INTENSE PROTON CORE AND HALO BEAM PROFILE MEASUREMENT: BEAM LINE COMPONENT MECHANICAL DESIGN*

R. Valdiviez, N. Patterson, J. Ledford, D. Bruhn, R. LaFave, F. Martinez, A. Rendon, H. Haagenstad, J. D. Gilpatrick
Los Alamos National Laboratory, Los Alamos, NM, USA
J. O'Hara
Honeywell, Albuquerque, NM, USA

Abstract

The 6.7-MeV, 100-mA proton beam being produced in the Low Energy Demonstration Accelerator (LEDA) RFQ will be injected into a 52-magnet lattice in order to study the formation of beam halo [1]. The LEDA RFQ beam has a rms size of 1 mm. At nine longitudinal locations along the lattice an assembly that incorporates both a wire scanner and a halo-scraper assembly will be placed to make current density measurements of the beam.

1 INTRODUCTION

One measuring axis of the wire scanner and halo-scraper internal assembly is shown in Figure 1, and consists basically of two scrapers that are tied together in series in a cooling loop. One wire is mounted in the assembly for scanning the beam. The wire will be used to scan the entire cross-section of the beam.

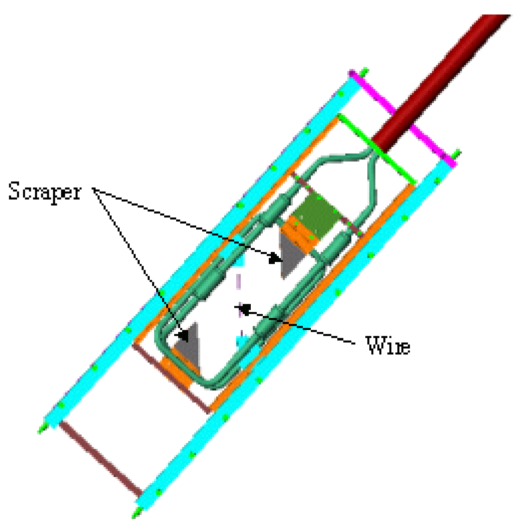

Figure 1: Wire Scanner/Halo Scraper internal measuring axis

The scrapers will be used to probe the beam to the approximate 2.5-rms-width location, or within 2.5 mm of the beam center. This will enable an overlap between the wire and scraper measurements of approximately 1-rms width, and provide a check on the two different measuring methods.

2 MECHANICAL ASSEMBLY DESCRIPTION AND OPERATION

Two independent frames or axes are used within each assembly, with one frame designated the X axis, and the other the Y axis. This makes a total of four scrapers and two wires per diagnostic assembly. The wires and scrapers are mounted on translatable frames in order to move them in and out of the beam, and are oriented on each frame to provide incremental measurements of beam current density in the direction of the axis of interest. The frames are positioned using a lead screw and stepper-motor combination, with a linear-incremental encoder for position tracking.

The wires will traverse the entire beam tube inside diameter, a distance of 1.1 in. The wire scan data is used to calculate the current-density distribution of the beam and determine the physical location of the beam center relative to the scraper positions. This data is then used to determine how far in to drive a given scraper based on the encoder measurement. The wires are positioned outside of the beam tube shadow when not making measurements.

The main function of the scrapers is to collect data further out in the beam cross-section where the current density is too low to be detected adequately with a wire. The scrapers will be inserted to the 2 or 2.5-rms-width region and no further into the beam to avoid thermally-induced damage to the scraper face. Each scraper is brought in from outside the beam tube shadow and stopped at the appropriate position for measuring.

3 WIRE THERMAL ANALYSES

Two different wire sizes and types have been considered in this design for measuring the beam-current density. The first is a 0.004-in diameter silicon-carbide

* Work sponsored by the U.S. Dept. of Energy

(SiC) wire. This wire has a 0.001-in diameter inner carbon core with a silicon-carbide coating applied over it. This is the wire type being used currently in the LEDA wire scanner. This wire type has been proven to be very durable in the proton beam [2]. The second wire type considered is a 0.001-in diameter carbon wire. This wire type has not been used in LEDA yet, so some development work is required to apply it to this diagnostic device. Thermal analysis has predicted that the smaller diameter of wire that is used the longer a beam pulse it can withstand before reaching a limiting, peak temperature [3]. In general, the longer a beam pulse that can be measured by the wire the more reliable the current-density measurement becomes. The limiting temperature is where the onset of thermionic electron emission occurs. This current from the wire-surface material is high enough to interfere with the beam-interaction current being measured on the wire, thus interfering with the beam current density measurement.

The main mode of heat loss for the wire is radiation heat transfer. Conduction along the wire to the mounting fixture is included in the modeling, but has been found to have very little effect on the peak temperature predicted for the wire. An emissivity of 0.83 is used for SiC [4], and a value of 0.7 [5] used for the carbon wire. The view factor is calculated for a thin wire looking at the inside of a tube normal to its axis. A value of 0.83 is predicted and used in the modeling.

At a beam operation of 100 mA, 0.5 Hz, and a pulse length of 20 µs the peak temperature predicted in the SiC wire is approximately 2700 ^{o}F. For these same conditions the peak temperature of the carbon wire is approximately 2300 ^{o}F. Both of these temperatures are below the thermionic electron emission temperature threshold of 2780 ^{o}F [6].

4 HALO SCRAPER MECHANICAL ANALYSES AND DESIGN

The halo scraper is comprised of a copper body with a graphite face. The sensing face of the scraper is 1.27-in wide by 1.27-in high by 0.125-in thick. Figure 2 is an illustration of the scraper. Poco graphite type AXF-5Q is the graphite used. The copper body is made of OFE copper. The two are joined with a titanium braze alloy TiCuAg that contains 4.5 % titanium, 26.7 % copper, and 68.8 % silver. A coolant channel is incorporated to remove the heat load. De-ionized water at a flow rate of 1.0 gal/min and a resistivity of approximately 1.5 Mohm-cm is used in the channel. The coolant flow velocity is 11.2 Ft/sec. The halo scraper is exposed to surface heat fluxes ranging from 150 Btu/s-in^2 to 2900 Btu/s-in^2 due to interaction with the beam. These heat fluxes correspond to the 4-rms-width and 2.5-rms-width beam positions respectively. The proton beam is stopped within the first 0.012-in thickness of the graphite face. This heat load is treated as a surface heat flux rather than as volumetric heating in the analytical thermal models. This is done in order to take a conservative approach to predicting the peak surface temperature [7].

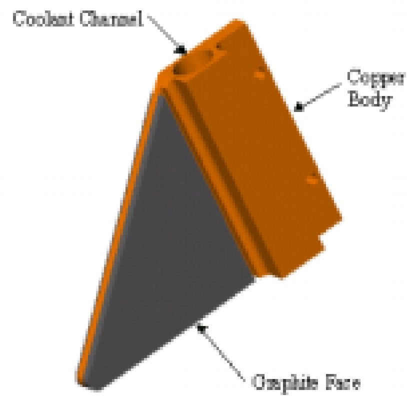

Figure 2: Halo scraper

The scraper is predicted to experience a peak graphite face temperature of 920 ^{o}F under pseudo-steady state conditions. This peak temperature corresponds to beam operation using a current of 100 mA, a 20 µs pulse length, and a 6 Hz repetition rate. The thermal pseudo-steady state of the scraper has the beam interaction region oscillating between a maximum and minimum temperature at the repetition frequency of the beam. A predicted pseudo-steady state temperature profile of the scraper is plotted in Figure 3.

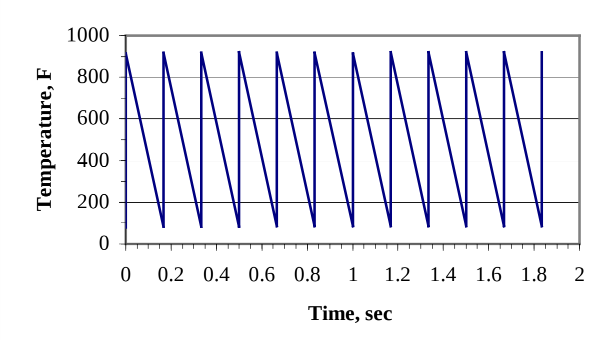

Figure 3: Predicted scraper temperatures

The thermal loads are applied to the scraper in a finite-element stress analysis model to predict the peak stresses in the graphite and copper. The Poco type AXF-5Q graphite has a compressive strength of 20,000 lb$_f$/in^2, and a flexural strength of 12,500 lb$_f$/in^2. The predicted peak principal stress in the graphite is 4,500 lb$_f$/in^2 in compression due to the thermal loading from the beam impingement. The copper is predicted to have a peak von Mises stress of 1,500 lb_f/in^2. These predicted stresses are well within the respective material's strength limits.

5 HIGH HEAT FLUX TESTING OF THE SCRAPER

The scraper experiences an appreciable mechanical-fatigue load due to the transient thermal loading of the beam interaction. The heated region of the graphite undergoes repeated compressive loading due to its thermal expansion against cooler graphite regions. This occurs at the beam-repetition rate and for as long as the scraper is in the beam. The braze joint at the graphite to copper interface has to withstand this fatigue loading along with transferring the heat flux associated with the beam interaction.

An electron-beam test has been conducted on a scraper in order to test the design under prototypical fatigue-loading conditions, and evaluate the capability of the braze joint to transfer the peak heat flux without appreciable degradation. The scraper has been exposed to a minimum heat flux of 3000 Btu/s-in^2 at a repetition rate of 5 Hz for approximately 200,000 cycles. This is expected to correspond to at least 500 measurements in the LEDA halo-experiment lattice. The electron beam parameters used for the test were a beam energy of 16.5 MeV, a minimum current of 1.5 nC, a 9 µs macropulse length, and 950 pulses within the macropulse. The scraper survived the test with no visible damage to the graphite, copper, or braze interface. Table 1 lists the relevant stopping powers.

Table 1: Material stopping powers

Material	Stopping Power (MeV-cm^2/gm)	Stopping Power (Mev-cm^2/gm)
	6.7-MeV proton [8]	16.5-MeV electron [9]
Graphite	99.1	~ 2.08
Copper	----	~ 2.51

During beam testing a heat flux of 6200 Btu/s-in^2 was placed on the scraper for approximately 36,000 cycles. This was done to test the scrapers ability to be inserted to the 2-rms-width location of the RFQ proton beam. Previous thermal modeling of the scraper with this high a heat flux predicted that excessive graphite evaporation could occur. The scraper survived this test with no visible damage to the graphite. Further testing in the proton beam will be required prior to repeated scraper operation at 2-rms widths.

6 VIBRATION TEST OF THE SUPPORT FRAME

A complete support frame assembly with scrapers and cooling tubes mounted has been tested to check for excessive flow-induced vibration in the structure. Because of the close positional requirements of the wire and scraper flow-induced vibration is a concern if the scrapers or wire mounts vibrate significantly due to the coolant flow. The nominal flow rate of de-ionized water is 1.0 gallon per minute through each scraper, corresponding to a bulk velocity of 11.2 Ft/s. The positional tolerance of the wire and scrapers in the beam is on the order of 0.004 in. No excessive displacements were measured on the scrapers or support frames [10].

7 ACKNOWLEDGEMENTS

The authors would like to acknowledge the efforts of D. Nguyen, L. Earley, S. Volz, R. Brown, and M. Serrano for conducting the high heat flux testing in the Advanced Free Electron Laser (AFEL) facility at LANL.

8 REFERENCES

[1] T. Wangler, "Beam Halo in Proton Linac Beams", these proceedings.

[2] J. Ohara, "Slow Wire Scanner Beam Profile Measurement for LEDA", Beam Instrumentation Workshop, Boston, May 2000.

[3] R. Valdiviez,"The Thermal Analysis of … Diagnostic Assy. Wires", LANL int. memo LANSCE-1:00-59.

[4] R. Siegel, J.R. Howell, "Thermal Radiation Heat Transfer", appendix D, second edition, Hemisphere Pub., 1981.

[5] General Electric, "Pyrolitic Graphite Engineering Handbook", comparison to commercial graphite section, 1963.

[6] J. D. Gilpatrick, "Beam Diagnostic Instrumentation for the Low–Energy Demonstration Accelerator (LEDA): Commissioning and Operational Experience", EPAC 2000, Vienna, Austria, June 2000.

[7] R. Valdiviez, "The Mech. Analysis of … Diagnostic Assy. Scraper", LANL int. memo LANCSE-1:00-58.

[8] W. Barkas, M. Berger, "Table of Energy Losses and Ranges of Heavy Charged Particles", NASA, 1964.

[9] National Academy of Sciences, "Studies in Penetration of Charged Particles in Matter", Report Number 39, 1964.

[10] R. Valdiviez, "Flow Induced Vibration Testing of the LEDA Wire Scanner/Halo Scraper Support Frames", LANL internal Memo LANSCE-1:00-66.