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A stretch/compress scheme for a high temporal resolution detector for the magnetic recoil spectrometer time (MRSt)

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A time-resolved detector concept for the magnetic recoil spectrometer for time-resolved measurements of the NIF neutron spectrum is presented. The measurement is challenging due to the time spreading of the recoil protons (or deuterons) as they transit an energy dispersing magnet system. Ions arrive at the focal plane of the magnetic spectrometer over an interval of tens of nanoseconds. We seek to measure the time-resolved neutron spectrum with 20 ps precision by manipulating an electron signal derived from the ions. A stretch-compress scheme is employed to remove transit time skewing while simultaneously reducing the bandwidth requirements for signal recording. Simulation results are presented along with design concepts for structures capable of establishing the required electromagnetic fields. *Published by AIP Publishing.* [http://dx.doi.org/10.1063/1.4959955]

I. PROBLEM DESCRIPTION

Neutron spectrometry is a valuable diagnostic tool which is used to evaluate plasma conditions in inertial confinement fusion experiments. Time resolved neutron spectra can give information on the dynamics of the fuel assembly formation and disassembly near stagnation. A magnetic recoil spectrometer (MRS) is currently fielded at the National Ignition Facility (NIF) and records a time integrated neutron spectrum by energy resolving protons (or deuterons) scattered from a plastic foil under neutron bombardment.[1] The ion energy is resolved using a magnetic spectrometer. An effort is underway to design a new instrument of this type which can record a time resolved spectrum of the neutrons produced at the NIF.[2] Here, we discuss a concept for a high temporal resolution detector that can capture and record the signal generated by the proposed magnetic recoil spectrometer (MRSt).

This new spectrometer is designed to accept either protons with 12–16 MeV energy range or deuterons with a 10.7–14.2 MeV energy range and separate the ions over an approximately 30 cm wide focal plane. A double magnet configuration is used to maintain the temporal coherence of the ion signal at each energy. To record the ion signal, a detector is needed which can record the arrival time of each ion and correlate the arrival time at the detector to the birth time of the original neutron to within 20 ps. Additionally, the detector must individually record a number of bins each of which collects over a 100 keV energy range. The detector design is particularly challenging due to the fact that the velocity difference of the incoming ions coupled with the path length differences through the magnetic spectrometer cause the ion signal to arrive at the detector with a temporal spread of approximately 20 ns over the 30 cm wide focal plane. Thus, there is a 0.67 ns/cm skewing of the incoming signal which complicates the detector design. A simple recording scheme would require 1000 separate channels each sampling at 20 ps intervals to prevent the skew from blurring the time history. Such a system is not practical using currently available technology.

II. DETECTOR CONCEPT

In order to simplify the time resolved detection, it is necessary to remove the time skewing of the ion signal. This may be done by first converting the MeV ions to secondary electrons and then manipulating the electrons with electric and magnetic fields. A schematic for the detector is shown in Figure 1. The ions are directed onto a cathode structure which uses a CsI film to generate secondary electrons from the ion signal. Electric fields present near the cathode accelerate electrons through an anode mesh into the drift region. The electrons are guided down the drift region by a magnetic field which confines the electrons but is too weak to perturb the ion trajectories. At the back of the drift tube, the electron signal is amplified by a microchannel plate and then collected by a set of anodes distributed along the dispersion axis and sent to a bank of digitizers. Converting high energy ions to electrons at a CsI cathode has been demonstrated previously in the construction and testing of an ion streak camera.[3]

Once the signal has been converted to low energy electrons, the time skew can be removed by adjusting the drift velocity of the electrons at different points along the cathode. Suppose the ions arrive at the focal plane at time $t_a(x)$ where x is the distance along the focal plane in the energy dispersion direction. For an electron drift region length L_d, the electron

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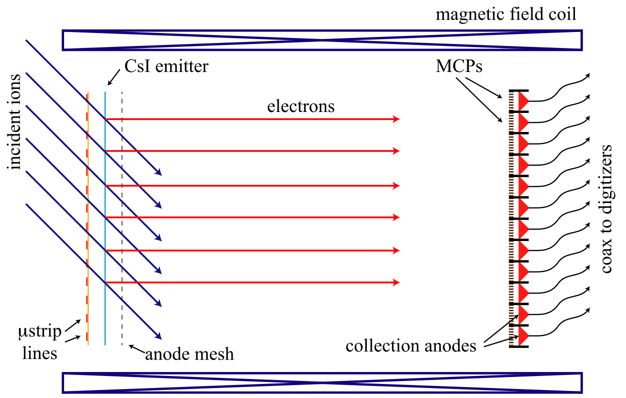

FIG. 1. Concept for an ion detector to record the signal from the MRSt. Incident ions are converted to secondary electrons at a CsI cathode. Electrons are accelerated into a magnetic field immersed drift chamber by an array of independently excited microstrip lines. At the end of their drift, the electron signals are amplified by microchannel plates and recorded by digitizers. Each channel represents one energy bin of the spectrometer.

transit time is

$$t_d = \frac{L_d}{v_e\{\phi[x,t_a(x)]\}}, \qquad (1)$$

where v_e is the electron drift velocity and, assuming that the transit time across the anode mesh to cathode gap is small, is determined by the potential difference ϕ across this gap. Now, in order to remove the skew of the incoming signal we require that variation in t_d along the dispersion direction of the cathode exactly compensates for the variation in ion transit time through the spectrometer,

$$t_a(x) + \frac{L_d}{v_e\{\phi[x,t_a(x)\}} = t_{det} = \text{constant}, \qquad (2)$$

and we may solve for the electron accelerating potential that is needed for the deskew

$$\phi[x,t_a(x)] = \frac{m}{2e}\frac{L_d^2}{[t_{det} - t_a(x)]^2}. \qquad (3)$$

A 20 ns time skew can be compensated by electrons drifting through 100 cm with energies ranging from 800 to 1800 eV. Such compensation may be realized by imposing a suitable voltage profile along the length of the cathode. Having removed the timing skew, we could in principle directly sample the electron signal in each energy bin at the very high sampling rate required for 20 ps resolution. However, in addition to the difficulty of providing many 20 ps digitizers, this rise time is beyond the bandwidth of the MCP amplifier. In order to simplify the back-end detection, we propose to lower the bandwidth requirements by using pulse-dilation of the secondary electron signal. The temporal magnification achieved with electron pulse-dilation is $M_\tau = 1 + (t_d/2)(\dot{\phi}/\phi)$ where $t_d = t_{det} - t_a$ is the electron drift time.[4] The potential ramp needed to achieve temporal magnification M_τ is

$$\dot{\phi}[x,t_a(x)] = (M_\tau - 1)\frac{2\phi[x,t_a(x)]}{t_{det} - t_a(x)}. \qquad (4)$$

If we choose $M_\tau = 25$, then the required temporal resolution of the back-end collection system is 500 ps and the required cathode potential ramp rates are 600–2000 V/ns over the electron drift energy range of 800–1800 eV.

Note that the potential gradient for removing the deskew essentially compresses the signal in time while the potential ramp for the pulse-dilation stretches the signal in time. These seemingly contradictory conditions can be met simultaneously by taking advantage of the spatial distribution of the incoming skewed ion signal. A time independent, spatially varying deskew potential is superimposed with a time dependent, spatially phased pulse-dilation ramp potential to satisfy Eqs. (3) and (4) concurrently.

III. CATHODE STRUCTURE

The DC deskew potential and the pulse-dilation ramp potential must both be applied at the location of the electron generation. Typically, the pulse-dilation ramp potential is introduced onto the cathode as an electromagnetic wave traveling down a microstrip transmission line. If the transmission line carrying the ramp potential is isolated with a capacitive break, the microstrip line at the cathode can be biased to an independent DC potential. This arrangement provides a method to apply both deskew and pulse-dilation potentials to the cathode.

Figure 2 shows a contour plot of the DC deskew potential applied to a set of microstrip lines. The propagation direction of the microstrip lines is normal to the page. Each microstrip line is biased to a different potential with the net effect of producing an accelerating potential that varies along the energy dispersion direction of ions ($\hat{x}$). Since the potential on each microstrip line is constant, the equipotential contours are nonmonotonic near to the microstrip lines. If electrons were born in this region, then the variation in accelerating potential would result in the large variations in electron drift times within one energy bin. This condition would temporally broaden the electron signal and the time history of the original ion signal would be lost. Away from the microstip lines and closer to the anode mesh the potential contours flatten out

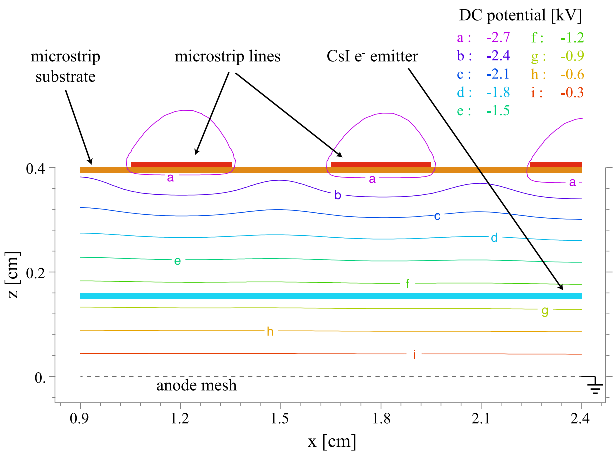

FIG. 2. Finite element solution for the electrostatic electron accelerating potential. Independent biasing of the microstrips results in a spatial gradient in the accelerating voltage which can be tuned to remove the time skewing of the ion signal from the spectrometer. The electron emitter is separated from the microstrips to reduce modulation of electron drift times.

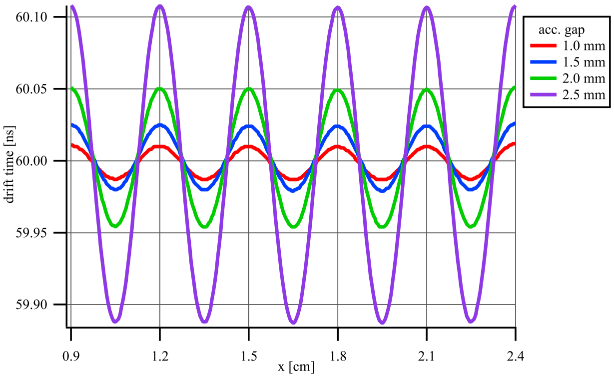

FIG. 3. Electron drift times for various accelerating gap distances. Microstrip line to mesh distance is fixed at 4 mm and the unit cell of the microstrip line structure is 3 mm. Spread in drift times about the average is reduced as the CsI emitter is moved away from the microstrip lines.

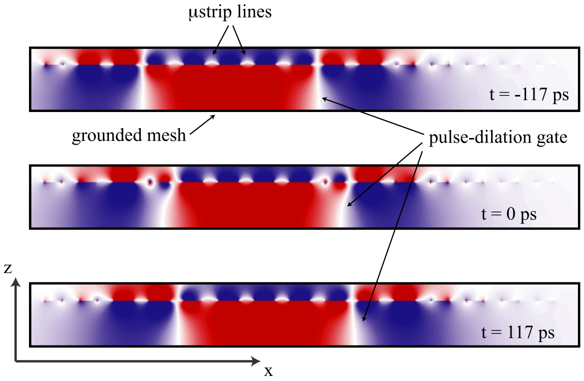

FIG. 4. Contour plots of ramp electric field E_z at three different time steps. Color map (red $+\hat{z}$ and blue $-\hat{z}$) denotes field direction. A pulse-dilation gate (white vertical stripe) is located where the ramp field vanishes and moves to the right as time progresses.

and the accelerating voltage is smoothly varying along $\hat{x}$. Therefore, the CsI layer is positioned on a thin substrate about halfway between the microstrip lines and the anode mesh.

Figure 3 shows the drift times for electrons born at various positions along the CsI emitter in the direction of the ion energy dispersion. For this particular case, the 1.5 mm wide microstrip lines are separated 1.5 mm from each other and the microstrip line to anode mesh distance is 4 mm. Results are given for CsI emitter to anode mesh distances of 1.0, 1.5, 2.0, and 2.5 mm. For each distance, the potentials on the microstrips have been adjusted to give a 60 ns average electron drift time down the 100 cm drift tube. Variation in electron drift time within one energy bin can be reduced to meet specifications by positioning the CsI emitter sufficiently far away from the microstrip lines. Since the CsI is an insulator, it may be necessary to apply the deskew potential with a pulsed field whose rise time is much longer than that of the ramp potential.

In order to reduce the bandwidth requirements for the amplifier and digitizers, temporal magnification of the electron signal is provided by launching ramp potentials along the microstrip lines. Each ramp potential is a bipolar pulse which initially accelerates and then decelerates electrons generated by the incident ions. The ramp excitations of the microstrip lines are delayed with respect to one another so the location of the pulse-dilation gate matches the incoming ion signal. Figure 4 shows contour plots of the accelerating electric field at three different time steps obtained from a simulation of the cathode structure. Each ramp pulse travels along a microstrip line whose propagation direction is out of the page. The ramps are launched with sequential timing from left to right. The white vertical stripe in Figure 4 marks the location where the accelerating field vanishes and represents the pulse-dilation gate. This gate is traveling in the $+\hat{x}$ direction as time evolves and can be tuned to match the incoming ion signal by adjusting the phase delay between ramps.

The cathode structure is the critical component of this detector design. It consists of an array of microstrip transmission lines, an anode mesh ground plane, and a CsI emitter located between the microstrips and mesh. Simulations have demonstrated that this structure can support both the spatially varying, time independent potential needed to remove the time skew of the incident ion signal and the fast potential ramps needed for temporal magnification. The detector concept presented here represents a path forward in the effort to record time-resolved neutron spectra with the MRSt from NIF implosions at 20 ps temporal resolution.

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[1] J. A. Frenje *et al.*, Phys. Plasmas **17**, 056311 (2010).
[2] J. A. Frenje *et al.*, "The magnetic recoil spectrometer (MRSt) for time-resolved measurements of the neutron spectrum at the National Ignition Facility (NIF)," Rev. Sci. Instrum. (these proceedings).
[3] A. G. Kravchenko *et al.*, Instrum. Exp. Tech. **47**, 157 (2004).
[4] T. J. Hilsabeck *et al.*, Rev. Sci. Instrum. **81**, 10E317 (2010).