due either to the IWG gap effect on the pinch dynamics or the current per wire or both.

The load hardware for these experiments was the same as in reference [3] with the final coaxial MITL anode-cathode gap chosen to be 3 mm. The return current cylindrical electrode which surrounded the wire array had nine slots around its circumference corresponding to an equal number of line of sights (LOS) where the various diagnostics observing the pinch were located [4]. The load current was measured with two magnetic flux monitors (B dots) which were located at the anode side of the central biplate MITL [3], 6cm away from the pinch axis and in almost diametrically opposite sites 150° apart.

EXPERIMENTAL RESULTS

During the 17 shots we collected a wealth of experimental results pertaining to the power, energy, rise time, FWHM, peak kinetic energy, and spectra of the x-ray radiated power. In addition we measured the spatial and temporal evolution of the array and the precursor and pinch plasmas both axially and radially. Special attention was paid to observe the precursor plasma and measure the time of its arrival on axis. In this paper we describe only a part of the obtained results: mainly energetics and rise times.

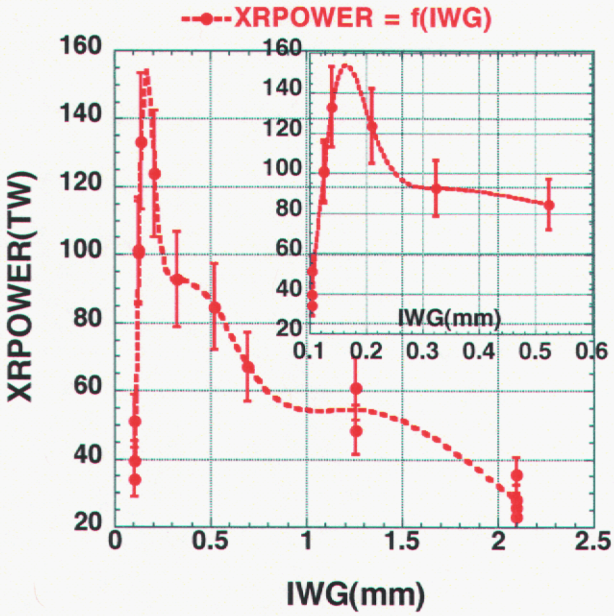

Fig. 1

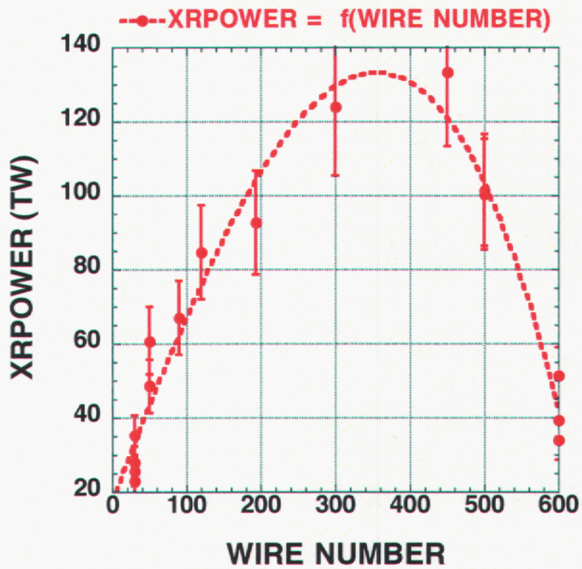

Fig. 2

FIGURE 1. X-ray peak power results as a function of IWG (Inter-Wire Gap).

FIGURE 2. X-ray peak power results as a function of wire number in the array.

Figures 1and 2 summarize all x-ray peak power measurements for the different inter-wire gaps and wire numbers. Figure 1 presents the dependance of peak x-ray power (XRPOWER) on the IWG. The insert zooms in the region of the smaller gap studied. Figure 2 shows the same results but now as a function of the wire number.

The peak power increases as the wire number increases or equivalently as the IWG decreases. However this trend does not continue at infinity. There is an optimum peak power output at approximately 370 wires or 0.13 mm IWG.

Figures 3 and 4 compare the rise time results of reference [2] (Figure 3) for aluminum with our tungsten results (Figure 4). Both experiments show an optimum IWG where the rise time becomes minimum. For the aluminum this gap is 0.7mm and for W 0.13mm.

It appears that this behavior observed first in aluminum and now in tungsten may be a universal phenomenon for all the materials. Just the location of those behavioral changes may vary from material to material. The results are suggestive to the fact that higher melting point and higher resistivity materials like the W have optimum and critical IWG of smaller values unlike the aluminum which exhibits similar behavior at relatively larger IWG.

The above trends observed in the W and Al array behavior are most probably due to 3D effects. 2D models can explain why when going to a larger number of wires the pinch quality and the power output of the array increase; however, they cannot explain the pinch quality decrease as the wire number becomes too large. Unfortunately to our knowledge there is not yet available a 3D model capable of explaining the behavior of the arrays at very large wire numbers.

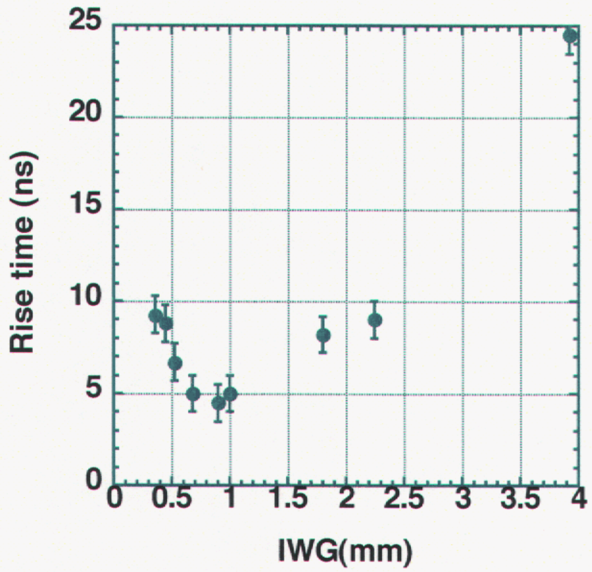

Fig. 3

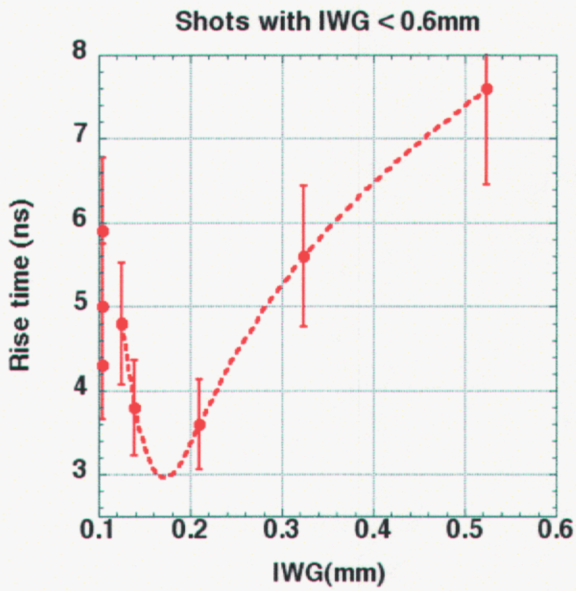

Fig. 4

FIGURE 3. Rise times for **Al** (aluminum) of Ref. [2].
FIGURE 4. Rise times for **W** (tangstem) of present work.

The precursor plasmas observations and measurements and the assumption of the stabilizing effect that may have a plasma distribution in the the array interior offer a plausible explanation. According to Ref. [5], as the wire number increases the ablated mass distribution inside the array becomes more azimuthally symmetric and leads to more stable pinches. However, when the IWG becomes smaller than the optimum, the global magnetic field dominates the private magnetic field, and the flow of ablated mass and plasma inside the array quenches very early in the driving pulse current. This happens when the IWG is approximately equal to π times the wire core size. The array then implodes like a thin plasma shell which is very prone to R.T. instability. It behaves like a thin foil.

CONCLUSION

We have measured the x-ray power output, energy and rise time of the 20 mm diameter, 10mm height, W wire arrays of mass 5.8mg for a wire number range between 30 and 600 wires. In addition we observed the precursor plasma behavior and the array implosion dynamics. The stagnated plasma behavior was also followed with x-ray self emission imaging. The power output, energy, rise time and stagnated plasma size are a strong function of wire number or interwire gap. A critical and optimum wire number and IWG were observed for W similar to those of Al but at four time smaller IWG. It is suggestive that this behavior is a universal phenomenon and most probably occurs in all materials at different wire numbers or IWG locations.

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