Neutron Emission Characteristics of a High-Current Plasma Focus: Initial Studies

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Abstract. The Texas A&M University plasma focus machine is operational and is beginning to provide good experimental data. It has its origins in several earlier machines and is located in a former service station building with a shield wall that provides a good geometry for neutron measurements. We are operating in the high pressure mode for a plasma focus, similar to previous efforts in the US. Early neutron measurements are providing some insight for the machine's operation.

INTRODUCTION

The new plasma focus machine (TAMU DPF) at Texas A&M University is operational and has a good geometry configuration for performing neutron time-of-flight diagnostics of the DPF itself and for diagnostic development. Thus, without any requirement for scaling, the TAMU DPF is an appropriate system for providing support for pulsed neutron needs in the $10^{11} - 10^{12}$ n/pulse range from the D(d,n)T reaction.

The capacitor bank to power this plasma focus stores 480 kJ at a maximum charge voltage of 60 kV. The capacitance of the bank is ~ 268 μ F, and its inductance is about 25 nH through the header insulator. The rise time of this system is ~ 4.3 μ s. Machine currents for these data are 1.4 to 1.8 MA.

The capacitors are the 1.85 μ F, 60 kV cans from the SHIVA I capacitor bank at Kirtland AFB. The bank is configured into six modules with 24 capacitors each, with a single ATLAS rail-gap for each module. The trigger subsystem is a Maxwell, shorted, charged cable design. The control system for this machine is Labview®-driven and fiberoptically coupled.

Physically, the TAMU DPF is located in a WW-II era base service station building with a characteristic room dimension of ~ 9 m square. The plasma focus device is located in the center of the room and aligned vertically downward. All time dependent data are measured at 90° to the gun axis. The walls of the building are unfilled concrete block. Located 1.2 m from the outer wall, a 60-cm thick concrete shielding wall extends around three sides of the experimental end of the building. In three

locations, steel line-of-sight pipes extend from the inside of the building through the concrete shield wall.

PLASMA FOCUS OPERATION

There are two distinct modes for operating a plasma focus. These are the low and high pressure modes, and they differ in several distinctive ways. Of course, there are mixtures of these modes, depending on the exact conditions for the machine dimensions, the maximum current, and the initial gas pressure before the discharge. The discussion is intended to magnify the extremes of these modes for clarity.

In the low-pressure mode of operation, the rz-pinch becomes current carrier starved much earlier in its history, probably due to the early onset of instabilities. The measured neutron source from this mode of operation includes a region that is roughly 2 cm in diameter and about 20 cm long in a 2-3 MA machine [1]. The neutron distribution tends to be forward directed with as much as a 50% anisotropy. Unfortunately, one frequently observes somewhat erratic and unreproducible behavior. The neutron yield scales as $I^{3.3}$, with saturation effects observed in the Posidon machine [2]. This is the operational mode that many of the European machines have used since the Fracatti [3] and Lemiel [4] systems were functional in the late 1970's.

FIGURE 1. Time of flight trace for the 8.85-m line-of-sight for shot 5 on 5/30/2001.

In the high-pressure mode of operation, the rz-pinch still experiences instabilities, but the growth rate appears to be slower due to mass flow through the pinch. The neutron emitting region from a pinch operating in this regime is about 1 to 2 mm diameter and ~1 cm long [5]. The neutron distribution is within about 10% isotropic, and the pinch behavior may be very reproducible. In this mode, the neutron yield

scales as I^{4-5} . This is the mode that essentially all of the early machines at Los Alamos used in the 1960's and 1970's[6].

NEUTRON MEASUREMENTS – INITIAL STUDIES

The neutron measurements have included total yield detectors and time resolved measurements. The total yield detection has been performed using the standard LASL silver detectors [7]. The active elements of these units are Geiger tubes. The detection uses silver activation that enables a quiet counting environment after the machine pulse. The two detectors are located 3.05 m and 4.37 m from the focus center line and at about a 25° back angle from the end of the anode.

The prompt neutron detectors use photomultipliers (PMT) coupled with plastic scintillators. The PMTs are Amperex XP2020 tubes and are 12 stage tubes with gains of about $10^7:1$. Linear currents are about 1 ampere. The scintillation material is Pilot U plastic. The combination of the Amperex XP2020 and the Pilot U scintillator is a good match in performance for rise and fall times, ~1.2-1.4 ns. The two detection stations used so far are 8.85 m and 17.4 m from the plasma focus and are at 90° to the machine axis. With few exceptions, both prompt neutron detectors are housed in 5-cm thick lead shields to reduce the (n,n') interaction signal.

FIGURE 2. Time of flight trace for the 17.4-m line-of-sight for shot 2 on 5/30/2001.

The scintillator thickness for the 8.85-m line-of-sight (LOS) is 0.635 cm, approximately 25% of the mean free path (MFP) for a 2.45 MeV neutron. However, it is only about 0.32% of the MFP of a 14.1 MeV neutron. By contrast, the 17.4-m LOS scintillator is 2.54 cm thick, about a MFP thickness for 2.45 MeV and about 12.7% MFP for 14.1 MeV neutrons. Thus, the shorter line of sight is very insensitive to the

higher energy neutrons, while the longer line of sight will have a better sensitivity but a correspondingly lower flux incident on the detector.

Figure 1 shows a trace recorded from the 8.85-m line-of-sight. In this trace, the alignment through the penetration in the shield wall is reasonably good, so the neutron pulse width of about 138 ns is not distorted by stray scattering in the geometry. While some of the hard gamma radiation from the (n,n') interactions is still recorded, the 2.45 MeV neutron pulse is the dominate feature. This trace, with a total neutron yield of about 3.9×10^{11} n/pulse, shows some indication of multiple pulses from the focus but provides no indication for the presence of 14.1 MeV neutrons .

However, another shot with a total neutron pulse of about 2.6×10^{11} n/pulse provides a possible 14.1 MeV neutron pulse from the partial reaction of the tritium produced Fig. 2. Other laboratories have reported the 14.1 MeV daughter neutron pulse for higher yield experiments, so this is not a new result. The timing of the observed pulse would indicate that it originated well after the 2.45 MeV pulse began, which is consistent with the partial reaction of a daughter isotope. Unfortunately, this pulse is entirely absent from the 8.85-m trace. Thus, one cannot provide a convincing analysis from this data to support a firm neutron energy identification.

SUMMARY

The TAMU DPF is operating at low voltages and beginning to mature as a facility that can provide useful neutron pulses for several applications. The presence of a thick concrete shield wall enables good geometry neutron time of flight measurements. We have acquired data to support earlier observations that the full-width-half-maximum neutron pulse from a higher current plasma focus is about 100 ns. As the machine is optimized and a wider array of diagnostic tools are employed, we expect to produce significant new data to support advanced applications.

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