

# WIRE-ARRAY HOLDER CRITICAL IN HIGH WIRE-NUMBER Z-PINCH IMPLOSIONS\*

**T. W. L. Sanford, R. C. Mock, T. L. Gilliland, J. F. Seamen, R. J. Leeper**

*Sandia National Laboratories\*  
Albuquerque, NM, 87185 USA*

**R. G. Watt, R. E. Chrien, G. C. Idzorek, D. L. Peterson**

*Los Alamos National Laboratory  
Los Alamos, NM, 87545-0010 USA*

**P. U. Duselis**

*Cornell University  
Ithaca, NY, USA*

## Abstract

The quality of high wire-number z-pinch implosions on Z using a dynamic-hohlraum configuration is significantly affected by the method of holding the wires. The two arrangements discussed here have led to differences of a factor of  $1.6 \pm 0.2$  in radial x-ray power, where the higher power is produced by the holder with the superior current contact at the cathode. In support of this observation, single exploding wire data taken on a 250-ns pulser indicate that improved wire-electrode contact at the cathode permits greater energy delivery to the wire prior to current shunting to surrounding wire-plasma corona.

## I. INTRODUCTION

The z-pinch configuration discussed here is that of the DH (dynamic hohlraum [1]) on Z [2]. This configuration has been developed as an intense source of x-rays for high-temperature ( $> 215$  eV) radiation transport [3] and ICF [4, 5, 6] studies. Two arrangements of holding and positioning the wires have been employed with this configuration: one is referred to as the “flop over” (Fig. 1), and the other as the “hang-down” (Fig. 2). Because of the high inductive voltages generated across the wire-array holder, it has been generally thought that little difference in the quality of the implosion would exist between differing methods of containing the wires with their associated differences in how the wires made electrical contact at the electrodes. In contrast to this expectation, a significant difference in radial as well as axial power is measured for the two arrangements discussed here.

## II. WIRE-ARRAY LOAD

The load for both arrangements was identical. It consisted of two arrays of tungsten wires in a cylindrical z-pinch configuration to form an imploding plasma shell [7], which generated x-rays upon impacting a low-opacity cylindrical target centered on the z-axis. In this arrangement, the high atomic-number plasma shell acts as a radiation case, trapping radiation generated within the target. The trapped radiation flows from the interior through an REH (radiation exit hole) into a region of interest, such as into a secondary hohlraum mounted above the REH for ICF studies [4]. Radiation measured in the radial direction, in contrast monitored the quality of the pinch.

For these applications the wire arrays had lengths of  $\sim 10$  mm, were mounted at radii of 20 and 10 mm, were composed of 240 and 120 wires, and had total masses of  $\sim 2$  and 1 mg, respectively. The high number of wires helped insure that the resulting imploding plasma shell acted as a relatively uniform hohlraum wall that developed high power as it impacted the target [8, 9]. The target was a solid cylinder of 14 mg/cc  $\text{CH}_2$  foam with a radius of 2.5 mm. Its mass approximately equaled the 3-mg combined mass of the two tungsten arrays. An 18-slot current return can surrounded the pinch. The power exiting the REH and emitted radially through one of the 4.8-mm wide slots was measured using filtered XRDs, whose energy was scaled by simultaneous bolometer measurements.

During vacuum pump down, the distance between the vertical AK gap in the load increases slightly. Owing to this change, the wires must be free to slide along one of the current contact points with the electrodes. This

---

\*Sandia is a multiprogram laboratory operated by the Sandia Corporation, a Lockheed Martin Company, for the U.S. Department of Energy under Contract No. DE-AC04-94AL85000.

# Report Documentation Page

Form Approved  
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE <b>JUN 2003</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>Wire-Array Holder Critical In High Wire-Number Z-Pinch Implosions</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Sandia National Laboratories* Albuquerque, NM, 87185 USA</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. IEEE International Pulsed Power Conference (19th). Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.</b>					
14. ABSTRACT <b>The quality of high wire-number z-pinch implosions on Z using a dynamic-hohlraum configuration is significantly affected by the method of holding the wires. The two arrangements discussed here have led to differences of a factor of <math>1.6 \pm 0.2</math> in radial x-ray power, where the higher power is produced by the holder with the superior current contact at the cathode. In support of this observation, single exploding wire data taken on a 250-ns pulser indicate that improved wire-electrode contact at the cathode permits greater energy delivery to the wire prior to current shunting to surrounding wire-plasma corona.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

### A. Flop-over Picture



### B. Illustration

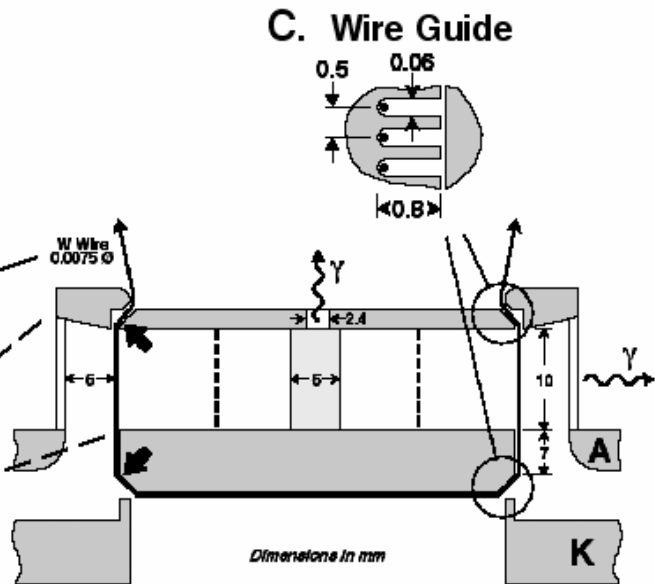
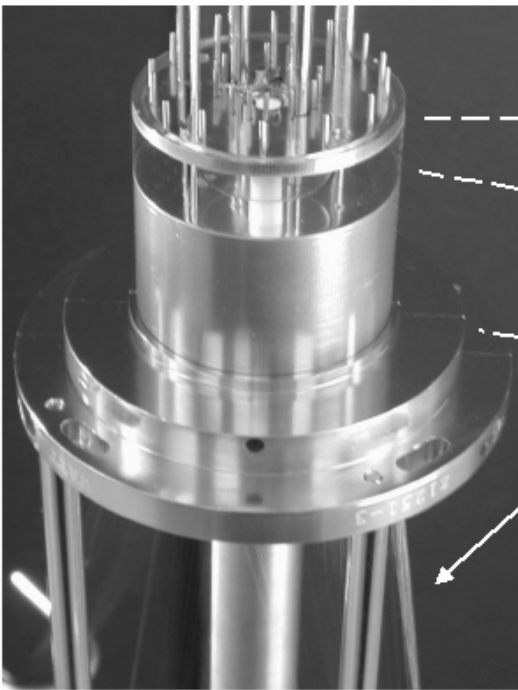
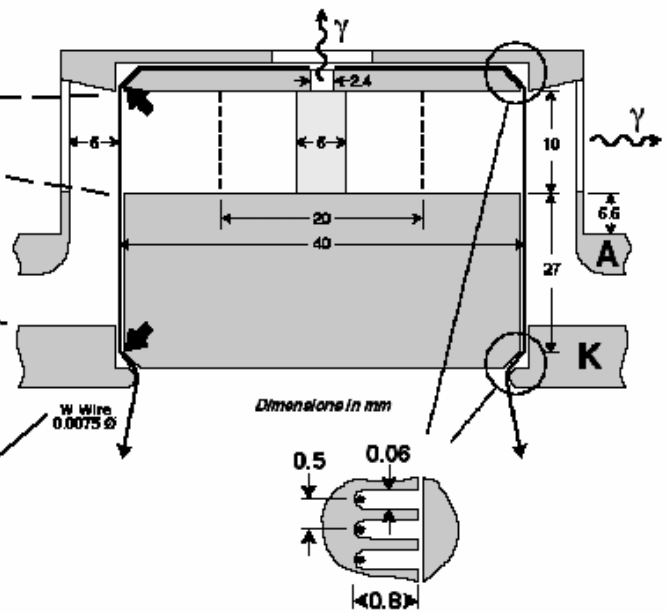


Figure 1. Flop-over arrangement.

### A. Hang-down Picture



### B. Illustration



### C. Wire Guide

Figure 2. Hang-down arrangement.

freedom was accomplished in the “flop-over” arrangement by initially draping the wires over the cathode-anode structure as shown in Fig. 1 (as in the original high-wire number loads developed for Saturn [see Fig. 1 in Ref. 10]), where an even number of equally-spaced guides position the wires azimuthally (Fig. 1C). The over hangs adjacent to the guides both (a) help center the wires in the 60- $\mu\text{m}$  wide guides and (b) force current contacts at the points indicated by the broad arrows. The wires are tensioned by weights (0.9 g) attached to the ends of each wire. The entire arrangement is then inverted (hence the name “flop-over”), placing the anode on the top, as illustrated in Fig. 1. In this orientation, the array is installed into Z. This arrangement has been used for the initial Z shots [2, 7] and the DH measurements discussed in references [3, 4]. Unfortunately, the hoop super structure (Fig. 1A), which permits tensioning the wires by the weights, is positioned above the REH. Often this structure interferes with diagnostic lines-of-sight viewing physics experiments also placed above the REH.

Accordingly, Sandia developed a second arrangement, the “hang down” (Fig. 2) [11], eliminating the super structure. In this arrangement the wires were effectively draped across the surface above the anode and allowed to hang-down through a gap in the radial feed at the junction with the vertical power feed (hence the name “hang-down”). Weights attached to the wire ends again provided the necessary tension. In this case, explicit current contact was made below the cathode surface as indicated by the broad arrow in Fig. 2. In this arrangement, contact with the cathode is less well defined, as contact points could be made in principle anywhere along the vertical power feed. A related situation occurs with the “flop-over” arrangement. In this case, however, the length along the vertical cathode surface is much reduced. In both arrangements, the tension on the wires and positioning in the guiding grooves are the same.

## II. RESULTS

The extra length in the vertical feed of the “hang-down” relative to the “flop-over” arrangement contributes only  $\sim 0.2$  nH to the total system inductance, and leaves the peak load current unaffected between the two arrangements (Fig. 3). In Fig. 3 (as well as Fig. 4) the ordinate is plotted as a function of the first-to-last spread of the 36 power pulses feeding the Z insulator stack [2]. In all cases, within the measured spread (17-33 ns) for the 9 “flop-over” and 12 “hang-down” shots discussed here, no decrease in load current or pinch quality (radial or axial) with spread was measured.

Figures 4A and 4B illustrate the factor of  $1.5 \pm 0.2$  increase in FWHM (full-width half-maximum) of the radial power pulse and the associated factor of  $1.6 \pm 0.2$  decrease in peak radial power, when contrasting “flop-over” with “hang-down” powers. Note also the significant increase in rms shot-to-shot variation measured with the “hang-down” relative to the “flop-over” arrangement,

namely 60% and 100% in the radial FWHM and peak power, respectively. Axial power measurements between the two arrangements were limited. Again, however, the peak powers measured out of the top (and a bottom REH) were less when the “hang-down” was used.

## III. DISCUSSION

Past measurements with high-wire number arrays have shown the importance of maintaining azimuthal symmetry for reproducible high x-ray power (see Fig. 5 in Ref. 12 or Ref. 13, for example). Here, the azimuthal positioning and tensioning of the wires was identical between the two arrangements. The principle difference between the arrangements was the position of the wire-electrode current contact at the cathode. Contact at the cathode may be crucial as supported by the measurements made at Cornell University using a 250-ns pulser to explode single 3-cm long, 25-mm copper wires when the only parameter varied was the wire-to-electrode connection (Fig. 5) [14].

The pulser increased current through the wire at a rate of  $\sim 15$  A/ns. Initially, the resistance of the wire increases due to Joule heating. Between 60 and 90 ns after the current pulse starts, the voltage peaks (Fig. 5). At this time plasma forms around the wire and current is shunted to the lower resistance plasma. As a result, the voltage drops quickly to near zero [15, 16], and heating (and associated energy deposition in the wire) diminishes. Figure 5 shows that the time at which shunting occurs depends on how the wire contacts the electrodes. The lowest peak voltage results when the wire is connected to the electrode with a simple pressure (P) contact, as illustrated in Figs. 1 or 2, when the wire is forced to the electrode by a weight tensioning the wire. Soldering (S) the wire to the anode (A) marginally increased the peak voltage and heating period, while soldering the wire to the

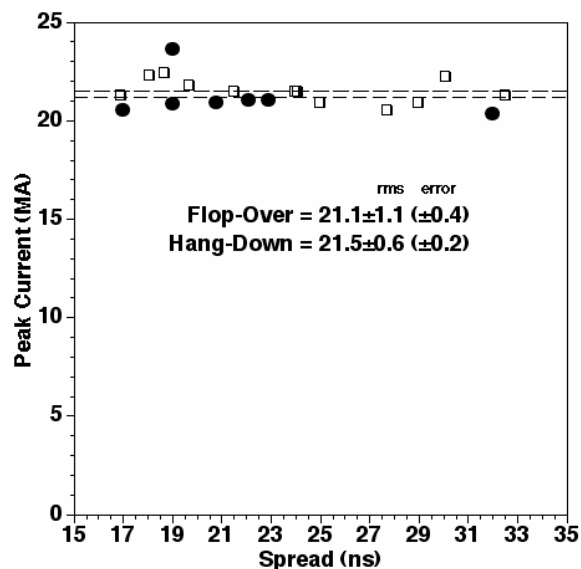


Figure 3. Peak load current versus spread in power-flow at insulator stack.

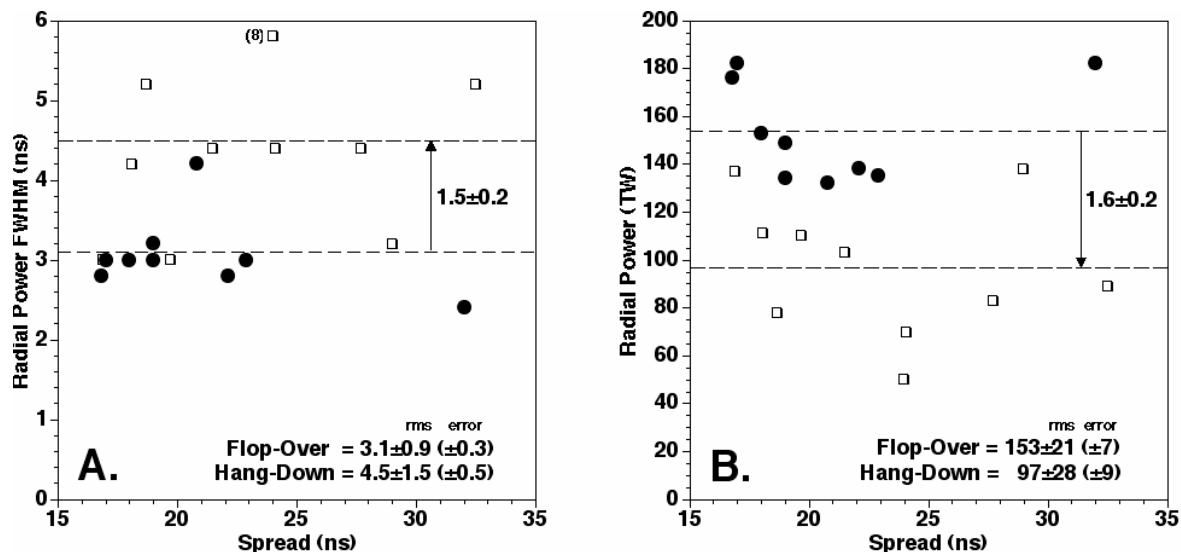


Figure 4. Radial power (A) pulse width and (B) peak versus spread in power-flow at insulator stack.

cathode (C) significantly increased the peak voltage and heating period. Soldering the wire to both the anode and cathode produced the maximum heating. Early in the current pulse the poor connections between the wires and electrodes may have heated and ejected electrons. These electrons would strike the plasma sheath, especially if they came from the cathode, and thus initiate an earlier shunt.

#### IV. SUMMARY

The less well-defined current contact at the cathode, the fundamental difference between the two arrangements, is the likely reason for the degraded pinch performance when using the “hang-down” geometry. A related “hang-down” design used in double-pinch experiments has, however, proved satisfactory [11]. In these experiments, however, the 50% thicker wire used twice the wire tension (weight), which permitted more pressure to be applied between the wires and electrodes.

In conclusion, the Cornell data supports the need for good electrical contact at the cathode for efficient energy deposition to the wire during the initial heating and implosion phase. Possibly then, the greater energy deposition (prior to current shunting) leads to a more

uniform expansion of the wires in the arrays, with associated improvement in the quality of the developing plasma shell.

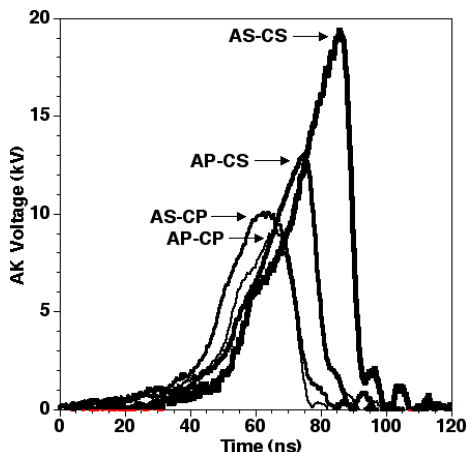


Figure 5. Voltage across AK gap versus wire-electrode contact (A= anode, C= cathode, P= press contact, and S= soldered).

#### V. REFERENCES

- [1] R. J. Leeper, *et al*, Nucl. Fusion **39**, 1283 (1999).
- [2] R. B. Spielman, *et al*, Phys. Plasmas **5**, 2105 (1998).
- [3] T. W. L. Sanford, *et al*, Phys. Plasmas **9**, 3573 (2002).
- [4] T. W. L. Sanford, *et al*, Phys. Plasmas **7**, 4669 (2000).
- [5] J. E. Bailey, *et al*, Phys. Rev. Lett. **89**, 095004-1 (2002).
- [6] S. A. Slutz, *et al*, Phys. Plasmas **10**, 1875 (2003).
- [7] T. W. L. Sanford, *et al*, IEEE Trans. Plasma Sci. **26**, 1086 (1998).
- [8] T. W. L. Sanford, *et al*, Phys. Rev. Lett. **77**, 5063 (1996).
- [9] C. Deeney, *et al*, Phys. Rev. E **56**, 5945 (1997).
- [10] T. W. L. Sanford, *et al*, Phys. Plasmas **6**, 1270 (1999).
- [11] M. E. Cuneo, *et al*, Phys. Rev. Lett. **88**, 215004 (2002).
- [12] K. G. Whitney, *et al*, Phys. Rev. E **56**, 3450 (1997).
- [13] M. E. Cuneo, *et al*, 11<sup>th</sup> Inter. Conf. On Emerging Nuclear Energy Systems, ICENES2002 Proceedings NTIS Doc# PB2003-102104.
- [14] P. U. Duselis and B. R. Kusse, Dense Z-Pinches: 5<sup>th</sup> International Conference on Dense Z-Pinches, edited by J. Davis *et al*. © 2002 AIP, p205.
- [15] D. B. Sinars, *et al*, Phys. Plasmas **7**, 429 (2000).
- [16] D. B. Sinars, *et al*, Phys. Plasmas **8**, 216 (2001).