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DESIGN OF NEUTRON STREAK CAMERA FOR FUSION DIAGNOSTICS

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Design of Neutron Streak Camera for Fusion Diagnostics*

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Abstract

The D-T burn time for advanced laser-fusion targets is calculated to be very short, < 50 ps. We describe the design of a neutron streak camera of 16 ps resolving time that can be used to study the temporal history of fusion burn. The cathode of the neutron streak camera is sensitive to neutrons and is curved such that the difference in the neutron path lengths from a point source to various parts of the cathode is compensated by electron transit times within the streak tube. Thus the cathode can be made large for high sensitivity, without sacrificing time resolution. The cathode is coated with $1 \mu\text{m}$ UO_2 . Each fission fragment leaving the cathode generates 400 secondary electrons that are all < 20 eV. These electrons are focussed to a point with an extractor and an anode, and are then purified with an electrostatic deflector. The electron beam is streaked and detected with the standard streak camera techniques. Careful shielding is needed for x-rays from the fusion target and general background. It appears that the neutron streak camera can be a viable and unique tool for studying temporal history of fusion burns in D-T plasmas of a few keV ion temperature.

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Introduction

In laser fusion, such as with the 150 kJ NOVA I laser under construction at our Laboratory, the D-T reaction is expected to be complete within 50 ps. In order to obtain some clues as to how the fusion reaction progresses, it is useful to measure the time-dependence of the neutron flux from the target. We describe here the design of a neutron streak camera, that will have a 16 ps resolving time and can be used to study the temporal history of fusion burn.

A neutron streak camera is essentially the same as an optical or x-ray streak camera, except that (1) the cathode is sensitive to neutrons, and (2) the cathode is curved such that the difference in the neutron path lengths from a point source to various parts of the cathode is compensated by electron transit times within the streak tube. In this way the cathode can be made large (several cm^2) for high sensitivity, without sacrificing time resolution. Time compensation is thus a key element to the development of a high sensitivity neutron streak camera.

Neutron Cathode

It is known that fission materials such as UO_2 make good cathodes for neutron diodes. This is because U has a large fission cross section (2.1 barns for 14 MeV neutron), and the highly charged fission fragment drags out a large number (> 200) of low energy secondary electrons as shown in Fig. 1. However, in order to be useful as an ultrafast streak camera, the energy spread of these electrons has to be small. We estimate the spread to be $\Delta E_e \sim 6$ eV FWHM, using the data of Jamerson et al.¹ Fortunately, this is adequate for our purposes as will be seen later.

The thickness of the cathode should be less than the range of the fission fragments ($\sim 10 \mu\text{m}$). The thinner the cathode, the smaller the electron transit-time spread and thus the better the time resolution. However thinner cathodes result in poorer detection efficiency. For a given cathode thickness one can increase the detection efficiency by making the cathode area larger. There is nonetheless an additional problem. The 14 MeV neutron is rather slow, only 17% of the speed of light. One mm path difference introduces a time spread of 20 ps. How can we then obtain a large cathode without jeopardizing the time resolution?

Compensating Neutron and Electron Transit Time Dispersion

Fig. 2 illustrates the basic relation for compensating neutron and electron transit time dispersions. Make a curved cathode so that the neutron and electron path differences are given by ΔS_N and ΔS_e respectively. Let β_N = neutron velocity, and β_e = electron velocity.

Then

$$\Delta t_N = \frac{\Delta S_N}{\beta_N} = \text{neutron transit time difference} \quad (1)$$

$$\Delta t_e = \frac{\Delta S_e}{\beta_e} = \text{electron transit time difference} \quad (2)$$

Choose β_e such that

$$\beta_e = \beta_N \frac{\Delta S_e}{\Delta S_N} \quad (3)$$

$$\Delta t_e = -\Delta t_N \quad (4)$$

Thus by choosing the electron velocity to satisfy equation 3 one can compensate the neutron transit time difference by the electron transit time difference (equation 4). Fig. 3 depicts the schematic of a neutron cathode and anode configuration.

Electron Beam Optics

We have modified the code GUNSLC² to compute the electron beam optics for a 5 cm diameter cathode of 2.5 cm radius of curvature. With a 10 kV extractor and a 30 kV anode, the secondary electrons can be focused at the 0.1 mm radius pinhole 3.7 cm from the cathode. The ray traces are plotted in Fig. 4. Ray 1 through 6 were traced to clear the pinhole. The electron transit time difference Δt_e for these rays and the corresponding neutron transit time difference Δt_N for 14 MeV neutrons emitted from a source 30 cm away from the cathode are tabulated in Table I. It is seen that the time differences can be compensated to within 4.2 ps. (Δt_{Ne}).

Neutron Streak Camera

A possible configuration of the neutron streak camera is shown in Fig. 5. The cathode is coated with 1 μm UO_2 (or up to 10 μm for higher detection efficiency, but with poorer time resolution). Each fission fragment leaving the 1-10 μm UO_2 cathode generates 400-200 secondary electrons. The electrons focused at the first pinhole with the extractor and the anode are refocused with the first electrostatic lens at the second pinhole. The vertical deflector separates the electrons from surviving positive ions if any, due to $0(n,p)$ and $0(n,\alpha)$ reactions in the UO_2 cathode. The electron beam can now be streaked and detected with standard streak camera techniques.

Having cancelled out the neutron and electron transit time dispersions, the resolving time of the neutron streak camera is now dominated by the following two factors.

- 1) Δt_k , the transit-time dispersion³ due to the electron energy spread ΔE_e . Here $\Delta t_k = 23000 \sqrt{\Delta E_e}/E = 11$ ps for an electric field E of 5000 V/cm at the cathode, and $\Delta E_e = 6$ eV.
- 2) Δt_t , the electron transit-time spread in the cathode material. For $1 \mu\text{m UO}_2$, this is 10 ps, assuming an electron scattering-limited velocity of 10^7 cm/s.

The overall time resolution of the neutron streak camera is then

$$(4.2 + 11 + 10^2)^{1/2} = 16 \text{ ps.}$$

Using the above geometry, for 10^{11} neutrons emitted isotropically from a point source 30 cm away, 100 fission fragments would leave the $1 \mu\text{m}$ thick cathode of 1 cm effective radius, generating 40,000 secondary electrons. However, in the ray trace with GUNSLC, the secondary electron angular spread was restricted to within $\pm 10^\circ$ with respect to the normal to the cathode. Under this restriction, the transmission of the secondary electrons through the 0.2 mm first pinhole is 27%.

X-rays from the fusion target can be adequately shielded with 1 cm W. A Monte Carlo calculation for the neutron transport shows that the neutrons inelastically scattered from the shielding into the cathode, and the γ -rays generated in the shielding, contribute less than 1% to the background. A detailed study has yet to be carried out to determine the shielding required to protect the phosphor screen from the direct neutrons and general x-ray background. The vertical deflector can bend the electron beams downward enough (≥ 5 cm) so that an adequate shielding can be placed between the neutron source and the phosphor screen.

It is known that the optical streak camera works well at 80 cm from the target (outside the target chamber). With a reentry hole in the target chamber and with adequate shielding for the electromagnetic pulse (EMP) we expect the neutron streak camera to function properly at 30 cm from the target. We are planning an EMP shielding test with an optical streak camera. Should it prove necessary, the electron beam in the neutron streak tube could be guided out of the target chamber.

In conclusion, it is possible that the neutron streak camera can be a viable and unique tool for studying temporal history of fusion burns in D-T plasmas of a few keV ion temperature and 10^{11} neutron yield. For higher ion temperatures, the dispersion of the neutron energy due to Doppler broadening would require the streak camera to be placed closer to the target. How close it can be placed near the target and still remain operational can be answered perhaps only with experiments.

References:

1. F.E. Jamerson, C.B. Leffert, and D.B. Rees, J. Appl. Phys. 36 355 (1965).
Also James N. Anno, J. Appl. Phys. 33 1678 (1962).
2. William B. Herrmannsfeldt, Electron Trajectory Program, SLAC-16, Stanford University (1973).
3. V.V. Korobkin, A.A. Malyutin, and M.Ya. Schelev, J. Phot. Sci. 17 179 (1969).

Figure Captions:

1. Neutron Cathode--mechanism of secondary electron generation.
2. basic geometry relation for analyzing and compensating neutron and electron transit time differences.
3. Schematic of a neutron cathode and anode configuration.
4. Ray trances with the electron beam optics code GUNSLC (Ref. 2).
5. A possible configuration of the neutron streak camera.

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Table I
Result of Ray Trace with GUNSLC

Secondary electron angular spread restricted to within $\pm 10^\circ$ w.r.t. cathode normal.

<u>Ray #</u>	<u>Radius (mm)</u>	<u>Δt_e (ps)</u>	<u>Δt_N (ps)</u>	<u>$\Delta t_{Ne} = \Delta t_N + \Delta t_e$ (ps)</u>
1	0	0.2	0	0.2
2	2	2.0	1.7	3.7
3	4	-3.1	6.8	3.7
4	6	-11.6	15.4	3.8
5	8	-24.4	27.6	3.2
6	10	-39.6	43.8	4.2

Neutron cathode — mechanism of secondary electron generation

Each fission fragment, ff , drags out 400–200 secondary electrons, all of low energy $<20\ \text{eV}$ with FWHM $\Delta E_e \sim 6\ \text{eV}$

Data from Jamerson et al.
Secondary Electron Yields from Fission Fragments, J. App. Phys. 36 355 (1965)

BASIC RELATION FOR COMPENSATING NEUTRON AND ELECTRON TRANSIT TIME DISPERSIONS

Let $\begin{cases} \beta_N = \text{neutron velocity} \\ \beta_e = \text{electron velocity} \end{cases}$

Then $\begin{cases} \Delta t_N = \frac{\Delta S_N}{\beta_N} = \text{neutron transit time dispersion} \\ \Delta t_e = \frac{\Delta S_e}{\beta_e} = \text{electron transit time dispersion} \end{cases}$

Choose β_e such that

$$\beta_e = \beta_N \frac{\Delta S_e}{\Delta S_N}$$

Then

$$\Delta t_e = -\Delta t_N$$

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Figure 2

NEUTRON CATHODE AND ANODE SCHEMATIC

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Figure 3

A NEUTRON STREAK CAMERA

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Figure 5