ABSTRACT

Jupiter is a Sandia initiative to develop the next generation of fast Z-pinch drivers for applications to high energy density physics, inertial confinement fusion, and radiation effects simulation. Jupiter will also provide unique capabilities for science research in a broad spectrum of areas involving ultra high magnetic fields, hot/dense plasmas, x-ray physics, intense neutron sources, etc. The program is based on the premise that a single facility using magnetically driven implosions can meet the needs in these multiple program areas. Jupiter requires a 450-500 TW, 8-10 MV, ~100 ns pulsed power generator to impart ~15 MJ kinetic energy to an imploding plasma load. The baseline concept uses a highly modular, robust architecture with demonstrated performance reliability. The design also has the flexibility to drive longer implosion times. This paper describes the Jupiter accelerator concept, and the research underway to establish the technological readiness to proceed with construction of the facility.

I. Introduction

The generation of intense x-ray pulses using magnetically driven implosions can be described in terms of the four-stage process shown in Figure 1. In the first stage, individual high voltage pulses are produced by a large number of pulsed power generator modules. The current from these modules is added in the second stage and delivered to a cylindrical plasma load located at the center of a vacuum test chamber. During the third stage, the magnetic forces generated by the drive current cause the plasma to implode converting the electrical energy into particle kinetic energy. The kinetic energy is finally converted into radiation energy in the final stage when the plasma stagnates near the axis of implosion. The magnetic energy stored near the load region continues to drive the collapsed plasma producing additional radiation. The total x-ray energy produced can thus exceed the kinetic energy in the implosion. Since the implosion system represents an additional power compression stage, the prompt radiation pulse can be several times shorter than the driving current pulse. The entire power compression/energy conversion process can also be made to be very efficient [1].

Progress in the field had been limited by problems associated with control of instabilities in the imploding plasma; however, the advent of fast pulsed power generators in the 1980s...
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led to fundamental changes and rapid progress. An analysis of the scaling of MHD instabilities in imploding plasma lines by Hussey et al., [2], shows that the Rayleigh-Taylor instability dominates in the worst, most unstable implosions. The result is that short, high-temperature radiation pulses can be more readily obtained using shorter implosion times. The use of high-power, short-pulse generators to drive plasma implosions shifts the problem emphasis from control of plasma instabilities towards the design of very large, reliable, high-efficiency, fast pulsed power accelerator systems. Advances made in pulsed power accelerator technology over the past fifteen years has allowed us to develop a design concept for Jupiter capable of delivering ~15 MJ of kinetic energy to an imploding plasma load. These implosions will produce 15-20 MJ of x-rays, e.g., 30 to 40 times the radiation produced by Saturn [3].

II. The Jupiter Design Concept

Figure 2 shows the concept for Jupiter. The driver consists of ~30 pulsed power generator modules based on the inductive voltage adder technology [4] that has proven to be robust and very reliable on the Hermes III facility [5] at Sandia. The Jupiter pulsed power generator module is shown in Figure 3. It consists of a four-stage inductive voltage adder with four pulse forming lines (PFLs) feeding each of the stages (submodules). The module thus delivers four times the voltage and four times the current produced by an individual PFL. One of the Jupiter PFL modules delivers roughly the same voltage and half the power as one PBFA II pulse forming module [6]. The chosen architecture is highly modular and the design requires little extrapolation in peak performance over what has been achieved at the component level on existing pulsed power facilities. The principal challenge for this concept is in our ability to execute a design that meets the high operational reliability, reproducibility, and life cycle costs required for Jupiter. The pulsed power generator modules will also provide the capability to drive implosions ranging from ~100 ns to ~500 ns.

Each of the four submodules consists of a ~755 kilojoule Marx generator, a two-stage water-dielectric pulse forming system, and a high power induction cell. All of the pulse compression stages in this design use SF$_6$ insulated high voltage gas switches for increased efficiency and reliability. The submodules will each deliver 3.3-4.0 TW at ~2.5 MV depending on the ultimate performance that can be reliably achieved. The submodule is the basic pulse forming building block and its output is synchronized, within a few ns, to a command signal by a laser triggering system. The four-stage module will deliver a 13-16 TW output pulse with a nominal FWHM of ~100 ns and a total energy of 1.2-1.5 MJ. Longer implosion times can be obtained by shorting out the second stage of the water-dielectric pulse forming system. The induction cells are designed to contain sufficient core material to allow for the longer volt-seconds required in this mode.

The output from each of the generator modules will be delivered to the central target chamber via long self-magnetically insulated vacuum transmission lines (MITLs). A
coaxial to double-triplate disk feed transition section at the periphery of the target chamber combine the individual current pulses as shown in Figure 4. Power flows down the triplate MITLs to post-hole convolutes located within a few centimeters of the chamber axis. This convolutes deliver the power to a single cylindrical Z-pinch load on axis.

III. Supporting Research and Development

Figure 5 shows a drawing of the advanced pulsed power testbed being built at Sandia to develop the component, submodule, and module performance needed for future high current z-pinch drivers. Testing of individual pulse forming components is under way. Emphasis has been placed on the performance of the self closing PFL output gas switch. Measurements using two switches indicate a ~ 1 ns one sigma jitter for these self closing gaps. Figure 6 shows the number of shots in the test sequence versus the measured spread in the closure time of the two switches.

The Hermes III accelerator has been reconfigured to produce a ~ 8 MV, ~300 kA, ~220 ns FWHM output pulse and has been equipped with a 12-meter extension MITL. This capability is being used for preliminary studies of the long-MITL transport efficiency, as well as the coupling efficiency into an inductive load. Results using a 300 nH inductive load indicates high transport and coupling efficiencies, and are consistent with particle-in-cell and analytic code calculations. The experiments will be extended to the scaled Jupiter inductance using Hermes III. These experiments are limited because of the relatively high impedance of Hermes III. When complete, the advanced pulsed power testbed will allow a better comparison to Jupiter.

The largest technical uncertainty associated with the construction of Jupiter pertains to the performance of the Z-pinch implosion with a ~ 55 MA current drive. The highest current drive experiments to date have been performed on Saturn at 8-10 MA. We are developing a Z-pinch drive capability for the PBFA II facility to enable the performance of 20-25 MA, ~100 ns, ~2 MJ, Z-pinch implosion experiments. This capability (PBFAII-Z) will be obtained by redirecting the output from the 36 individual PFLs through a short vacuum insulator stack and using a set of MITLs, similar to those used on Saturn, to deliver the summed current pulse to a Z-pinch load. A drawing of the PBFAII-Z configuration is shown in Figure 7. It will be operational in the third quarter of FY96.

IV. Summary and Conclusions

Advances in fast pulsed power technology has enabled the development of intense pulsed x-ray sources with an overall conversion efficiency of 15-20 percent. Experiments performed on Saturn will be extended to PBFAII-Z which should provide radiation
outputs of 1.5-2.0 MJ. The proposed Jupiter facility will extend that capability to ~ 15 MJ of x-rays. Extrapolation of hohlraum results obtained to date show that temperatures ≥ 200 eV could be achieved on Jupiter. A design concept for Jupiter based on the inductive voltage adder technology has been developed. Pulsed power component development is underway and has resulted in a self closing gas switch with a one sigma jitter of ~ 1 ns. Initial power flow experiments using long MITLs are being conducted on Hermes III and will be extended to Jupiter-like conditions when the advanced pulsed power testbed is complete. PBFA II-Z is a modification to the front end of the existing PBFA II accelerator and will provide a ~20 MA Z-pinch capability. It will also be used to study the limitations of vacuum power flow in the post-hole convolutes and final feed region.

V. Acknowledgments

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VI. References

Magnetic Driven Implosions

Fig 1. The four stages of magnetically driven implosions.

Fig 2. Drawing of concept for the Jupiter laboratory x-ray facility.
Fig 3. Drawing of concept for the Jupiter pulsed power generator module

Fig 4. Sectional view of the power flow feeds within the central vacuum chamber
Fig 5  Drawing of the advanced pulsed power testbed under development

Fig 6  Measured spread in closure time for two PFL output gas switches
Fig 7 Drawing of the PBFA II Z-pinch drive configuration