Design of the Jupiter Accelerator for Large X-ray Yields

Juan J. Ramirez, Ph.D.
Sandia National Laboratories
Albuquerque, New Mexico 87185-1178

ABSTRACT

Nanosecond Pulsed Power provides the unique capability to deliver high energy and high power at low cost and high efficiency. One important application of this technology is to the generation of intense, high-energy laboratory X-ray sources using magnetically driven implosions. Saturn generates ~500 kilojoules of x-rays using this process. This paper presents a detailed design concept for a ~15 MJ laboratory X-ray source and discusses the resultant capabilities for high energy density physics studies.

INTRODUCTION

The Particle Beam Fusion Accelerator-II (PBFA-II) was built at Sandia National Laboratories in 1985 as part of the national ICF program [1] and is the highest power accelerator in the world today. Saturn was built in 1987 [2] and is used as an intense source of ~1 MV bremsstrahlung radiation. It is also used as the power source for fast magnetically driven implosions and generates ~0.5 MJ of X-rays in this mode.

The generation of these intense X-ray pulses can be described in terms of the four stage process shown in Figure 1.

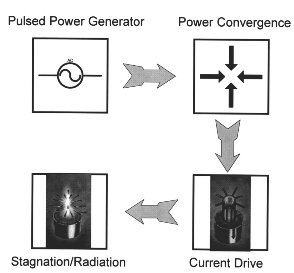

Fig 1. The four-stage process for magnetically driven implosions.

Individual high electrical pulses are first produced by a large number of pulsed power generator modules. The current pulses from these modules are 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 very efficient [3].

Progress in the field has been limited by problems associated with control of instabilities in the imploding plasma. However, the advent of fast pulsed power drivers in the 1980s has led to fundamental change and to rapid progress. An analysis of the scaling of MHD instabilities in imploding plasma lines by Hussey, et al. [4] 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 reliable, high-efficiency, fast-pulsed power accelerator systems.

THE JUPITER FACILITY

Figure 2 shows a concept for the proposed ~15 MJ Jupiter laboratory X-ray facility.

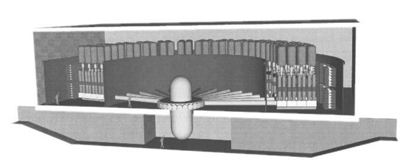

Fig 2. Concept for the proposed ~15 MJ Jupiter laboratory X-ray facility.

The driver consists of ~30 pulsed power generator modules based on the inductive voltage adder technology [5] that has proven to be robust and very reliable on the Hermes III facility [6] at Sandia National Laboratories. In this concept the outputs from the individual generator modules are added in parallel within a central vacuum chamber and the summed pulse is fed to a Z-pinch load located at the chamber axis.

The Jupiter pulsed power generator module is shown in Figure 3.

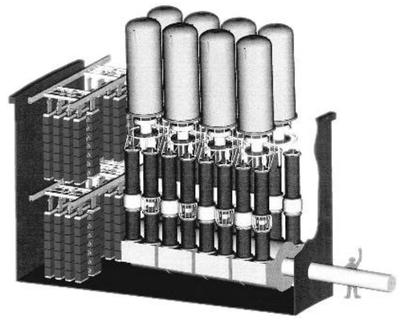

Fig 3. Drawing of the Jupiter pulsed power generator module.

It consists of a four-stage inductive voltage adder with four pulse forming lines (PFLs) feeding each of the stages (submodules). The generator 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 PFL module. 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 the chosen generator concept is in our ability to execute a design that meets the high operational reliability, reproducibility, and the life cycle costs desired for Jupiter. Our plans are to complete construction of an advanced pulsed power module testbed by the end of FY96 and to develop the requisite integrated performance capability using this facility. This testbed will thus enable us to validate component design criteria, evaluate fault modes, establish the dynamic range for reliable system operation, and determine the service and maintenance requirements. Results will be integrated into a comprehensive system design study for Jupiter.

The major uncertainty in this effort pertains to our ability to scale the Z-pinch to the power and energy levels specified for Jupiter. Jupiter will provide implosion times ranging from ≤100 ns to ~500 ns to minimize concerns about Z-pinch plasma instabilities.. The implosion time flexibility is provided by the pulse forming system. Each of the four submodules shown 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 to within a few ns by a laser triggering system. The generator 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. Jupiter will consist of 30-36 of these modules arranged in parallel around a central target chamber. Longer implosion times are provided 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). Results of a study on the design of the inductive voltage adder and transport down these long MITLs is presented by M. G. Mazarakis in the proceedings of this conference [7]. 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. These convolutes deliver the power to a single cylindrical Z-pinch load on axis.

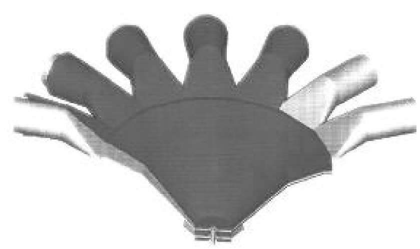

Fig 4. Sectional view of power flow feeds within the central vacuum chamber.

PBFAII-Z

PBFA II-Z will provide a Z-pinch drive capability to PBFAII. It will enable 20-25 MA, ~100 ns, 1.5-2.0 MJ implosion experiments. This capability should be available by the Fall of 1996. The PBFAII-Z experiments will validate our understanding of vacuum power flow through convolutes and of Z-pinch implosion dynamics. It will represent a half-way step between Saturn and Jupiter and will provide the necessary confidence for scaling to Jupiter parameters.

SUMMARY AND CONCLUSIONS

Magnetically driven implosions using fast pulsed power generators form the basis for a growing international collaboration on high-power, high-energy laboratory X-ray sources. Advances in nanosecond pulsed power technology in the past decade have enabled the development of intense pulsed X-ray sources with an overall capacitor to X-ray conversion efficiency of 15-20 percent. Experiments performed by a collaboration of U.S., U.K., and CIS scientists on Saturn at Sandia National Laboratories, and on Angara V at Trinity 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. Extrapolation of hohlraum results obtained to date show that temperatures ≥ 200 eV could eventually be achieved on Jupiter. It will provide an unparalleled capability for ICF, high energy density physics and radiation effects science experiments.

References

1. B. N. Turman, et al., “PBFA II - A 100 TW Pulsed Power Driver for the Inertial Confinement Fusion Program,” Proc. 5th IEEE Pulsed Power Conf., Arlington, VA, June 10-12, 1985, pp. 155-161.
2. D. D. Bloomquist, et al., “Saturn, A Large Area X-ray Simulation Accelerator,” Proc. 6th IEEE Pulsed Power Conf., Arlington, VA, June 29-July 1, 1987, pp. 310-317.
3. P. J. Turchi and W. L. Baker, J. Appl. Phys. 44, 4936 (1973).
4. T. W. Hussey et al., J. Appl. Phys. 51, 1452 (1980).
5 J. J. Ramirez, et al., “Very High Pulse-Energy Accelerators,” Proc. 1989 Particle Accelerator Conf., Chicago, IL, March 20-23, 1989, 1446.
6. J. J. Ramirez, et al., “Hermes III - A 16 TW, Short Pulse, Gamma Ray Simulator,” Proc. 7th International Conference on High Power Particle Beams, Karlsruhe, West Germany, July 4-8, 1988, pp. 148-157.
7. M. G. Mazarakis, et al, “Design and Power Flow Studies of a 500-TW Inductive Voltage Adder Accelerator “, in Proceedings of this Conference.