SAND80-0550C CONF-800640--12

PULSED POWER ACCELERATORS FOR PARTICLE BEAM FUSION*

T. H. Martin, G. W. Barr, J. P. VanDevender, R. A. White, and D. L. Johnson
Pulsed Power Systems Department - 4250
Sandia National Laboratories, Albuquerque, New Mexico 87185

Summary

Sandia National Laboratories is completing the construction phase of the Particle Beam Fusion Accelerator-I (PBFA-I). Testing of the 36 module, 30 TW, 1 MJ output accelerator is in the initial stages. The 4 MJ, PBFA Marx generator has provided 3.6 MA into water-copper sulfate load resistors with a spread from first to last Marx firing between 15 to 25 ns and an output power of 5.7 TW. This accelerator is a modular, lower voltage, pulsed power device that is capable of scaling to power levels exceeding 100 TW. Research on the upgrade of PBFA-I to PBFA-II is already underway.[1] PBFA-II will be a 100 TW, 3.5 MJ output accelerator which will provide a testbed for breakeven target experiments.

This type of accelerator's high efficiency and low cost make it an attractive candidate for a fusion energy reactor system. Present accelerator efficiencies range between 30 to 40 percent from the Marx generator to the electron or ion beam diode and construction costs are less than ten dollars per joule. The elements of the PBFA technology and their integration into an accelerator system for particle beam fusion will be discussed.

Overall Program Update

During the last 12 months, the Electron Beam Fusion Accelerator[2] (EBFA) has been modified to accelerate either electrons or ions and renamed the Particle Beam Fusion Accelerator (PBFA). This modification was accomplished with a slight cost increase and with no change in delivery time and represents an example of the flexibility of this approach to fusion. Figure 1 shows ion beam focussing progress which initiated the change. Recently, the focussed ion power density was increased by a factor of ten. Simultaneously, target design improvements (shown as circles labelled SL and LLL) resulted in a several fold reduction in the required beam intensity for breakeven. These two factors indicate that scientific feasibility demonstration of ICF can be accomplished on PBFA-II, our next accelerator upgrade.[2] Present ion current densities approaching 1 MA/cm^2 and present ion output energies over 150 kJ have been achieved in separate experiments.[3] Reasons for choosing ions over electrons are shown in Figure 2.

The changes involved between PBFA-I and PBFA II are shown in Figure 3. The present .8 TW modules will be upgraded within the same volume and the accelerating voltage will be increased from 2 to 4 MV for better coupling to the targets and more flexible magnetically-insulated outputs. The present 36 modules will be increased to 72 and the upgrade will be preassembled and then placed into the present tankage. The installation of the upgrade will require one year. PBFA-II will be described in more detail at this conference by D. L. Johnson.[1]

PBFA-I Accelerator Description

As seen in Figure 4, the electromagnetic power is obtained by operating 36 modules in parallel. Each module has a sequence of energy stores which are separated by synchronized switches. The primary energy store is a 112 kJ Marx generator composed of capacitors charged to ± 100 kV. The Marx switching is accomplished with triggered gas switches. The Marx energy is transferred to a water intermediate storage capacitor in 800 nanoseconds while achieving a peak power of 7 TW with the 4 MJ transfer. The water capacitors then transfer the energy to the pulse forming line in 200 nanoseconds through 36 triggered gas switches. This triggered switch provides the timing synchronization for all modules and has a rms uncertainty of 1.6 ns. The modules each have two parallel pulse forming lines which are switched into a wave mixer using self-breakdown, multichannel, water-dielectric switches.

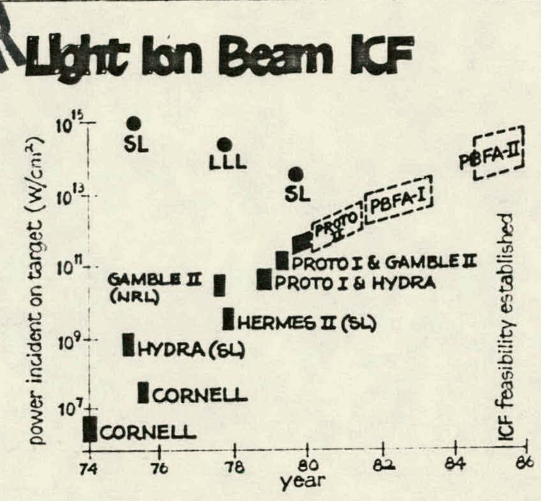

Fig. 1. Light Ion Beam ICF.

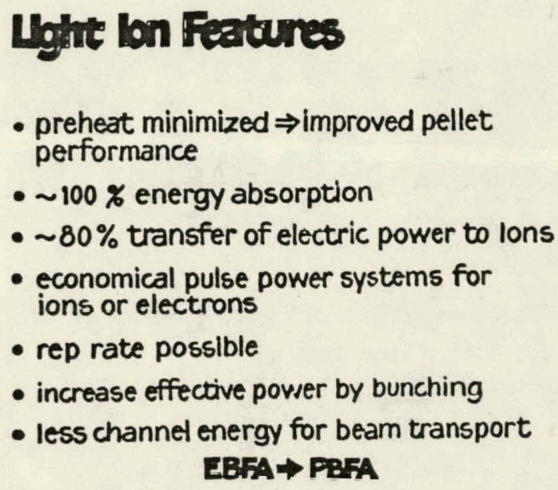

Fig. 2. Light Ion Features.

*This work was supported by the U. S. Department of Energy under Contract DE-AC04-76-DP00789.

DISCLAIMER

PBFA I → PBFA II

	PBFA I		PBFA II
particle type	e	→	i
power/module	.8TW	→	1.3TW
pulse length	40ns	→	40ns
voltage	2MV	→	4MV
number of modules	36	→	72
	(module operational)		(module under development)

- upgrade will take 1 year - mid '83 - '84
- same tank, controls, etc.

Fig. 3. PBFA-II Changes.

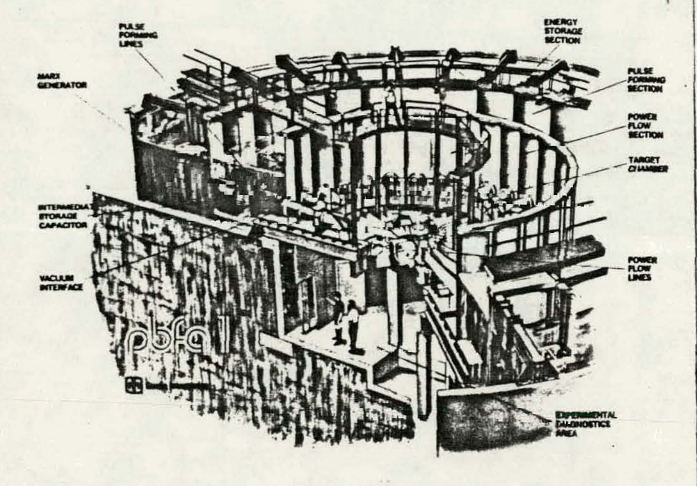

Fig. 4. PBFA-I Artist's Conception.

The output pulse (40 ns) then flows through a line transformer to the vacuum insulator. The resulting 2 MV pulse is placed on the magnetically-insulated transmission lines[4] and transported at stresses of 2 MV/cm to the target chamber. Diodes then convert the electromagnetic energy to particle beam energy between 20 cm and 90 cm away from the target. The ions are then focussed or transported in plasma channels to the target.

Present Construction Status

The accelerator building has been completed and the accelerator is nearing completion. The first accelerator output is expected by July 1980. A photograph of the tank is shown as Figure 5. The Marxes are fully modularized and can be replaced simply by removing one unit with the crane and inserting the next unit. The Marxes are positioned by I-beam supports as shown in Figure 6. The Marx Pulser Unit (MPU), which triggers four Marx generators, is shown on the tank floor. It is located behind the main Marx as shown in Figure 7. These MPU's are developed by Maxwell Laboratories for Sandia and are detailed in a separate report. A safety switch which can direct a trigger pulse either to ground or the main Marx is included and will be discussed later. The Marx generator output is switched mechanically between the water/oil feedthrough insulator and a water resistor load as shown in Figure 8. These components are in the oil-insulated section.

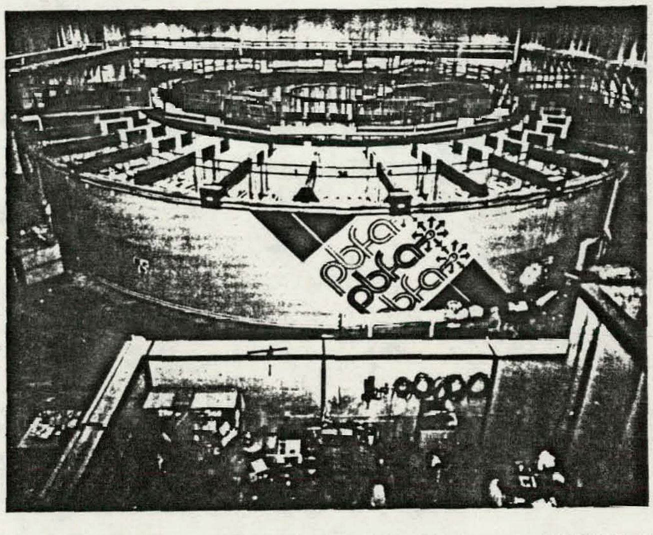

Fig. 5. PBFA-I Tankage.

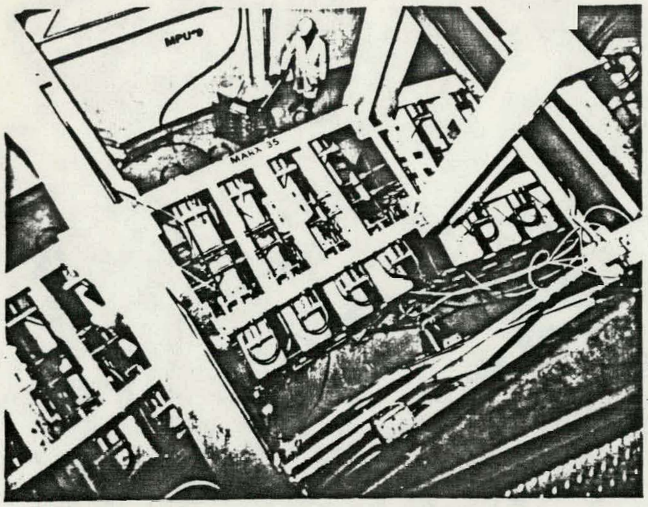

Fig. 6. PBFA-I Marx Generator.

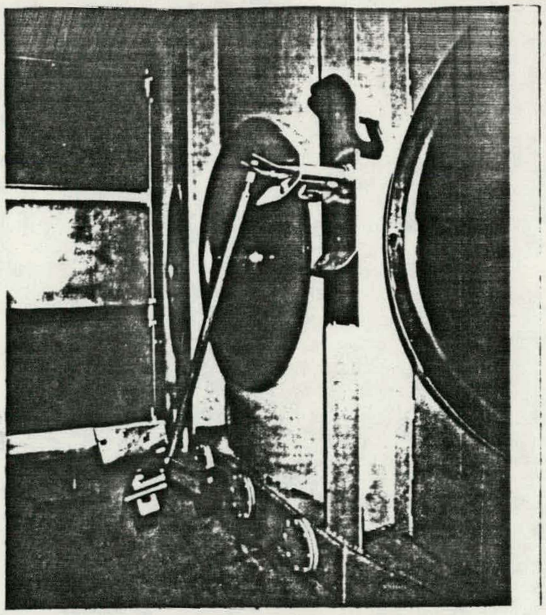

Fig. 8. Marx Safety Switch.

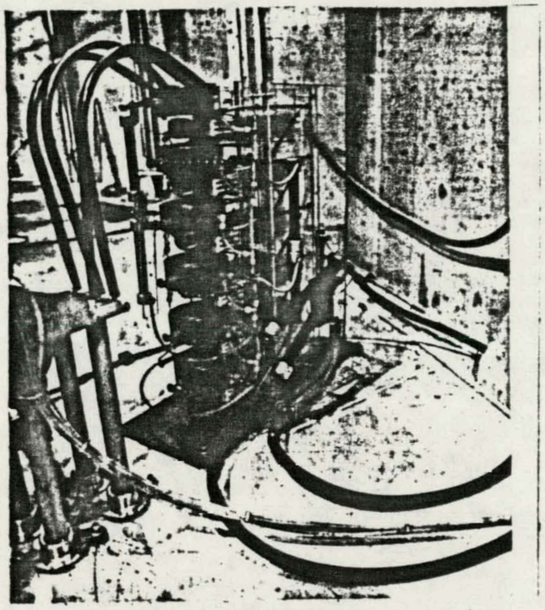

Fig. 7. PBFA-I MPU.

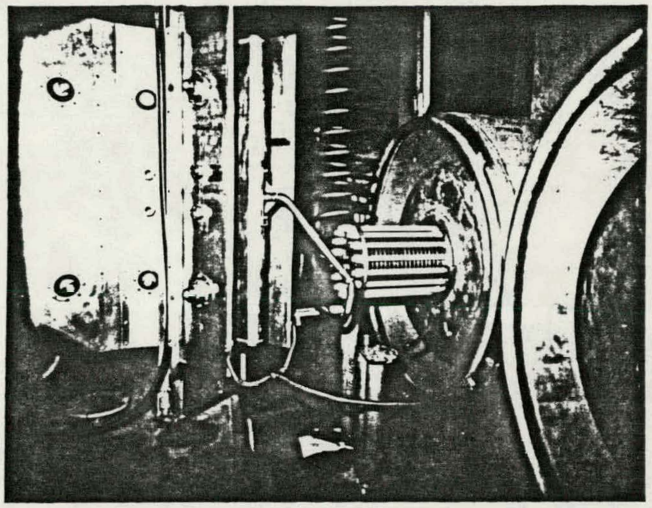

Fig. 9. PBFA-I Water Switch.

The 21 nfd water-insulated energy storage capacitors are shown in Figure 9 along with a 3 MV-triggered switch, These components are all in the water section.

The front of the pulse forming lines connect through a water-insulated line transformer to the vacuum interface. The front of the vacuum interfaces and the magnetically insulated lines are shown as Figure 10. Thirty-six of these lines then converge on the pellet chamber as shown in Figure 11. Note the four technicians to provide relative scale.

Module Protective and Testing Devices

A common failure mode for modular pulse power accelerators is a prefire. This occurs when the Marx generators are being charged or are waiting for the trigger pulse. When a prefire occurs and no protective devices are available, two consequences can occur. First, the experiment, which usually takes many manhours to install, is destroyed. Second, the 3 MV gas trigger system may not fire and the water capacitors will arc over and destroy themselves. To prevent these problems, three energy divertor switches were installed as shown in Figure 12. The first switch, between the trigger Marx and the main Marx, will divert any prefiring timing circuit or trigger pulse generating circuits up to a few seconds before accelerator operation. In addition, this system will be exercised from the control room to show correct operation of the triggering system prior to the experiment. The second switch, which connects the Marx generator with the intermediate store, is normally connected to a dump resistor. In case of a main Marx prefire, the energy is routed into these dump resistors. Again those resistors are used to test the timing and firing of the entire accelerator to this point just prior to a chamber experiment. The previously described switches are remotely operated. The third switch must be manually set and connects the SF_6 triggered switch to a dump resistor. The resistor connection is made to check the main gas switch trigger, trigger systems, and switch functions. By using these built-in test points and exercising the

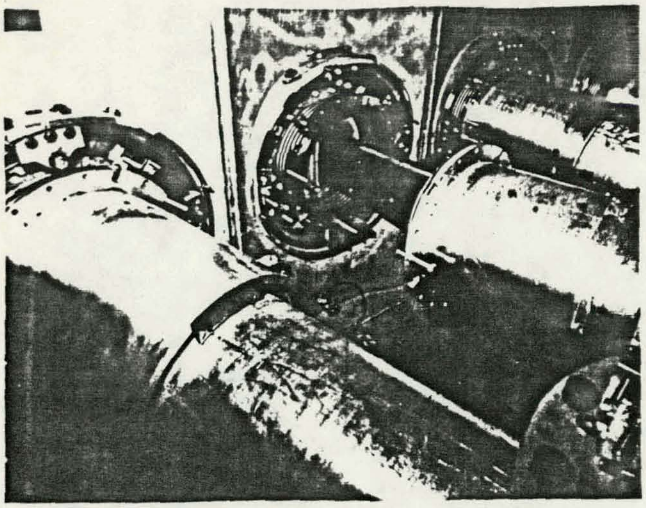

Fig. 10. Magnetically-Insulated Transmission Lines.

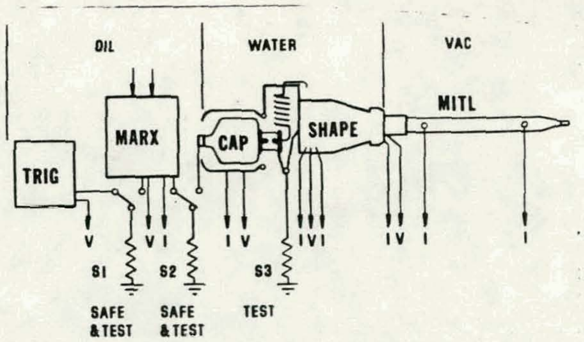

Fig. 12. PBFA-I Diverter Test.

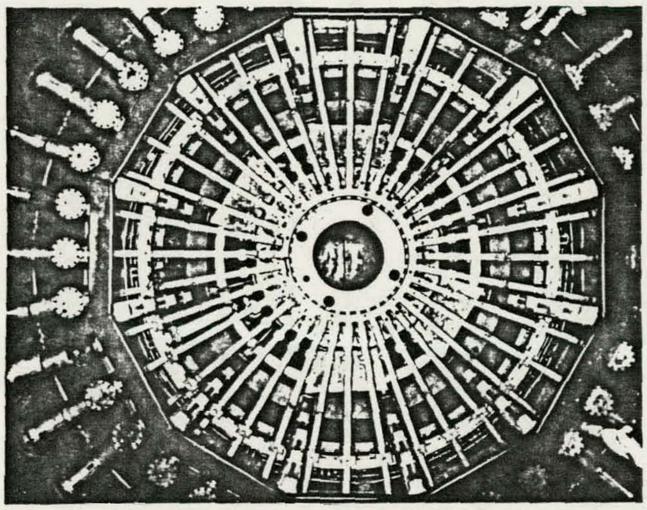

Fig. 11. PBFA-I Central Section.

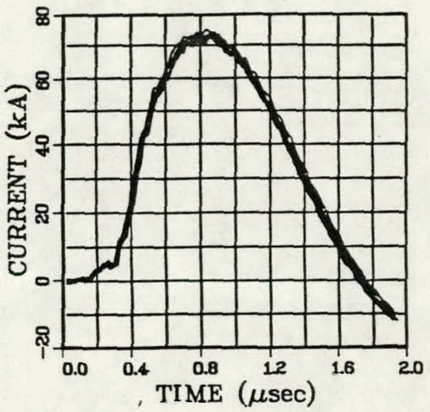

Fig. 13. Marx Generator Output Data.

accelerator frequently, the accelerator should provide reliable pulses for experimenters and yet allow relatively standard, lower reliability components to be utilized in the accelerator.

Marx Generator Experimental Results

The thirty-six Marx generators have been charged to $\pm$ 100 kV which places approximately 4 MJ total energy in the banks. The Marx was then discharged into its resistive loads and the voltage and currents were measured.

The voltage monitors generally have more electrical noise than the lower impedance, better shielded current monitors. Subsequently, all timing data was obtained from the current monitors. The current monitor outputs were recorded using a fast time sweep to provide more accurate data. A composite trace showing six Marx generator currents into their 14 ohm loads is shown in Figure 13. The Marx generator erection transient and discharge currents are similar in both time and amplitude. A total current of 2.6 MA at a power of 2.6 TW for 70 kV Marx charge is shown.

The generator timing spreads were measured by using Tektronix 7912 digital recorders and data processing equipment. The time between first and last Marx current traces were measured and the total spread was obtained. See Figure 14. Spreads between 15 and 25 nsec were typical. This spread indicates a one-sigma jitter between 4 and 6 nanoseconds for these generators. Most of the testing was performed at a 70 kV Marx charge (approximately 2 MJ) then several proof shots were performed at a 100 kV charge and 4 MJ stored. The spread measured contains all jitter due to trigger generators, trigger Marx generators and the main Marx generator.

This series of tests showed the Marx generators, charging systems, and triggering systems to be operating well with lower jitter than expected. Installation of the water section components is almost completed and the power flow lines are installed. Initial operation of the accelerator is expected this month.

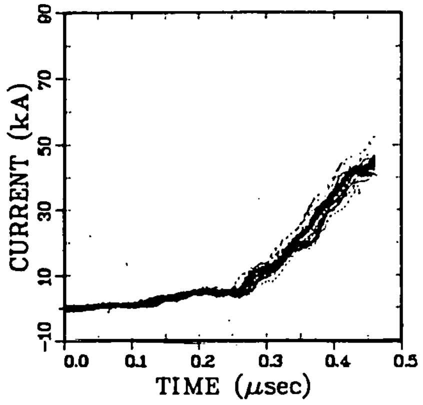

Fig. 14. Marx Generator Timing Data.

References

1. D. L. Johnson, J. P. VanDevender, and T. H. Martin, Preliminary PBFA-II Design, to be presented at the 1980 Fourteenth Pulse Power Modulator Symposium, Orlando, FL, June 3-5, 1980.

2. T. H. Martin, J. P. VanDevender, G. W. Barr, and D. L. Johnson, EBFA—Pulsed Power for Fusion, presented at the Third International Topical Conference on High Power Electron and Ion Beams, Novosibirsk, USSR, July 3-6, 1979.

3. G. W. Kuswa, Progress Toward Fusion with Light Ions, to be presented at the Eighth International Conference on Plasma Physics and Controlled Nuclear Fusion Research, Brussels, Belgium, July 1-10, 1980.

4. J. P. VanDevender, J. Appl. Phys. 50, 3928 (1979).