HIGH INTENSITY BEAM PROFILE MONITORS FOR THE LAMPF PRIMARY BEAM LINES*

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Abstract

Two types of beam profile monitors[1] are in use at LAMPF
to measure the properties of the 800 MeV, 500 μA proton
beam external to the linac. Both types use secondary
electron emission from a wire to produce a current sig-
nal proportional to the amount of proton beam that
intercepts the wire. The wire scanner system uses a
pair of orthogonal wires which are passed through the
beam and the harp system uses two fixed planes of par-
allel wires. Most of the harps are not retractable and
are exposed continuously to the primary beam. The high
beam intensities available lead to a number of techni-
cal problems for instruments that intercept the beam or
are close to primary beam targets. The thermal, elec-
trical, radiation-damage, and material selection pro-
blems encountered, and some solutions which have been
implemented are discussed.

Introduction

The high intensities of the 800 MeV proton beam at
LAMPF impose several restrictions on any device used to
monitor the beam profiles. To hold beam loss to accept-
able levels, the multiple scattering must be small.
The device must exist in the beam where average current
densities are as high as 10 mA/cm^2. The high energy
density deposited by the beam implies that the device
must operate in vacuum, must not be distorted by ther-
mal expansion, must not melt, and must be strong enough
to withstand shock waves due to sudden vacuum failures.
Since cooling must be by radiation, the emissivity
should be high. If the secondary emission process is
to provide the signal, then thermionic emission must be
a small fraction of the secondary emission current. In
addition, the device should be capable of operation for
periods of several years in an environment where the
radiation dose is 10^8-10^9 rads/year. Since some of
these devices must be located under many tons of shield-
ing and are not easily accessible, high reliability is
also an important consideration.

Wire Scanners

Design

A wire scanner (Fig. 1) consists of an actuator that
moves two mutually perpendicular signal wires through
the proton beam in a controlled way. The secondary
emission current from the wires is measured as a func-
tion of position of the wires. This signal is analyzed
to provide centroid and shape information about the
proton beam.

The signal wires are 0.004 in diam silicon carbide fila-
ments[2] that are spring mounted to compensate thermal
and radiation-induced expansion. To each side of each
signal wire, is attached a clearing field electrode
that is at a positive potential to ensure complete re-
moval of all secondary emitted electrons (Fig. 2).

The signal wire assembly is moved along a line 45° from
the horizontal so both horizontal and vertical profile
data are obtained at the same time. The driving force
is supplied by a stepper motor and the vacuum seal is
an AM350 bellows. The electrical leads and vacuum
feedthroughs are mineral (MgO) insulated coaxial cables
so all components within 60 cm of the proton beam are
quite radiation resistant. The actuator drives the sig-
nal wires at 4.8 mm/s along the x and y axes when it is
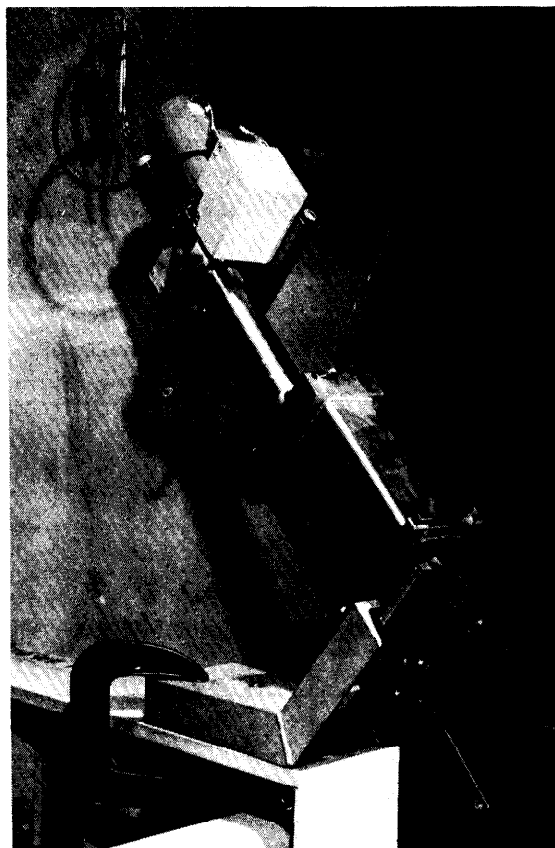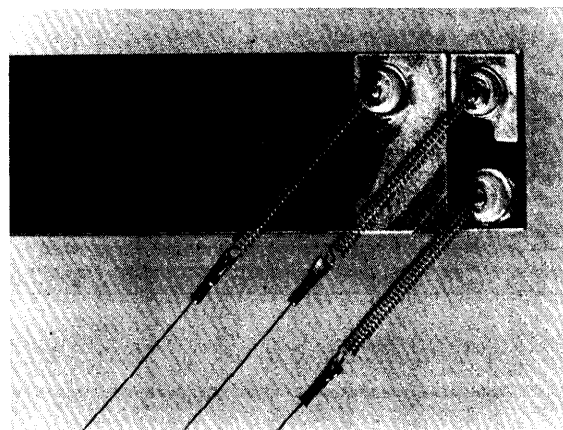operated at its maximum speed.

Fig. 1 - Wire scanner assembly.

Fig. 2 - Attachment of SiC signal wire (center) and two
adjacent SiC clearing field wires to a wire scanner fork.

Operation

The secondary emission current is about 2% of the proton
beam current that intercepts the signal wire. This cur-
rent is integrated and digitized for each proton beam
macropulse. The computer-controlled data-acquisition
system has the capability of subtracting a constant
level of background and of averaging several measure-
ments.

Figure 3 shows a set of profiles obtained by several of
these devices. The proton beam had a peak intensity of
7 mA and consisted of 550 μs macropulses at 120 Hz. Each
point is the average of 16 measurements as the signal

wires passed through the beam. Since the actuator stroke is 3 cm, the time required to obtain the data for these profiles is about 6 s.

Conclusions

The silicon carbide wires have allowed use of these devices at beam currents above 360 µA average. The long radiation and nuclear interaction lengths of SiC produce negligible scattered beam (<100 nA), the low density keeps the heating to tolerable levels and SiC is thermally stable to ∿2700°C. The filaments we use have a very thin coating of carbon on the surface so the emissivity is about 0.8 allowing efficient radiative cooling. Still, at currents above 500 µA average, the thermionic emission currents become a problem for small beam sizes. If we can develop reliable 0.001-0.002 in wires and mountings, we can probably push the use of the wire scanners to 1 mA average current.

These devices operate in a vacuum of $\sim 10^{-7}$ torr so there is no problem with collection of ions from beam-gas collisions.

The electronics[3] used for integration and amplification provide excellent signals for average beam currents as low as 0.1-1 µA.

Data-acquisition time is acceptable and up to six wire scanners can run simultaneously producing data for 12 profiles in about 6 s. The overhead for transmitting this data between computers and displaying it is considerably greater and could profitably be reduced.

The use of ceramic insulators, mineral-insulated cables and feedthroughs, and bellows and Al O-ring vacuum seals has produced an acceptably radiation-hardened device. Maintenance is minimal and consists primarily of radiation-resistant oil lubrication of the moving parts and occasional replacement of worn parts. The only SiC signal-wire failure in ∿2 years was due to melting of the solder connection to the actuator by an ion pump discharge in an abnormally high pressure vacuum.

Harps

Design

The harps (Fig. 4) consist of two orthogonal planes of signal wires and three planes of clearing field wires at a potential of 57 V. The signal wires are attached to alumina ceramic substrates via silver-based printed circuit inks. The ceramic boards and the clearing field planes are mounted on a central stainless steel frame. This assembly hangs from a vacuum-sealing lid that contains the electrical feedthrough for each signal wire. A pair of p.c. edge connectors is mounted on the atmospheric-pressure side of the lid.

The potentials developed on the signal wires range up to 5 V for our readout system. This potential tends to inhibit secondary emission in a nonlinear way[4] for the various parts of the profile. A potential of 0.5 V produces a 40% reduction in secondary emission current if the clearing field is not present.

Both carbon and silicon carbide filaments have been used as wires. The carbon filaments are easily prestressed and soldered to the printed lands but suffer from low strength since the maximum diameter commercially available is 0.002 in. We are presently using 0.004 in diam silicon carbide filaments with a tensile strength of $\sim 4 \times 10^5$ psi. The wire is mounted by crimping a copper adapter to each end of the wire and using a spring to maintain $1-2 \times 10^5$ dynes of tension while

absorbing elongations up to 0.1 in. Figures 2 and 5 show these mounting details.

Operation

The secondary emission current flowing to each wire is integrated on the capacitance of the coaxial cable
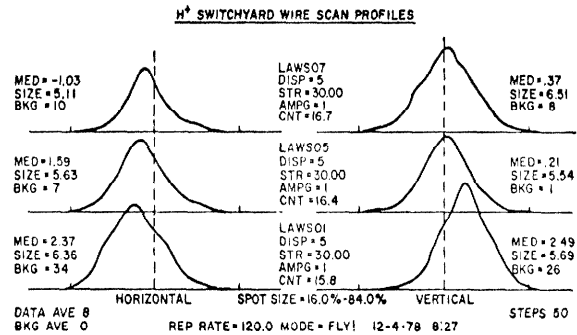

Fig. 3 - Wire scanner profiles. The tick marks on the horizontal axis are 1 cm apart.
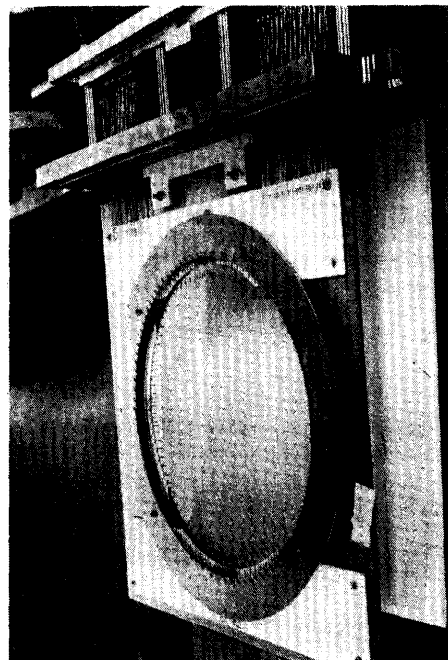

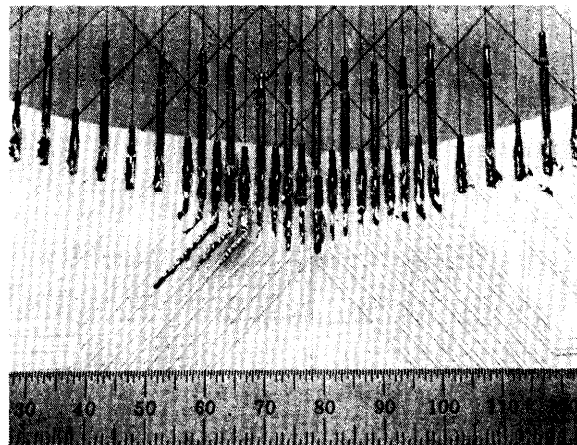Fig. 4 - Harp assembly. Inner diameter is 33 cm.

Fig. 5 - Details of spring mounting. Scale is mm.

attached to the signal wire. The resulting signals are multiplexed[5] by FET switches to an amplifier, A/D converter and into a PDP 11/10 computer. The computer continually cycles through the list of selected harps, discharges the cables, acquires data, and stores it in memory. A background subtraction is performed if it has been requested.

When the PDP 11 receives a request for data from the main control computer, it transmits the requested data immediately if no parameters need to be changed. If new parameters are sent to the PDP 11, then new data must be acquired before the return transmission. A sample data display is shown in Fig. 6.

For average proton beam currents of 500 μA, the cable capacity is discharged, the induced signal current is integrated for 2 or 4 macropulses and the voltage on each cable is then read without any amplification. For currents below 5 μA, integration times as large as 1 s are used with additional amplification up to 25X. The ambient noise level limits useful gains to 25X. When integrating for times that are an appreciable fraction of 1 s, the background subtraction becomes quite important since the FET switches have leakage currents as large as 1 nA. The minimum measurable beam current is about 10-100 nA if the beam spot is $\leq$1 cm wide.

Conclusions

The harps perform as required for current levels from $\sim$1 to $\geq$675 μA average proton beam currents. Most difficulties are associated with the thermal loads, gas flow forces and radiation damage to which the devices are subjected. These difficulties are manifested by loss of signal wire or by failure to transmit the signal from the wire to the data acquisition electronics.

The soft solder melting point of $\sim$200°C has been exceeded at times, resulting in loss of mechanical joints. The present emphasis is on crimping, spot welding, and a type of hook and eye construction.

Initial construction utilized carbon filaments as wires because of their refractory nature and large radiation length. The 0.002 in diam filaments that are commercially available had insufficient strength to withstand the forces associated with rapid pressure changes in the vacuum system. Silicon carbide filaments with a thin carbon coating were substituted for the carbon filaments. Since SiC elongates $\sim$1% when subjected to hadron fluences of $\sim$10^{20} cm^{-2}, it was necessary to develop the aforementioned method of spring loading the wires to maintain tension. The great tensile strength of the SiC is adequate to prevent breakage by sudden loss of vacuum in most cases.

The ceramic insulated electrical feedthroughs perform quite well when dry, but are prone to exhibit low resistance when they become damp. The question of how to build a radiation-hardened, moisture-proof electrical connector or vacuum feedthrough is still being examined.

The reliability of the edge connectors has been a continuing source of difficulty. A quantity of molded ceramic connectors were originally obtained. Shrinkage was difficult to control and breakage was a problem. There were indications that they were susceptible to the same moisture problems mentioned for the ceramic insulated feedthroughs. Due to our inability to obtain more of these connectors, we are now pursuing the use of plastic connectors. A promising material is Ryton[6] which is reported to show no change in properties for a radiation dose of 5 X 10^9 rads. Our improved knowledge of the dose levels at the harp locations indicates that this plastic may survive for periods of five years or more.

The signal cables that connect to the harp are either RG-174 or mineral-insulated coaxial cable. The mineral-insulated cable is rather unreliable due to the difficulty of producing and maintaining a good hermetic seal at each end of the cable. We are presently pursuing improved radiation-resistant plastic insulated cables and are using RG-174 since it will probably survive for at least a few years at most locations. The increased reliability of the RG-174 has overriden the high radiation resistance requirements for the present.

We note two environment requirements for the harps. If the beam-line pressure rises to $\geq$10 μm, the ionized gas begins to make appreciable contributions to the harp signals and the profiles are no longer faithful representations of the proton beam. Also, if the harps are not adequately protected from the secondary particles produced in targets or beam stops, secondary emission from the relatively large printed lands on the ceramics becomes an appreciable signal and badly distorts the desired result.

References

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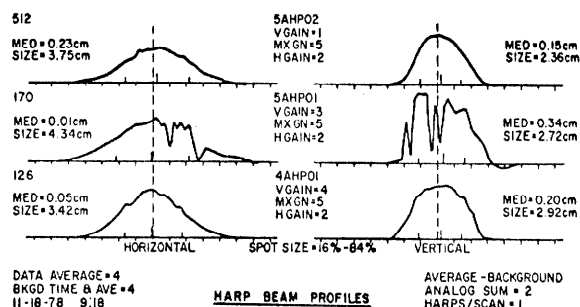6. Registered trademark of Phillips Chemical Company, a polyphenylene sulfide resion.

Fig. 6 - Harp data displays. Tick marks below the axis are 1 cm apart. Ragged profiles are due to low insulation resistance of several cables and vacuum feedthroughs.