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ABSTRACT

Pegasus II is the upgraded version of Pegasus, a pulsed power machine used in the Los Alamos Above Ground Experiments (AGEX) program. The goal of the program is to produce an intense (>100 TW) source of soft x-rays from the thermalization of the KE of a 1 to 10 MJ collapsing plasma source. The radiation pulse should have a maximum duration of several tens of nanoseconds and will be used in the study of fusion conditions and material properties. This paper addresses z-pinch experiments done on a capacitor bank where the radiating plasma source is formed by an imploding annular aluminum foil driven by the JxB forces generated by the current flowing through the foil.

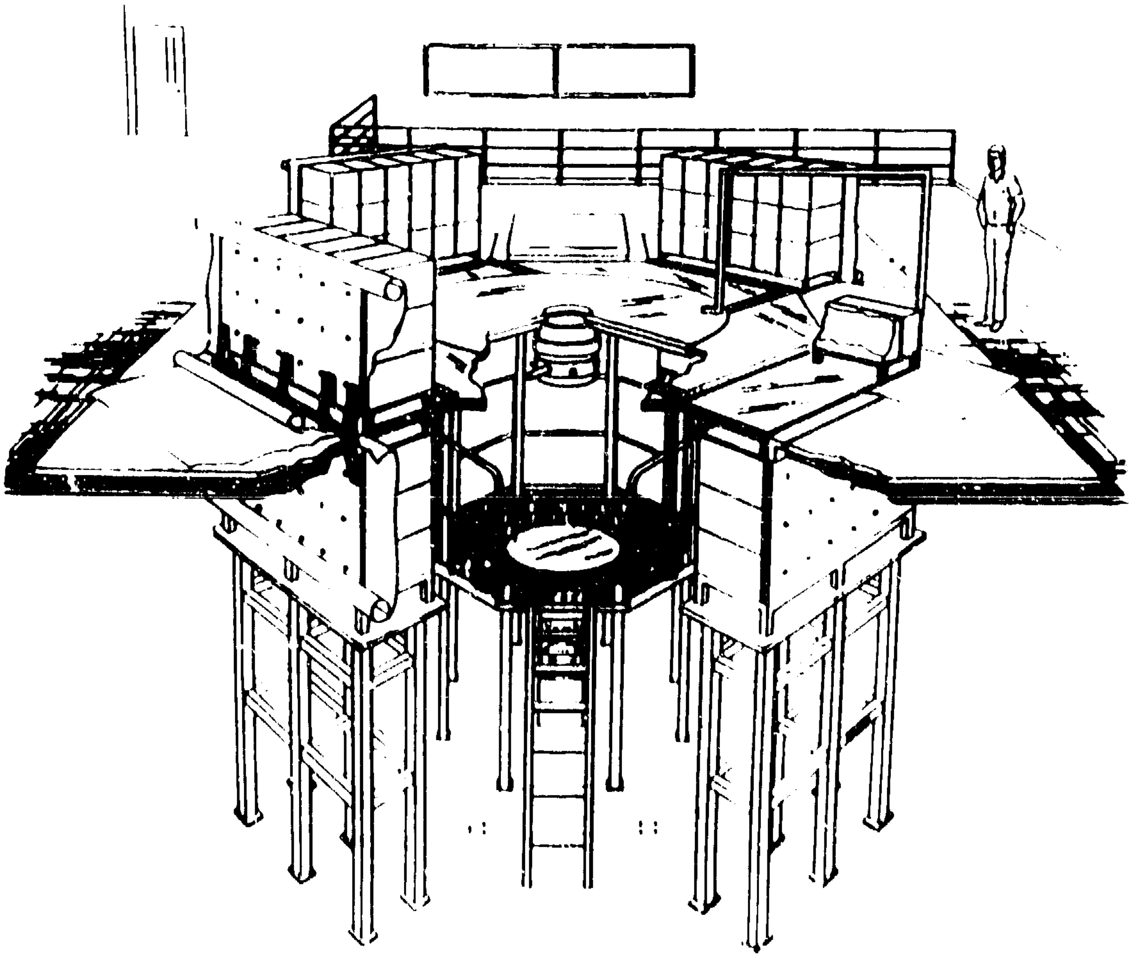


Fig. 1. Pegasus II capacitor bank facility.

FACILITY DESCRIPTION

Pegasus II machine parameters include a stored energy of 4.3 MJ at 100 kV, a system inductance of 30 nH and current capability of 15 MA. This quadruples the energy of Pegasus I at this voltage. The upgrade was accomplished by replacing the capacitors rated at 10 kJ stored energy at 60 kV with capacitors rated at 30 kJ at 50 kV. The new capacitors have a current capability of 250 kA/capacitor and can stand up to 20% reversal at full charge for a rated lifetime of over 3000 shots. To stay within this voltage reversal specification, series fuses are employed to shut off the current after peak current. The bank itself is composed of two halves charged to opposite polarity. Each half has four modules with eighteen capacitors each. The modules are placed around a radial transmission line with the load in the center of the line (see Fig. 1). Detonator switches that form an annular aluminum jet that penetrates the polyethylene switch insulation are used to switch the bank. The facility has been used in "direct drive" z-pinch implosions of thin aluminum foils, high magnetic field diffusion experiments, pulse sharpening and switching experiments using a plasma flow switch, and most recently, in liner experiments where the load is an aluminum cylinder with a 0.4 mm thick wall.

EXPERIMENTAL RESULTS

The purpose of the "direct drive" z-pinch implosions is to experimentally test the theoretical predictions of instabilities and their growth rates and to try various means to suppress these instabilities. Direct drive shots also allow us to separately study foil implosion dynamics that would otherwise be possibly hidden in interactions between the plasma of the foil and the plasma of the pulse sharpening switch. In the direct drive mode, the bank is fired directly into the foil without employing any switching to sharpen the driving current pulse. The foil dimensions are typically 2 cm in height, 5 cm in radius, and $2.5x10^{-5}$ to $7.5x10^{-5}$ cm in thickness. The foils are manufactured by evaporating aluminum onto a polyvinyl alcohol (pva) form. The pva form is then dissolved in a bath of water leaving the foil attached to the mounting rings which are themselves on an insertion fixture. Discharging Pegasus directly into such a load yields an implosion time much less than the quarter cycle time of the capacitor bank meaning that a relatively small fraction of the stored energy is available to drive the implosion. Foil implosion times from 1.8 to 2.5 µs are observed depending on the foil thickness. The quarter cycle time for Pegasus I was 4 µs and for Pegasus II is 8 µs with a static system inductance of 30 nH. The current waveform is shown in Fig. 2 for a Pegasus II "direct drive" shot.

Earlier work on Pegasus I used a pure aluminum foil $2.5x10^{-5}$ cm in thickness that was secured both top and bottom by steel fingers attached to the foil mounting rings. This configuration gave a radiation pulse of about 200 ns in width with some interesting structure. The difficulty of mounting a foil in this configuration has led us to using a foil that is suspended by its top mounting ring only. A 1-mm gap around the bottom ring is bridged by plasma when the bank fires. More recent foils have also had a thin parylene coating on their inside surface. This was originally added for strength in the early experiments. Calculations have shown that using a 3x thicker foil than the 2.5×10^{-5} cm thickness would result in a more stable implosion and of course couple more of the bank's energy into the implosion. The enhanced stability should actually give a hotter plasma even with the extra mass. These experiments were done both on Pegasus I and Pegasus II and are discussed below.

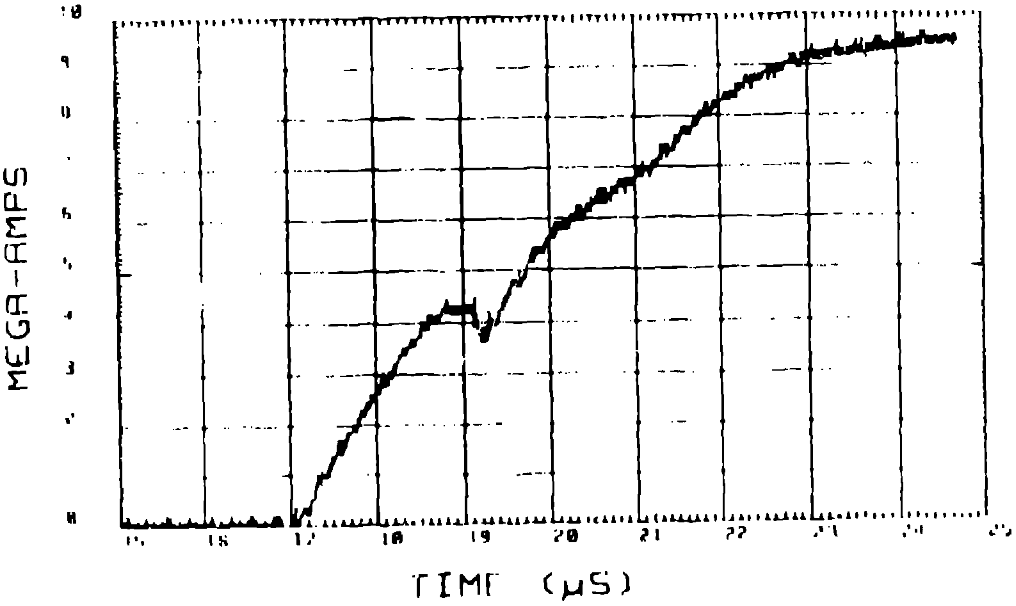


Fig. 2. Current waveform for a Pegasus II "direct drive" shot.

In Fig. 3, a typical array of electrical diagnostics is shown for a plasma flow switch shot. The array is the same for a direct drive shot except that the number of B-dot probes in the coaxial region of the power flow channel is reduced. Note that B-dot loops are located in the load slot at radii both outside and inside of the foil radius. Diagnostics fielded on the foil implosion shots consist of current and voltage diagnostics mentioned above in Fig. 3 and also include a four channel filtered bolometer, a four channel filtered XRD array, a grazing incidence spectrometer, a time resolved multichannel transmission grating spectrometer, x-ray pinhole cameras, and fast framing and streak cameras. All diagnostics that are recorded electrically have their signals transmitted over fiber optic links to the shielded screen room. All diagnostics are on battery power when the machine is fired to avoid ground loop problems. This method of having no electrical connections to the machine when it is charged and fired has given essentially no noise fed into the screen room or building via the AC mains.

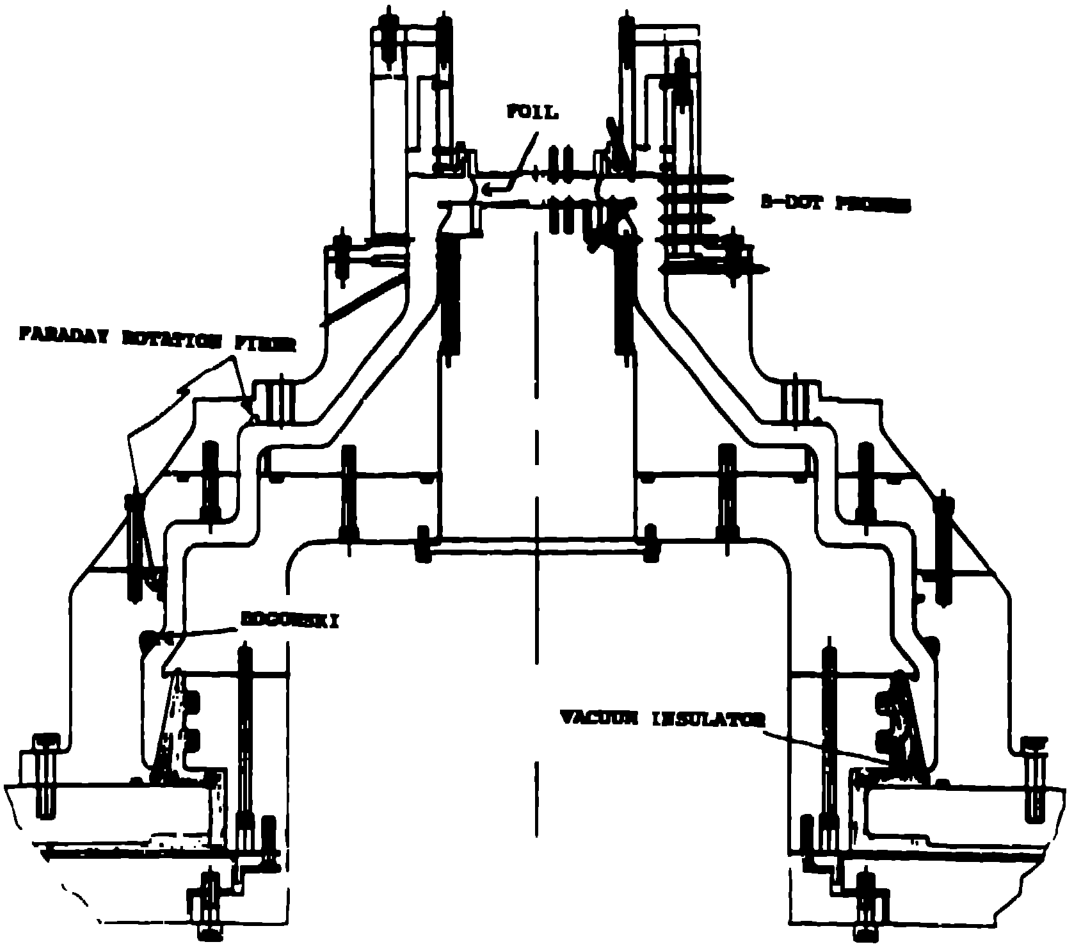


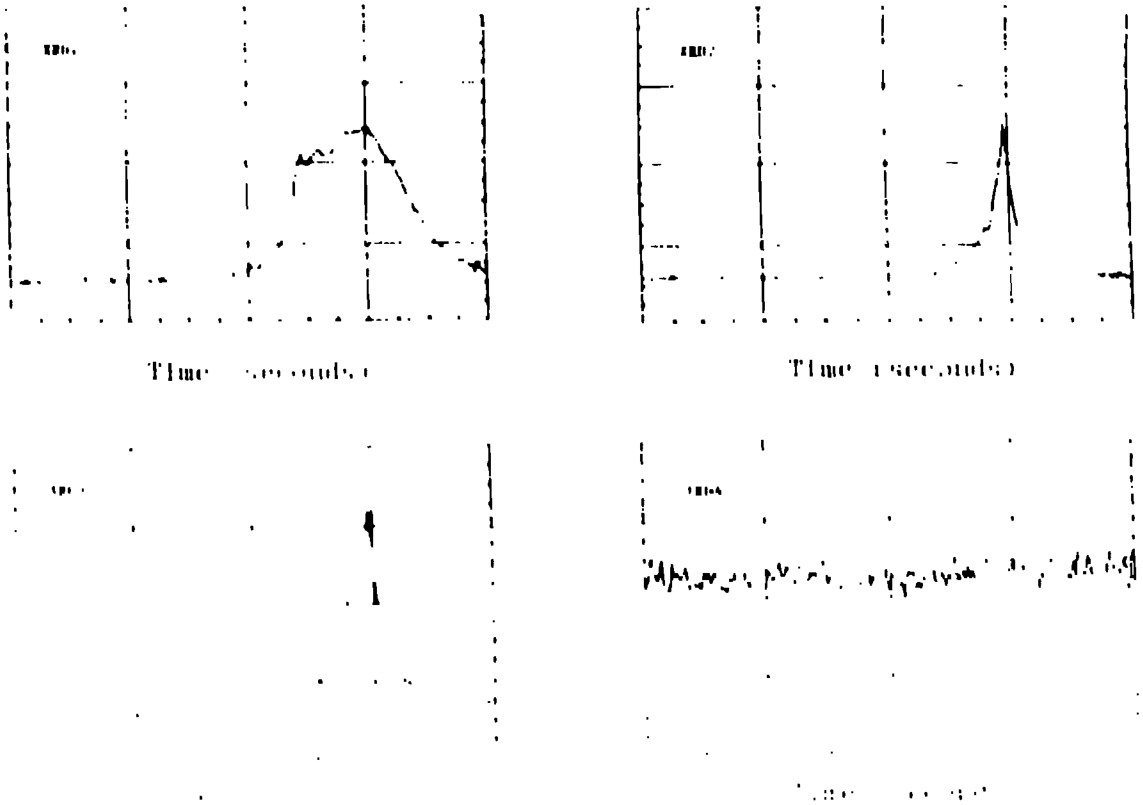
Fig. 3. Pegasus II power flow channel.

The implosion on Pegasus II produced a total radiated energy of 125 kJ as measured by a thin film bolometer. The peak current before the I-dot reversal, due to the inductive voltage produced by the implosion, was 4.3 MA. The charge voltage on Pegasus II was chosen to match the I-dot on the Pegasus I experiment (i.e., 80 kV for Pegasus II vs. 84 kV for Pegasus I). Fast framing camera photographs of the actual implosion (Fig. 4) show very similar structure for the two shots and are in good agreement with theoretical predictions. This structure is expected to broaden the radiation pulse when the foil stagnates on axis.

The framing camera photographs in Fig. 4 above have an exposure time of 157 ns with 200 ns between frames. The two vertical lines are vanes. Time runs alternately bottom to top, left to right. The instabilities are clearly visible by the distortion of the luminous edge of the foil.

The unfiltered XRD channel gave a pulse width ~ 500 ns. The signal begins as the current begins to "roll over" (see Fig. 2) and peaks near the current minimum. The filtered XRD channels had a FWHM of about 200 ns with a single peak on the Pegasus II shot. On the identical Pegasus I shot, the XRD signals had two peaks, which indicate two separate implosions. This was predicted in simulations between these (supposedly) two identical shots is still being investigated theoretically. The filtered XRD signals for a Pegasus I shot are shown in Fig. [illegible] and these filters are identified in Table [illegible]. Major time divisions are [illegible]00 ns.

Fig. 5 Framing camera photographs of a "direct drive" foil implosion



[illegible] Pegasus [illegible]

Table I. XRD filters

XRD1	100 lpi Au mesh (1.79% transmission)
XRD2	158 $\mu g/cm^2$ Saran + 20 $\mu g/cm^2$ Al + 150 lpi SS mesh
XRD3	600 $\mu g/cm^2$ Al + 150 lpi SS mesh
XRD4	400 $\mu g/cm^2$ Mylar + 24 $\mu g/cm^2$ Al + 150 lpi SS mesh

Spectra were obtained on both a grazing incidence and a transmission grating spectrometer. A calibration problem with the transmission grating spectrometer at low photon energies prevents agreement on a blackbody temperature or on whether the spectrum has a blackbody shape. The grazing incidence spectrometer data yields a temperature between 37.5 and 50 eV. A different cutoff filter should provide a closer estimate of the fitted blackbody temperature.

Figure 6 is the time resolved spectrum from the transmission grating spectrometer. Intensity is proportional to the energy in a wavelength interval and the photon energy increases from right to left (65 eV to 1896 eV). Time is streaked from top to bottom. The total streak duration is 2 microseconds.

Fig. 6. The time resolved spectrum from the transmission grating spectrometer.

SUMMARY

Direct drive foil implosion experiments have been performed on the Pegasus facility to investigate the validity of theoretical predictions. To date, the predictions have accurately predicted the radiation output and instability growth in the imploding foils. Future shots are planned to investigate the effect of the ratio of the parylene thickness to the aluminum thickness on the stability of the implosion and to compare these results to pure aluminum foil implosions. The results of these tests will determine the best configuration for an imploding load to be used with a plasma flow switch. The plasma flow switch should increase the energy coupled into the load and produce a more narrow radiation pulse.

ACKNOWLEDGMENTS

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