

LANSCE HARP UPGRADE: ANALYSIS, DESIGN, FABRICATION, AND INSTALLATION*

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Abstract

The primary goal of this newly installed beam profile measurement is to provide the facility operators and physicists with a reliable horizontal and vertical projected beam distribution and location with respect to the proton beam target and beam aperture. During a 3000-hour annual run cycle, 5 μC of charge is delivered every 50 milliseconds through this harp to the downstream TRMS Mark III target. The resulting radioactive annual dose near this harp is at least 6 MGy. Because of this harsh environment, the new harp design has been further optimized for robustness. For example, compared to an earlier design, this harp has half of the sensing wires and utilizes only a single bias plane. The sensing fibers are 0.079-mm diameter SiC fibers. To hold these fibers to a rigid ceramic structure, a collet fiber-clamping device accomplishes the three goals of maintaining a mechanical fiber clamp, holding the sense fibers under a slight tensile force, and providing a sense-fiber electrical connection. This paper describes the harp analysis and design, and provides fabrication, assembly, and some installation information, and discusses wiring alterations.

INTRODUCTION

The Los Alamos Neutron Science Center (LANSCE) facility primary beam target, TRMS Mark III, has been replaced [1]. This target's primary goal is to convert 800-MeV protons to various energetic neutrons. In order to perform this conversion efficiently, the incoming proton beam position and width are measured using a common measurement device known as the "harp" that samples the transverse profile with respect to the beam pipe aperture. The

interesting aspect of this particular harp is that due to its location, inside the TRMS Mark III target, it is in a very harsh environment. For a single 3000-hour annual run cycle, this particular harp is expected to receive 6 MGy of absorbed dosage [2]. Since the expected target lifetime is at least 5 years, the harp will receive at least 30 MGy. Therefore, its design should be sufficiently robust to withstand this harsh environment.

1L HARP THEORY

The 1L harp's principle of operation is very basic (Figure 1). Fibers sample the projected beam charge distribution in two orthogonal planes. An intervening plane of fibers between the two signal planes is biased such that secondary electrons emitted from one signal plane are not allowed to impinge on the second signal plane. Generally, a small amount of the proton beam's energy deposited into the fiber and is converted to emitted secondary electrons (SE). The current flow of these SE leaving the fiber is measured by external electronics to produce a series of amplitudes for each projected beam distribution.

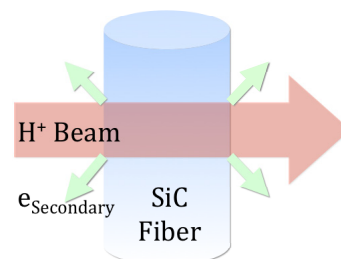


Figure 1: The 800-MeV beam passing completely through the SiC fiber and depositing a small amount of the beam's energy. A subsequent amount of the deposited beam energy is converted to SE emission.

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The Sternglass theory states that the SE emitted electron yield is

$$Y = \frac{Pd}{\epsilon} \frac{dE}{dx} = (0.002 \text{ cm/MeV}) \frac{dE}{dx}, \quad (1)$$

where Y is the SE yield from a proton beam current impinging on the SiC fiber, P is the probability that an electron will escape from the SiC fiber material (typically, ~0.5), d is the average depth from which electron escape from the SiC fiber material (typically, ~ 1 nm), and ε is the average amount of kinetic energy lost by an ion per ionization in material (typically, ~25 eV) [3,4]. For an 800-MeV proton beam, the energy loss in SiC, dE/dx, is 1.98 MeV/g/cm², and the density of SiC is 3.0 g/cm³ resulting in a SE yield of 0.0119.

The secondary electron emission current, *i_{SE}*, from a proton beam impinging on a fiber is

$$i_{SE} = Y i_b, \quad (2)$$

where *i_b* is the proton beam current impinging on the 0.079-mm SiC fiber.

A typical 12.5-mm by 14.5-mm transverse rms beam has an integrated charge of 5 μC. This beam bunch is 300-ns long and has roughly a triangular longitudinal distribution. The integrated proton beam charge impinging on a central vertical fiber is 12.6 nC. Using Sternglass’s theory, the calculated peak SE emitted current from this central vertical wire is 1 mA.

To reduce the number of “shadow” electrons that may impinge upon the downstream signal SiC fibers, a bias plane between the two transverse signal planes is biased positively so as to attract SE. Furthermore, to optimize emitted SE, each of the transverse signal plane fibers is biased negatively.

Since each fiber’s emitted SE current is proportional to the quantity of impinging beam current, the SE integrated charge during a single pulse for each signal fibers provides a sampled transverse beam distribution.

The peak SiC fiber temperature was calculated at the center of the beam distribution. This calculation assumes 1-dimensional geometry

with no conduction along the fiber, i.e., radiative cooling only. The energy lost from the 300-ns long, 20-Hz pulsed beam provides an energy input into the fiber, and fiber radiative cooling throughout all time provides an energy output term.

With production quality beams and a 12.5-mm by 14.5-mm transverse rms beam has an integrated charge of 5 μC, attains steady state equilibrium within ~ 60 seconds and reaches peak temperatures of ~ 1480 K.

1L HARP DESIGN

Since one of the goals for this particular harp replacement was to simplify its construction, this TRMS Mark III harp consists of three individual planes, two transverse signal planes and a single intervening bias plane. Figure 2 shows an exploded view of these three planes.

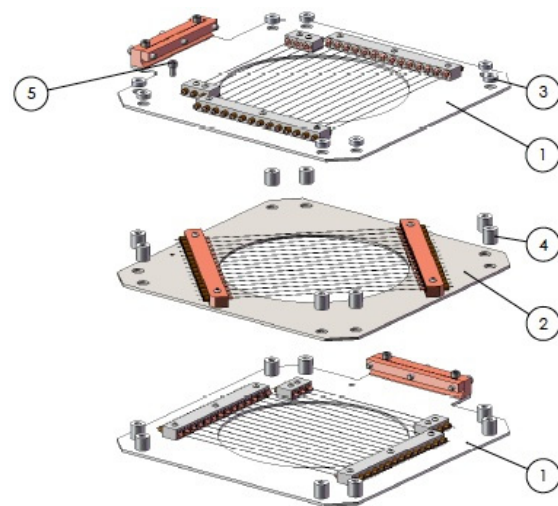


Figure 2: The exploded perspective drawing of the TRMS Mark III harp shows the two signal planes (#1), the bias plane (#2), various Macor spacers (#3 and #4), and the bias plane potential circuit trace connection (#5).

The transverse signal planes each have 17 SiC fibers extending across the 101.6-mm (4-inch) beam aperture. The TRMS Mark III harp design also has increased the distance between distribution bins, or fiber pitch, to 6 mm, for two reasons: (1) it does not require a spacing of 3 mm between fibers, and (2) simplicity. The Macor circuit board material is 1.52 mm thick, with the circuit traces initially flashed with Ni

and then covered with a Au plating [5]. The intervening bias plane is constructed in the same manner, except that the circuit board is fabricated from a 1.52-mm thick 304 SS card, such that each wire takes on the same bias potential as the supporting metal card. The seventeen bias-plane wires are clocked at a $\pi/4$ radian angle with respect to the two signal plane fibers.

The connections, first developed for the wire scanners for the Low Energy Development Accelerator and further used at the Spallation Neutron Source, use a collet-style fiber holding mechanism that simultaneously accomplishes three goals. The collet mechanisms hold each fiber mechanically rigid, yet provide a slight tensile force on each fiber to account for a slight change in length due to local heating, and maintain electrical connections to each fiber. Furthermore, this collet system holds and tensions the signal fibers in a manner that is believed to impart less stress in the filament and give better stress uniformity than could be expected from the crimping system used in the TRMS Mark II harp.

Figure 3 shows the schematic of each projected signal plane. There are seventeen 10-pF capacitors that provide a way to verify that each fiber is properly connected via the collet clamps.

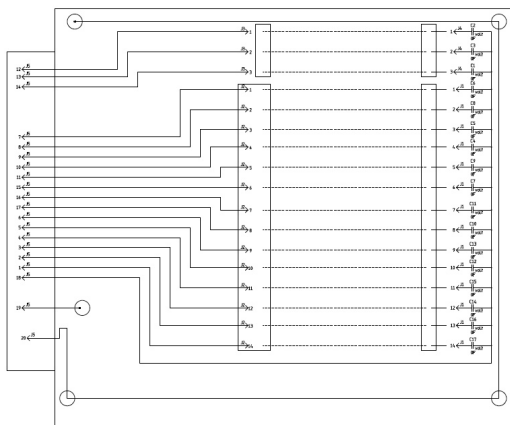


Figure 3: A single projected signal plane that has 17 capacitors that isolate the incoming “integrity” signal from the fiber signals.

Figure 4 shows an “integrity” drive and fiber sense signal. With this technique, we will detect

a fiber misconnection independent of beam delivery.

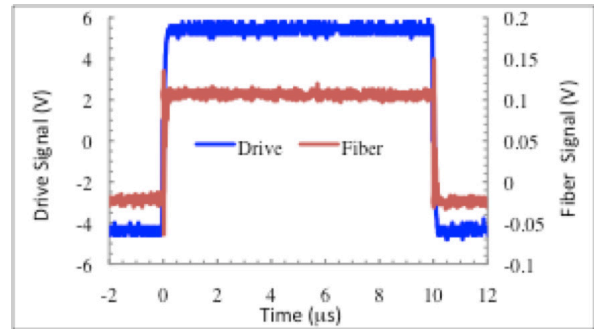


Figure 4: Two oscilloscope traces consisting of an “integrity” drive signal (blue) and an intact-fiber signal (red).



Figure 5: Three planes of 1L Harp with 0.079-mm SiC fibers attached using a collet style of clamp.

The Cu collets, pictured in Figure 6, clamp a fiber with two jaws and use a spring under compression to both force the ring collar to provide force to the clamping jaws and to the fiber. As the fiber is heated by beam impingement, the slightly expanding fiber will still maintain its alignment due to these compressed springs. Figures 7 and 8 show the

1L harp mounted in its instrument carrier, which bolts on the end of the insert beam pipe within the TRMS target assembly.

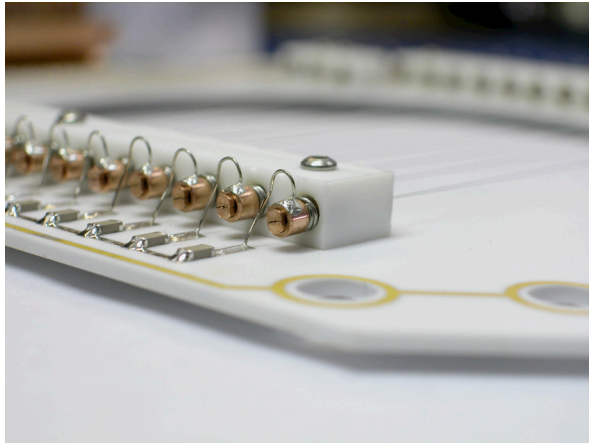


Figure 6: The clamp side of the collet and the 10-pF capacitors that provide some isolation for an injected “integrity” signal.

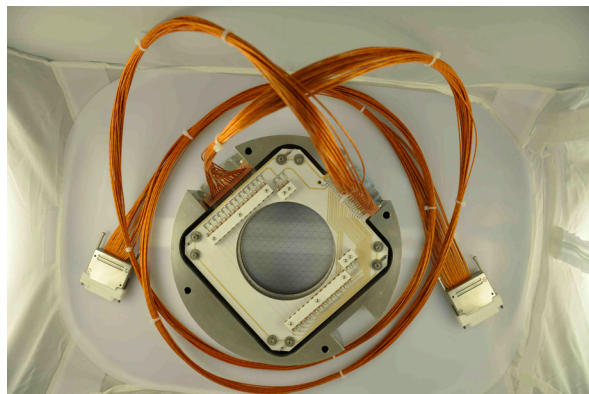


Figure 7: The harp in its instrument carrier prior to installation on the bottom of the insert.

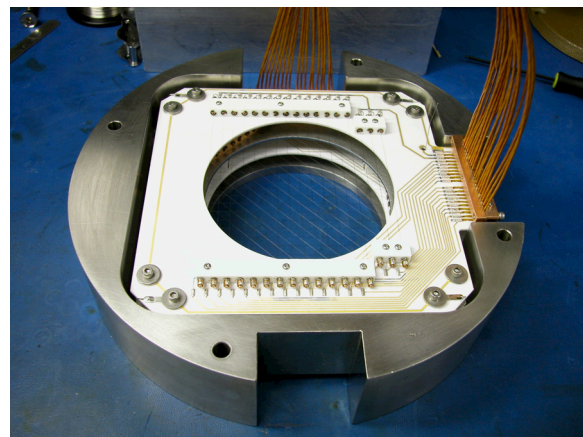


Figure 8. A closer view of the 3-plane harp installed in its instrument carrier.

1L HARP FABRICATION & INSTALLATION

The fabrication of the harps was initiated by manufacturing the ceramic printed circuit boards. These printed circuit boards were first designed by a mechanical and electronics designer. The mechanical designer defined the circuit board dimensions and the electronics designer laid out the circuit traces on the circuit board design. After the circuit boards were fabricated without circuit traces and then Ni traces as defined by the electronics designer was initially placed on the ceramic circuit boards. A 13-micron Au layer was plated on the traces to avoid radioactive mixed waste.

Figure 9 is a drawing showing the collet style anchorage system of the Mark III harp. Figure 10 shows one of the anchorage and tensioning collets used in the Mark III harp. The collets are made UNS C10100 full hard copper, and were difficult to machine because of the ductile nature of the copper combined with the relatively long length and small diameter of the collet. The manufacturer, Model Products of Albuquerque, NM, suffered a high loss ratio during turning of the collet shafts. The slots in the end of the collets were cut using EDM wire cutting performed by Excel Manufacturing, also of Albuquerque. The collets are drilled through to an internal diameter of 0.38 mm.

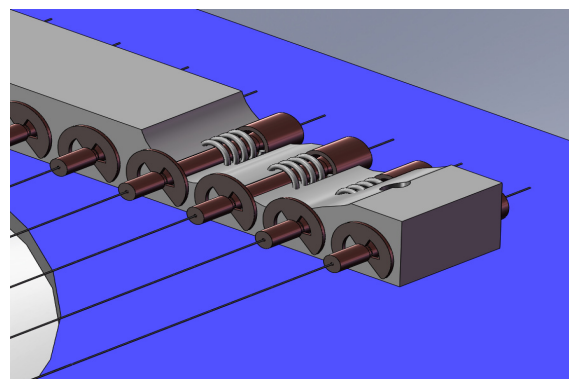


Figure 9. The cut-away drawing above shows copper collets placed in a Macor dielectric holder.

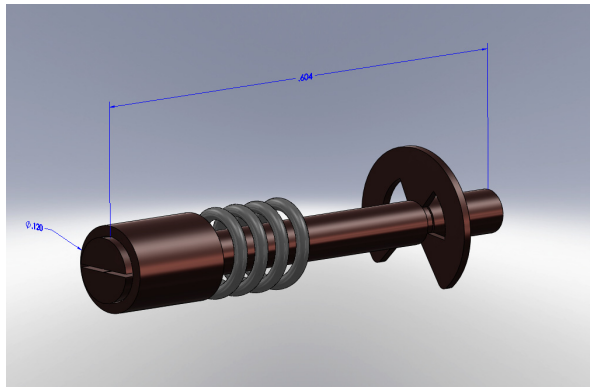


Figure 10. The collet assembly. The spring pushes against the Macor block and the collet collar, causing the collet to clamp and tension the signal wire simultaneously.

A special set of kapton coaxial cables was purchased and installed on the individual signal-plane circuit boards [6]. One set of in-vacuum cables reaches from the signal plane circuit board strain reliefs to its associated conflat flange D-connector feedthrough (see Figures 7 & 8) [6]. Another special set of equivalent coaxial cables on the air-side cable mates to this same D-connector feedthrough and makes the proper connections to an existing MS connector [6]. The rest of the existing cable plant is used.

The TRMS Mark III harp was installed into the instrument carrier and then both were attached to the beam pipe insert. With the appropriate bore sighting tools, the harp's alignment offset was measured and recorded.

FUTURE PLANS FOR ELECTRONICS

Presently, each fiber's signal is sent to a CAMAC 7166D QDC (charge integrating digitizer). In the coming year, we hope to install another, more recent set of electronics that will digitize the integrated charge and will be capable of providing the distribution and position of this measurement for the horizontal and vertical projected planes.

SUMMARY

The new harp implements a simple, robust technique for measuring a simple beam distribution for two orthogonal planes for the beam within the TRMS Mark III target. It was further simplified from the TRMS Mark II target

harp. Some of these simplifications included 50% fewer fibers in the harp and a single bias plane. The improvement also includes the addition of isolating capacitors that provide a method of testing fiber integrity.

REFERENCES

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- [2] Private communication with Charles Kelsey (LANSCE Division) and his discussions with radiation protection personnel.
- [3] S. J. Sternglass, "Theory of Secondary Electron Emission by High-Speed Ions," The Physical Review, published by the American Physical Society, Second Series, Vol. 108, No. 1, October 1, 1957.
- [4] M. Plum, "Interceptive Beam Diagnostics - Signal Creation and Materials Interactions," 2004 Beam Instrumentation Workshop, Tutorial, May 3 - 6, 2004.
- [5] Manufacturer of the Macor circuit boards were manufactured Cetek Technologies, Inc., 19 Commerce Street, Poughkeepsie, NY 12603, Tel. 845-452-3510. The printed circuit boards were plated by Elcon, Inc., 1009 Timothy Drive, San Jose, CA 95133, Tel. 408-292-7800.
- [6] AccuGlass Vacuum Cable information can be obtained from <http://www.accuglassproducts.com/home.php?cat=307>.