Design and Development

of the LEDA Slow Wire Scanner Profile Measurement

Federal Manufacturing & Technologies

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Design and Development of the LEDA Slow Wire Scanner Profile Measurement*

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Abstract

The Low Energy Demonstration Accelerator (LEDA) [1, 2] is being developed at Los Alamos National Laboratory as part of the Accelerator Production of Tritium (APT) project. One of the diagnostics being developed to commission LEDA [3] is a slow wire scanner beam profile measurement. Initial profile

measurements will be made at 6.7 MeV beam energy and 100 mA beam current. The wire scanner is an interceptive device that will move two silicon carbide coated graphite mono-filament fibers (wires) through the beam, in order to obtain the profile. Some of the design considerations discussed are; Mechanical design, wire temperature analysis, secondary electron detection, signal processing, and system control.

1 scanner Mechanical Design

Fig. 1 shows the LEDA Slow Wire Scanner. The wire scanner will be mounted at 45° angle to the beam line in the diagnostic pump port of the LEDA High Energy Beam Transport (HEBT) [4]. The sensing wires are 100 µm silicon carbide fibers mounted on an aluminum fork. This material was selected based on the successful use of silicon carbide at LANSCE (Los Alamos Neutron Science Center) [5]. In order to prevent the x and y scanning wires from being in the beam at the same time the wires are mounted in a "V" design. Two biasing wires surround each signal wire. The biasing wires are also silicon carbide and will have a high voltage on them. The biasing wires prevent the secondary electrons from back streaming on to the signal detection wires and also will optimize the Secondary Electron Coefficient (SEC) of the wires. This configuration called for approximately 370 mm of travel to get both signal fibers fully through the beam scanning area. To clear the fork back out of the scanning area requires an additional 90 mm of travel.

1.1 Drive System

A fractional horsepower stepper motor moves the scanner through the beam. Coupled to the stepper motor is a modified Huntington Labs linear motion feed through. The stepper motor drives a ball screw that converts rotary to linear motion.

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There are two separate position feedback systems, a rotary potentiometer and a linear optical encoder. Preliminary system testing shows the rotary potentiometer has an uncertainty of 0.17 mm and the linear optical encoder has an uncertainty of 0.013 mm.

1.2 Vacuum Considerations

The drive system lies outside the vacuum boundary of the beam line. A flexible welded bellows seals the actuator to atmosphere. The actuator mounts to the beam line with the use of metal sealed flange connections. Inside the vacuum chamber the actuator bolts to the fork that is in turn connected to a recirculating ball linear bearing. The linear bearing moves on a precision guide rail. The linear bearing guide rail system stabilizes the wire configuration during data acquisition.

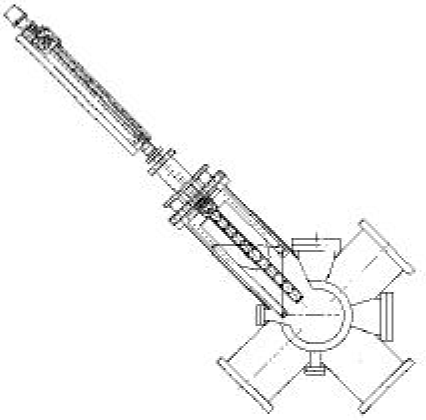

Figure 1: LEDA Slow Wire Scanner

2 Wire Temperature analysis

The sensing wires will intercept the beam as they move through it. The protons that move through the wire will interact with the electrons in the wire material atoms. The electron will sense an attractive force due to the oppositely charged proton. This force can cause the electron to move to a higher lying shell (excitation) or if it is large enough it can actually remove the electron (ionization) [6]. The energy lost to the wire material comes at the expense of the proton, and this energy will cause a temperature increase in the wire material. The problem with this measurement technique is that if the energy deposited in the wire becomes too great it can cause the destruction of the wire. In order to predict the operating parameters that the wire is capable of surviving it was necessary to do a thermal analysis of the sensing wires.

2.1 Governing equations

The analysis began by performing an energy balance on a control volume around the wire [7] and arriving at the following governing equation:

$$0 + \rho \frac{dE}{dx} I_{peak} V - \varepsilon\sigma\left(T^4 - T_{surr}^4\right)A_s = \rho V c_p \frac{dT}{dt}$$

Where,

r - wire material density (gm/cm^3).

dE/dx - stopping power (MeV-cm^2/g).

I_{peak} - peak current of the beam (µA/cm^2).

V - the volume of the wire under consideration (cm^3).

e - emissivity of the wire material.

s - Stephan-Boltzman coefficient (W/(cm^2-K^4)).

T - temperature of the wire (K).

T_{surr} - temperature of the surroundings (K).

A_s - surface area of the wire (cm^2).

c_p - specific heat capacity of the wire material (J/(g-K).

dT/dt - time rate of change of temperature (K/s).

The first term represents the energy entering the control volume that, in this case, is zero. The second term represents the energy generated inside the control volume, which is due to the stopping power [8] of the wire material and to the beam current. The third term represents the energy out, or the radiant cooling of the wire. The term on the right hand side represents the energy stored inside the control volume.

2.2 Numerical Analysis

A numerical integration technique is used to determine the time rate of change of temperature (dT/dt). Early on in the development of the scanner it became clear that no material would be able to withstand the intense CW beam conditions. It was therefore necessary to determine what pulsed mode operating parameters the wire material could tolerate. Fig. 2 shows a typical plot of the temperature rise in a 100 µm silicon carbide wire at a 500 µs beam macro pulse length and a 1 Hz beam repetition rate.

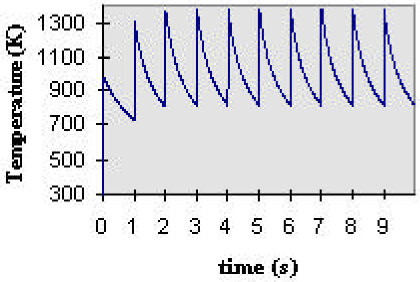

Figure 2: Temperature rise in SiC Wire

A series of analyses were done at various pulse lengths and repetition rates in order to determine the safe operating conditions of the wire. Fig. 3 shows the safe wire operating conditions based on a 500 ms beam pulse length at different repetition rates. The primary requirement was to keep the wire temperature below 1400 K, based on manufacture supplied data (Textron Systems, Wilmington, MA).

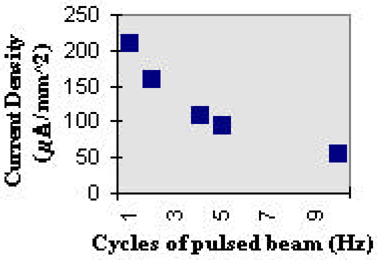

Figure 3: Scanner operating parameters for 500 µs beam pulse length.

2.3 Finite Element Analysis

A finite element analysis (FEA) was also done on the wire. Included in the FEA was the effect of the thermal conductivity of the material. Fig. 4 shows the results of an FEA model of a SiC fiber exposed to a 500 µs beam pulse and the conduction effects as the heat is being transferred along the wire axis.

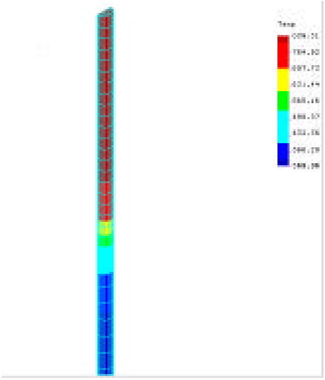

Figure 4: FEA model showing conduction effects

3 Secondary electron detection

The signal for this measurement is taken directly from the sensing wires. The signal will be the sum of the protons stopped in the wire and the secondary electrons leaving the wire surface.

3.1 Secondary electron yield

Protons passing through the wire surfaces generate secondary electrons, both as they enter and as they exit. Using Sternglass's theory [9] the amount of secondary electrons generated can be stated as follows:

$$Y = \frac{Pd}{\varepsilon}\frac{dE}{dx}.$$

Where,

Y = electron yield.

P = probability that electron will escape (0.5).

d = average depth from which the electron escapes (nm).

e = average kinetic energy lost by an ion per ionization in material (MeV).

dE/dx = stopping power (MeV-cm^2/g).

The anticipated secondary electron yield for the LEDA wires is: Y= 0.012, which corresponds to a 16 mA signal at the distribution peak with 100 mA beam current.

3.2 Signal processing

The current or charge measurement electronics will be packaged in VXI format. An onboard Digital Signal Processor (DSP) will enhance measurement and data analysis features. An on-line calibration and verification system will also be included.

3.3 Secondary Electron Coefficient, Ψ , calculation

One of the features being incorporated into the scanner control system will be the ability to do an on-line calculation of the SEC, Ψ. This is done by measuring a beam profile, normalizing the average beam current present during each point in the scan, as measured by the ac Beam Current Monitor system. The average SEC is calculated as the measured wire current divided by the theoretical current intercepted by the wire, assuming a Gaussian distribution.

4 System control

The wire scanner will be controlled by the Experimental & Physics Industrial Control System (EPICS) [10, 11]. Motion control sequences are written in State Notation Language, the EPICS implementation of a finite state machine. There will be three main screens.

4.1 Calibration Screen

This screen will be used to perform the on-line system verification. The operator will have the capability to check the condition of the sensing wires and verify the voltage on the biasing wires. The operator will also be able to verify the scanner position accuracy by running the scanner, acquiring position information and comparing this information against past performance.

4.2 Status and Scan Execution Screen

This screen will provide the operator information about the scanner and other accelerator functions. There will be links to the Run Permit system, information on beam pulse width, beam repetition rate, and the measured beam current. The operator will select from five types of scans.

Fast scan: This scan is intended to provide a quick, coarse resolution profile.

Slow scan: This scan is intended to provide a high resolution profile.

Find peak scan: This scan is a combination of the fast and slow scans.

Go to position and stay: The scanner will move to the operator-defined position and remain there.

User-defined scan: The operator has the ability to define the scan range (for both x and y axes) as well as the desired bin size (distance between data points).

4.3 Data Analysis screen

This screen is where the profiles will be displayed. There will be two plots, one for each axis profile. Interactive Data Language (IDL) will be used for data reduction. IDL is a commercial software package used for analysis and display of scientific data. The operator will have the ability to display calculated moments of the raw data and the parameters determined from a Gaussian fit.

5 Summary

Wire Scanner system testing and development are continuing. The scanner is scheduled for use this fall during The LEDA commissioning process.

6 Acknowledgements

The LEDA Slow Wire Scanner design was based heavily on scanners currently in use at LANSCE. The LANSCE-2 group was responsible for the design of these scanners. We gratefully acknowledge their generosity and assistance.

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