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The Refurbished Z Facility: Capabilities and Recent Experiments

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The Z Refurbishment Project was completed in September 2007. Prior to the shutdown of the Z facility in July 2006 to install the new hardware, it provided currents of ≤ 20 MA to produce energetic, intense X-ray sources (≈ 1.6 MJ, > 200 TW) for performing high energy density science experiments and to produce high magnetic fields and pressures for performing dynamic material property experiments. The refurbishment project doubled the stored energy within the existing tank structure and replaced older components with modern, conventional technology and systems that were designed to drive both short-pulse Z-pinch implosions and long-pulse dynamic material property experiments. The project goals were to increase the delivered current for additional performance capability, improve overall precision and pulse shape flexibility for better reproducibility and data quality, and provide the capacity to perform more shots. Experiments over the past year have been devoted to bringing the facility up to full operating capabilities and implementing a refurbished suite of diagnostics. In addition, we have enhanced our X-ray backlighting diagnostics through the addition of a two-frame capability to the Z-Beamlet system and the addition of a high power laser (Z-Petawatt). In this paper, we will summarize the changes made to the Z facility, highlight the new capabilities, and discuss the results of some of the early experiments.

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1. Introduction

In July of 2006, the Z accelerator was shut down in order to completely rebuild the facility with hardware designed and fabricated under the Z Refurbishment Project. The first shots after reconstruction occurred in September of 2007. Since then Z has been firing routinely, but at a reduced shot rate to accommodate fielding of new and upgraded diagnostics and to commission and optimize the new pulsed-power components. There have also been a number of physics experiments conducted to exercise new capabilities as the facility is brought up to full voltage and current. During the commissioning activities, the facility has been able to demonstrate its design goals for peak current and repeatability.

Before the refurbishment, Z provided X-rays (1.6 MJ, > 200 TW) and high currents (≤ 20 MA) for various high energy density (HED) experiments. To date, the refurbished Z facility has been able to provide over 26 MA to an isentropic compression experiment (ICE) load and has achieved pre-refurbishment-level X-ray radiation from wire-array implosions. The bulk of the physics shots to date have been ICE loads to address dynamic materials properties at high pressures. Facility operation at full voltage and current has been limited by a few pulsed-power issues that are presently being resolved.

In addition to refurbishing the Z facility, Sandia's experimental capabilities have also been enhanced by the recent ability of the Z-Beamlet Laser's (ZBL) to generate two distinct backlit images and completion of the first Z-Petawatt (Z-PW) shot into the Z target chamber, which will enable high-photon-energy backlighting and fast ignition experiments on Z. In the following we summarize changes made to Z, recent achievements on Z and the Z-Beamlet/Z-Petawatt facilities, and future research directions.

2. Summary of changes made to Z

The architecture of the refurbished Z (ZR) accelerator is based on the original Z facility where 36 Marx generators charge 36 multi-stage pulse-forming-line modules, stacked two high in a circular configuration [1]. Each of the 18 module pairs connect to a four-level, multi-ring water–vacuum insulator stack and drive four conically-shaped magnetically-insulated transmission lines (MITLs) in vacuum. These lines are connected near the center of the facility with a post-hole convolute

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so that the load receives the sum of the currents from all 36 modules.

Compared to the previous Z facility, ZR's Marx banks have twice the initial stored energy, a 50% higher overall impedance, and incorporate all new stainless-steel pulsed-power components. Each ZR module has a higher-capacitance, longer-length intermediate store water capacitor, a redesigned 6 MV gas switch with its own trigger laser, a coaxial pulse-forming line in water, and a set of self-breakdown water switches between the coaxial and vertical tri-plate pulse forming lines. The transition from the coaxial geometry to the tri-plate water transmission lines is done abruptly at the water switches to minimize reflections and to conserve radial length. Another set of self-break water switches follows the first tri-plate line for pre-pulse suppression and provides connection to a second tri-plate line. For each pair of modules this second set of lines merge near the stack into a single tri-plate line with half the impedance. Thus this line, which combines the outputs of the upper and lower modules, delivers the same drive waveform to all four levels of a vertical-to-horizontal water convolute that connects to the four levels of the insulator stack. A diagram of the component layout is shown in Fig. 1.

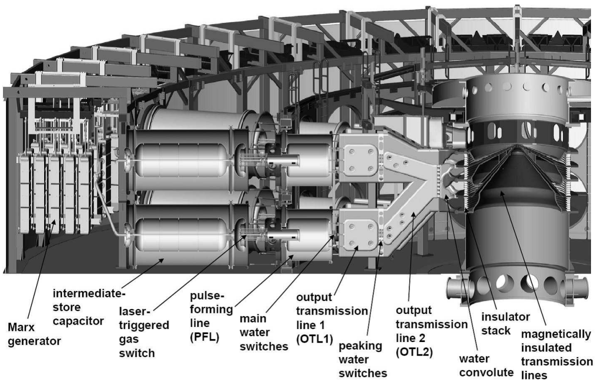

Fig. 1. Cross-section of the ZR accelerator, Marx generator to load.

A unique feature of this design is that each pulse-forming section acts as a stepped-impedance transformer to increase the voltage at the stack [2]. The length of each section is approximately 50 ns, and the impedance at each junction is increased by the same factor to achieve a total facility output impedance of 0.18 Ω (3.24 Ω for each output tri-plate). Hence, the transformer is optimized for 100 ns pulse lengths. The choice of the facility impedance was based on efficiency arguments [3].

A few pulsed-power component issues have been identified during the start-up and checkout of ZR. Although not specifically anticipated, they are not unusual when compared to similar efforts in starting up entirely new facilities. Issues being resolved include flashing of the laser-triggered gas switch housings which leads to shortened switch lifetime, electrical tracking of the coaxial pulse-forming-line oil–water barriers, fracturing of some of the Rexolite rings in the vacuum insulator stack from mechanical shock leading to subsequent-shot electrical breakdown, and higher than expected loss of current in the MITLs on shots with a relatively high-impedance loads. Design modifications have been identified for these areas and improvements are being presently fielded. Other components and subsystems have worked extremely well.

3. Recent ZR achievements

The first shot of the refurbished Z occurred on September 17, 2007, and achieved 17.5 MA into a fixed-inductance load with a relatively low 60 kV Marx Bank charge voltage. On shot 1775, the tenth shot after the refurbishment, ZR achieved a peak load-current of 26 MA into an ICE-type load. ZR also demonstrated reproducibility of the peak MITL current to within ±1% with shots 1795 through 1798, which were done with the same Marx Bank charge voltage in long-pulse mode, but without pulse-shape tailoring. Circuit-code simulations of both short-pulse and long-pulse modes have matched measurements to within several percent. These simulations use a full-circuit Bertha [4] model that uses the Marx charge voltage and gas-switch trigger times as input parameters. The code output is compared with electrical measurements in the accelerator and at the load [5]. For the first shot with over 26 MA peak current, the MITL peak-current simulation agrees with measurement to within 2%. Generally, good agreement between simulation and measurement has been achieved over a broad range of charge voltages and laser timing spreads, and provides confidence in our understanding of the operation of the facility.

The shots on ZR since September 17, 2007 have been used primarily for pulsed-power and diagnostic check-out, dynamic material response measurements, and initial wire-array X-ray production and related physics. While only a few wire-array implosion shots have been conducted at reduced Marx charge voltage since the refurbishment, they have achieved pre-refurbishment-level X-ray energy and power. The majority of shots to date have been in long-pulse, tailored pulse-shape mode for dynamic material response experiments. For these experiments, peak currents are often below 20 MA, but have a current rise time of up to 500 ns. Peak pressures of approximately 4 Mbar have been achieved.

4. Recent Z-Beamlet and Z-Petawatt achievements

Sandia's ZBL is a single-beam high-energy Nd:glass laser used for backlighting experiments at Z. A two-frame capability was recently fielded to generate two distinct backlit images with adjustable time delay ranging from 2 to 20 ns between frames. The new system will double the rate of data collection and allow the temporal evolution of high energy density phenomena to be recorded on a single shot. Work is progressing towards implementing a four-frame capability in the near future.

In parallel with the Z Refurbishment Project, design of a Z-PW laser system began in 2002. In December 2007, the first Z-PW shot was taken into an inactive ZR accelerator using a surrogate on-axis parabola in the Final Optics Assembly to demonstrate radiographic capability. The Z-PW laser will enable high-photon-energy backlighting and fast ignition experiments on Z in the 10–40 keV range. At this point, Z-PW has demonstrated 415 J uncompressed and 125 J compressed. More accurate measurements are underway to determine the beam spot size, but we can infer that the present intensity is in the range of 5×10^{17} to 10^{18} W/cm^2.

5. Future research directions

Future experiments on ZR will focus on three unique capabilities: (1) dynamic materials property measurements, (2) magnetically-driven implosions for fusion and X-rays, and (3) fast pulsed-power technology development. Precision material properties measurements are facilitated by the high pressures (> 4 Mbar) and high--velocity (> 30 km/s) flyer-plate experiments that can be done on ZR. Magnetically-driven implosions of wire arrays have not yet produced higher soft X-ray energy and power than the previous facility, but with twice the stored energy we can expect to exceed Z levels in the near future in support of high energy density science, inertial confinement fusion (ICF), radiation effects science, diagnosis of plasma processes, and astrophysics and planetary sciences experiments.

ZR programs will also enable development of fast pulsed-power technology in the areas of high-voltage breakdown in vacuum, water, gases, and along insulator surfaces. The facility also provides a testing capability for new architectures and techniques, with the goal of building facilities capable of achieving break-even or high-gain fusion, and capable of high repetition-rate operation.

Research on refurbished Z and enhanced ZBL/Z-PW facilities is performed in collaboration with many groups from around the world. ZR will continue to routinely drive ICF capsule implosions focusing on implosion symmetry and neutron production. A broad range of HED experiments will include radiation-driven hydrodynamic jets, equation of state, phase transitions, strength of materials, and detailed behavior of z-pinch wire-array initiation and implosion [6].

6. Summary

The refurbished Z accelerator has been operating since September of 2007. It is still in a commissioning phase, but is doing both facility checkout and physics shots. The stored energy was doubled, and all pulsed-power components were replaced. Issues discovered during startup are being addressed, and to a large extent, solved. The facility has met initial goalsin peak current and repeatability, and has been able to produce tailored current pulse shapes for dynamic material property experiments. Initial wire-array shots have only been done at reduced voltage and presently are producing output equivalent to that of the previous Z facility. This output is expected to increase as charge voltage is increased. The facility is being fired regularly at 2 to 3 shots per week, with the anticipation of 4 shots per week at full voltage and current by 2009. Future HED research will benefit from integrated capabilities of refurbished Z, enhanced ZBL, and new Z-PW.

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