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AUTHOR(S)   P. H. Lee, P. Turchi, R. L. Bowers, C. E. Findley,
A. E. Greene, H. W. Kruse, H. Oona, J. V. Parker,
D. L. Peterson, J. C. Cochrane, B. G. Anderson,
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**Los Alamos National Laboratory
Los Alamos, New Mexico 87545**

PLASMA FLOW SWITCH EXPERIMENTS ON THE PEGASUS FACILITY*

J. C. Cochrane, Jr., B. Anderson, R. R. Bartsch, R. Bowers, C. Findley, A. Greene, H. Kruse,
H. Oona, J. V. Parker, D. Peterson, G. Sandoval
Los Alamos National Laboratory
Los Alamos, New Mexico

P. H. Y. Lee
TW
Redondo Beach, California

P. Turchi
Ohio State University
Columbus, Ohio

Abstract

Plasma flow switch experiments conducted on
Pegasus have shown that a conducting layer of plasma
shunts the load slot preventing efficient switching of current
to the load. This effect is seen computationally. The
magnitude of the effect depends on the specific parameters
of the switch plasma and current level. Computations have
also shown that a plasma boundary layer "trap" would
effectively remove enough plasma from the inner conductor
of the power flow channel so that efficient switching would
occur. This plasma trap has been successfully
demonstrated when used with a static load. It has not yet
been tested with an imploding load.

Introduction

Pegasus is a fast capacitor bank that is presently
used in support of the Los Alamos Foil Implosion Program.
The bank has a maximum stored energy of 1.5 MJ at
120 kV (±60 kV charge voltage). The capacitance is
216 µF with a total system inductance of 30 nH. Typical
operating parameters are a charge voltage of ±44 kV with a
peak current into the plasma flow switch (PFS) load of 6.5
MA in 3.3 µs. The quarter cycle time of the bank when fired
into the static system inductance is 4 µs. The capacitors
are arranged around a circular transmission line in four
models of 36 capacitors each. Each module is switched by
solid dielectric switches activated by detonators.

The role of Pegasus in the Los Alamos Foil
Implosion Program is an experimental facility for the study
of inductive energy storage systems driving plasma
radiation sources. Key issues are the requirement for a
fast, high-current opening switch and the need for a better
understanding of the implosion process. The fast opening
switch chosen for investigation is the PFS. Ideally, this
switch acts like a conducting washer moving down a
coaxial channel. The switch provides a current path that
isolates the load from the current until the PFS passes over
the load. The load then becomes part of the circuit in (to a
first approximation) the transit time of the switch passing
over the load (Fig. 1). The PFS used on Pegasus has a
velocity of 6-7 cm/µs and has a theoretical switching time
of 300 ns for a 2-cm-high load. The geometry of the PFS in
the power flow channel (PFC) is shown in Fig. 2.

The PFS dimensions chosen for Pegasus are based
on the dimensions of the switch used in the Quickfire
experiments on the SHIVA Star bank at AFWL[1]. Given our
lower current capability, the switch mass is chosen to have
the same acceleration as the switch mass used in Quickfire.
PCF dimensions are such that the time scales are also
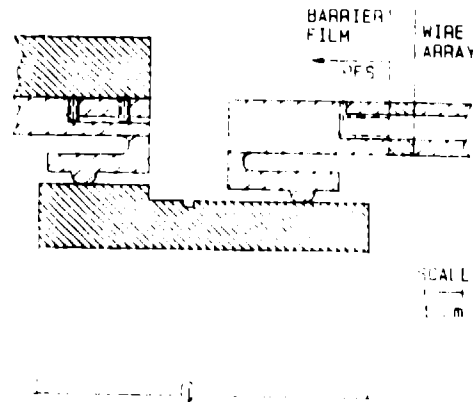
Fig. 1. Plasma flow switch schematic.

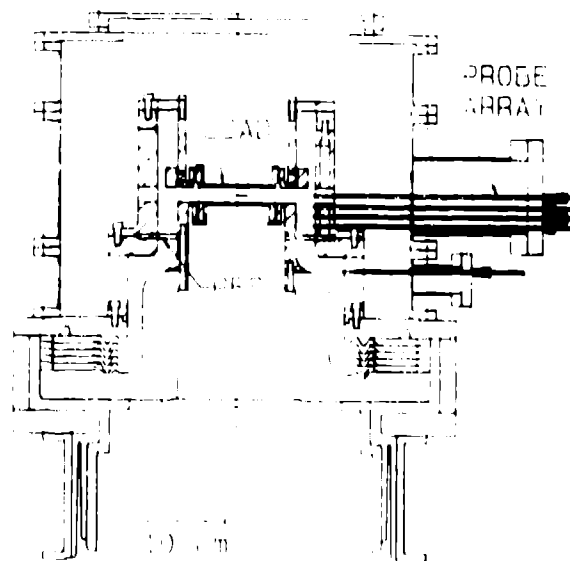Fig. 2. PFS installed in the power flow channel.

the same. The total switch mass is 40 mg with an equal
distribution of mass in the aluminum wire array and in the 1-
micron-thick barrier film. The aluminum wire array is a
chordal array of 160 wires, each 0.0025 cm in diameter.
When the wire array mass distribution is combined with the
uniform mass distribution of the Mylar barrier film, a $1/R^2$

mass distribution is achieved to within 7%. The barrier film is located 0.63 cm downstream of the aluminum wire array. The aluminum wires initially short the coaxial PFC and provide the initial current path for the capacitor bank. The current rapidly vaporizes the wires forming a plasma behind the barrier film. The barrier film vaporizes about 800 ns later. The barrier film serves to reduce, but not eliminate, precursor currents in the PFC. The plasma is accelerated toward the load by the J x B force of the current and reaches the load in 3.3 μs. The L-dot of the switch causes the bank current to decrease just before switching. The load is a 2500-Å-thick, 2-cm-high, 10-cm-diameter hard-mounted aluminum foil. It is located in a slot 2-cm wide and 2.7-cm deep. "Dummy load" shots, used to study switch characteristics, replace the aluminum foil with a thick-wall aluminum cylinder. This cylinder allows insertion of B-dot probes at the surface of the load.

Experimental Results

The primary diagnostic used in observing the PFS behavior is an array of B-dot probes. The location of the probes in the outer coaxial portion of the PFC is shown in Fig. 2. An array of load probe locations is discussed later. The probes are typically not aligned in the axial direction so as to avoid interactions with each other. The probes are constructed of a single turn formed by bending the inner conductors of small semi-rigid coax (RG 405) back to the shield and attaching the two with a solder joint. The typical area of the probes is 3.5×10^{-6} m^2. Typical axial length of the effective probe area is 2-3 mm. The shield of the cable is covered with shrink wrap for insulation and the tip of the probe is protected by inserting it into a quartz jacket filled with epoxy. Many of the probes are re-usable. The probe signals are integrated by 300 μs integrators and transmitted to the screen room over analog fiber optic links with 20 MHz bandwidth where they are recorded on digitizers.

The probes in the outer coaxial electrode of the PFC show the typical current steepening as the plasma sheath progresses down the channel. Early dummy load shots had 4 MA switched into the load (Fig. 3). This was about 70% of the available current and had a rise time of 250-350 ns. Note that the current in the PFC is crowbarred.
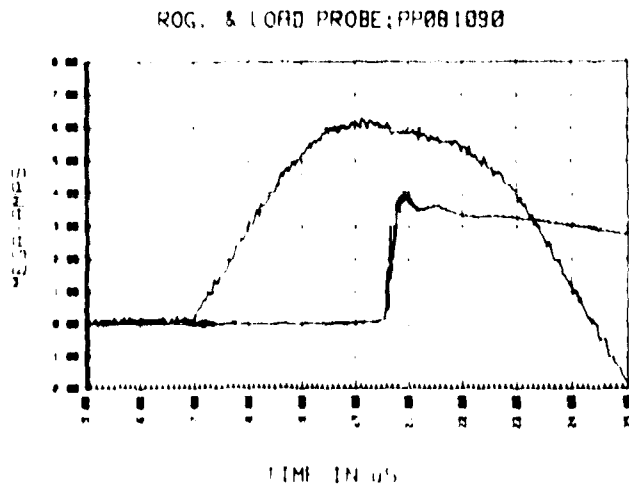
This occurs when the vacuum insulator flashes over due to the PFC voltage polarity changes. When foils were used as a load, the amount of radiated energy was much less than expected if the current into the dummy load was also switched into the foil. These results are similar to the early AFWL results[2]. Further investigation of current transfer into the load slot showed only about 2-2.5 MA were being switched into the load slot at radii of less than 4 cm when implosion loads were used.

Simulations were done on the basic design of the PFS[3] that indicated the load slot was being shunted by a plasma layer laid down on the inner conductor of the PFC by the PFS (see Fig. 4). In Fig. 4, density contours are plotted, and the switch plasma has just crossed the load slot. Ideally, the plasma would move across the load slot in a thin planar slug leaving no mass behind. This situation is consistent with the experimental observation that the current switched into the load slot decays with an L/R constant that is long compared with the 20 μs observation time. This current is typically 50% of the current flowing the PFC as indicated by the probes in the outer wall of the PFC. This implies that a fraction of the total current is switched into the load slot, and then the slot is shunted by the plasma. This plasma does not implode because of the trapped magnetic field of the switched current. The plasma layer has also been observed more directly by probes located at radii just inside of and just outside of the load slot.

A computational effort was made to see what modifications to the basic PFS geometry would eliminate the plasma boundary layer. Several "fixes" were tried including a barrier just before the load slot. It was found that a slot cut into the inner conductor of the PFC would effectively trap the boundary layer. This result is displayed in Fig. 5, which again plots density contours of the switch plasma as it is crossing the load slot. The boundary layer is seen to be impacted on the downstream side of the trap, and the load slot is no longer being shorted by a dense plasma.

ROG. & LOAD PROBE: PP081090

TIME IN μS

Fig 3 Bank current (Rogowski) and current switched into a dummy load
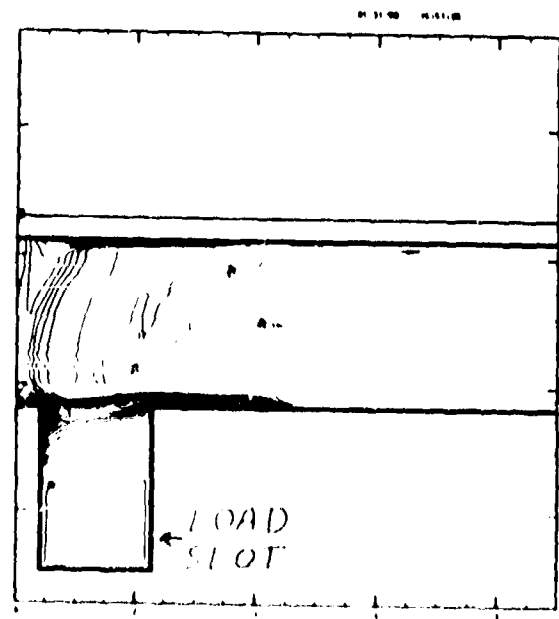
LOAD SLOT

Fig 4 Density contours showing the PFS covering the entrance to the load slot. PFS motion is right to left
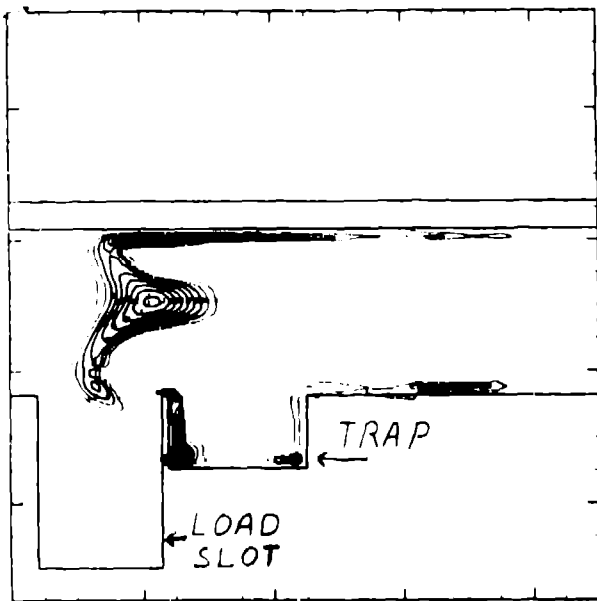
Fig. 5. Density contours with a plasma boundary layer trap machined into the inner conductor of the PFC Just upstream of the load slot.

Experimental test of this computation consisted of firing a shot without the trap to try and observe the boundary layer and then to repeat the shot with the trap in place. Figure 6 shows the experimental arrangement with the plasma boundary layer trap in place. The trap is immediately to the right of LP1 and LP2 in the figure. The load probe positions were the same in both cases. The load probe currents without the trap are shown in Fig. 7. The 300 ns delay between probes LP1 and LP4 is the transit time of the PFS crossing the load slot (2 cm). Notice the 1 μs time delay in current arriving at LP1 and LP2, which is located at a radius 4 mm less than LP1. This is consistent with a conducting layer between the probes. When flux does penetrate the layer, current arrives within 50 ns at probes LP2 and LP3. Again, the switched current is 4 MA, which is consistent with all of the dummy load shots. With the trap inserted, the switched current, shown in Fig. 8, is, to within probe calibration error (±5%), all of the current in the PFC at the time of switching.
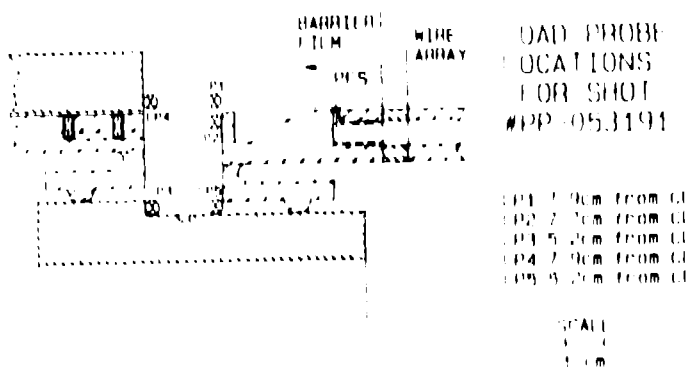

Fig. 6 Load probe locations for probing the effects of the plasma boundary layer and its effect on switching both with and without the boundary layer trap.
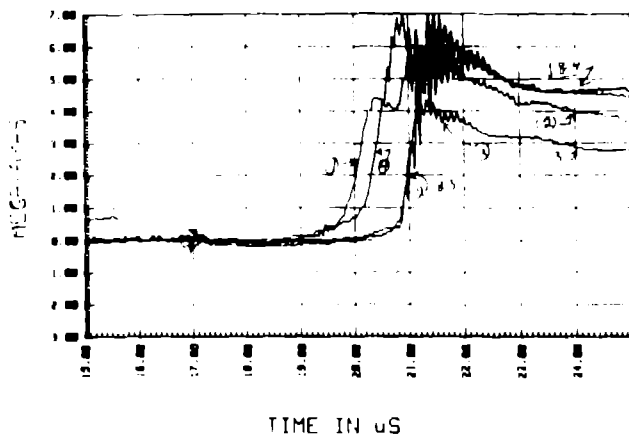

TIME IN uS

Fig. 7. Load probe currents without the plasma boundary layer trap. Probe numbers correspond to Fig. 6.
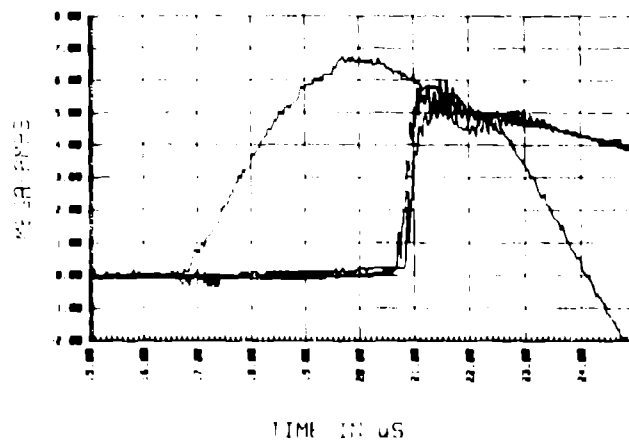

TIME IN uS

Fig. 8. Bank current and current switched into the load (both at upstream and downstream positions) with the plasma boundary layer trap inserted.

Summary

Computations have predicted and experiments have verified that a slot cut into the inner conductor of the PFC effectively traps the plasma boundary layer that the PFS lays down on the inner wall of the PFC in Pegasus experiments. This trap gives a current transfer into the nonimploding load of 90-100% with a risetime of 250-300 ns. At present current levels, this is an average I-dot of, 2×10^{13} A/s. We have not yet tested the effect of the trap with an imploding foil load.

References

[1] J. H. Degnan, et al., "Experimental Results from SHIVA Star Vacuum Inductive Store/Plasma Flow Switch Driven Implosions," IEEE Transactions on Plasma Science, Vol. PS-15, No. 6, Dec 1987, pp. 760-765.

[2] W.L. Baker, et al., "Quickfire Plasma Flow Driven Implosion Experiments," Digest of Technical Papers, 5TH IEEE Pulsed Power Conference, Washington, DC, 1985, pp. 728-731.

[3] D. Peterson, et al., IEEE 1991 Proceedings.