Pbar Note 545

A 10 μm Resolution Secondary Emission Monitor for Fermilab's Targeting Station

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Abstract
Improvement in focusing the proton beam onto the antiproton production target necessitates the development of a higher resolution beam profile monitor. Two designs for the construction of a multiwire profile monitor grid are presented. The first is a conventional strung and tensioned Ti wire design. The second is a photo etched Ti grid of wires bonded to a ceramic substrate. Both have a central wire spacing of 125 μm. The completed beam profile monitors are designed to operate in a 120 GeV beam pulse of 5×10^{12} protons with a 1.5 μs duration and will be installed in late 1993.

I. INTRODUCTION

Efficient antiproton production relies greatly on the precision with which a highly focused proton beam can be placed on target. Antiprotons are produced at the Antiproton Source Target Station by bombarding a 10 cm nickel target with a bunched proton beam from the Main Ring. The present intensity of this beam is 2.1×10^{12} protons per pulse and this will rise to 5.0×10^{12} protons per pulse with the future Fermilab upgrade to the Main Injector. At present, the targeting station utilizes a multiwire Target Secondary Emission Monitor (TSEM) with 250 μm spacing between wire centers to measure the targeted beam's profile and position [1]. This original monitor's design was based on a predicted rms proton beam size of 400 μm. With the present rms beam size at target (averaged over both horizontal and vertical planes) equal to 160 μm and smaller beam sizes expected in the near future, it is obvious that a higher resolution monitor is needed to ensure that the proton beam interacts with enough wires so that its width may be determined accurately. In addition, with the advent of increasing beam intensity, great care must be taken to ensure that higher resolution TSEM wires do not melt from their interaction with the proton beam.

II. DESIGN CRITERIA

Ideally, the wire size and spacing of a new refined resolution TSEM should be minimized while still ensuring the survivability of the wire planes in the TSEM's harsh operating environment and during the TSEM's delicate assembly process. In order to accurately fit a Gaussian distribution and determine the proton beam distribution's mean and sigma in both planes, the beam must interact with at least 4 wires. This implies a wire center spacing equal to at least the average beam rms size of 160 μm and an individual wire diameter considerably less than that is desired.

The TSEM's operating location is just upstream (approximately 25 cm) of the target. This results in a highly radioactive environment. The TSEM must be constructed of inorganic materials resistant to high radiation doses (>5000 rad/hour) and resistant to the high temperatures expected from the beam heating of the TSEM wires (see *Beam Heating* section).

In addition, for optimum secondary emission effects, a vacuum environment for the wires and their associated electron collection foils is required. This demands use of vacuum compatible materials and design techniques to achieve a vacuum pressure on the order of 10^{-7} torr.

III. CONSTRUCTION

Two new designs of the TSEM have been developed to offer the needed resolution and satisfy the design criteria. Both designs are similar in all respects except for the method of wire plane construction. One design uses conventional strung wire technology while the other utilizes new photoetching techniques. Both result in 50 μm diameter wire planes with 125 μm wire centers, essentially doubling the resolution of the present TSEM.

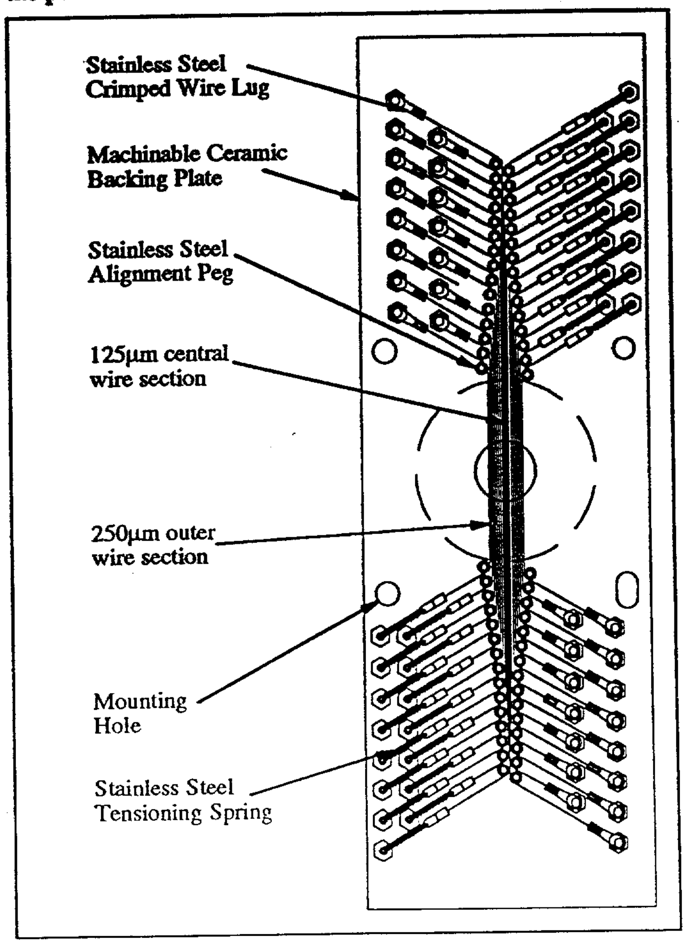

Figure 1. Schematic of new strung wire plane design.

*Operated by the Universities Research Association under contract with the U.S. Department of Energy

A. Wire Plane Construction- Strung Wire Design

The strung wire design uses conventional technology as demonstrated by the original TSEM [1] to create a wire plane by stringing 30 titanium wires (50 μm diameter) in a tightly toleranced pattern. The wires are strung at a center to center spacing of 125 μm in a central 1.9 mm wide region (16 wires) and at a center to center spacing of 250 μm in two 3.0 mm wide regions (7 wires each) to either side of the central region. This combination provides good resolution at the center and a larger outer area of monitor sensitivity for initial beam steering. The pattern is maintained by a machinable ceramic base plate (22.9 cm x 7.6 cm by 6.4 mm thick) into which two "V" shaped arrays of stainless steel pegs are inserted (see fig. 1). Each wire end is bent by 45 degrees around a peg and held in place by anchoring screws placed about the periphery of the ceramic base plate. The ends of the wires are crimped in standard stainless steel wiring lugs. One lug on each wire is connected directly to the appropriate anchoring screw while the other is connected to an anchored constant force (95 g/cm) spring. Each wire is sized to stretch the attached spring 2-5 mm to allow for elongations due to beam heating (see *Beam Heating* section). The guide hole patterns for alignment pegs are numerically machined in the ceramic base plate to a center to center tolerance of +/-10 μm. A central hole in the ceramic base plate allows the proton beam to intersect the wires without interference.

Improvements over the previous strung wire design include easier alignment of the wires during the assembly process due to the closely machined ceramic base plate (versus the loose peg and template method used previously) and the use of crimped lug wire connections rather than the sometimes unpredictable spot welding method. This is evidenced by the short assembly time required for a new strung wire plane (typically 8 hours for stringing 30 wires).

This wire plane design results in individually tensioned 50 μm diameter titanium wires with a minimum center spacing of 125 μm. Observed error under microscope reveals an estimated positional error of +/-10 μm or 8% of the nominal wire spacing. The design is relatively robust and should not degrade in the harsh targeting environment.

B. Wire Plane Construction- Photoetched Design

The photoetched design utilizes exact photoetching technology to create a wire plane by chemically etching a 30 wire pattern from a 50 μm thick titanium (3Al-2.5V) foil bonded to a 7.6 cm by 7.6 cm by 4.8 mm thick ceramic support plate (see fig. 2). The pattern features signal read out pads around the periphery of the backing plate. Electrical signal connections to the wires are made by spot welding ceramic coated copper wires directly to the exposed titanium pad surfaces. The wire spacing and diameters are identical to those of the strung wire design.

The etching process was developed by Max-Levy Autograph of Philadelphia [2]. Initially, the 30 line pattern is etched halfway through the thickness of a complete piece of titanium foil. The partially etched foil is then bonded to the alumina backing plate, etched side down, with a sodium silicate inorganic binder. Care is taken to keep the foil flat over the central hole in the backing plate. After curing the bond, the delicate wire pattern is etched into the remaining titanium foil thickness from the unetched side. This leaves the wire pattern intact on the ceramic plate including the unsupported lengths of wires directly over the central hole. Finally, a Cotronics ceramic paint [3] is layered over the visible wire pattern leaving only the access pads on the periphery and the wires in the central region exposed.

The final result is a one piece TSEM wire plane with 50 μm diameter titanium wires on a minimum center spacing of 125 μm. Observed error under microscope reveals an estimated positional error of +/-15 μm or 12% of the nominal wire spacing. Most of this error is due to a slight bowing of the wires over the central unsupported region. The bowing is believed to be caused by the extruded titanium foil stress relieving during the removal of much of its bulk during the etching process. In fact, bowing seems to be minimized when the extrusion marks apparent on the unetched foil are oriented perpendicular to the etched wire direction.

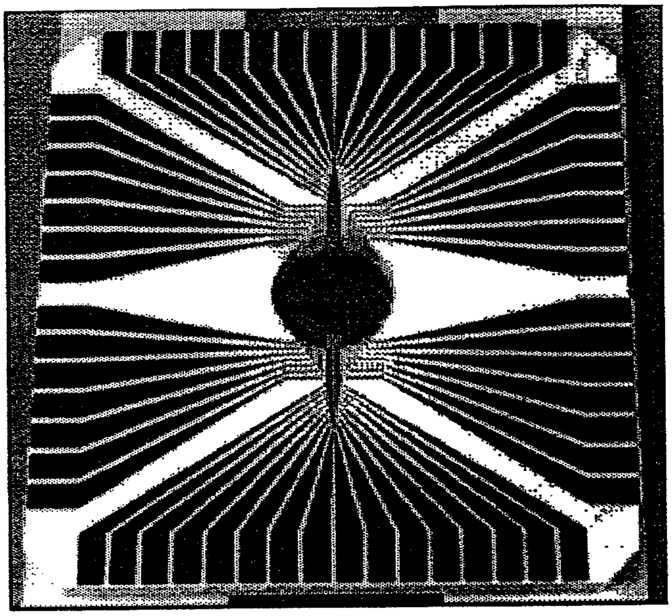

Figure 2. Photograph of photoetched wire plane design before applying ceramic over coat.

C. Vacuum Vessel Construction

Both designs utilize similar vacuum vessel designs consisting of two 33.7 cm diameter conflat type vacuum flanges. The flanges are modified to provide an enclosed area between the flanges 25.4 cm in diameter and 4.4 cm in depth. The chamber is equipped with 38 μm thick titanium foil beam windows. Electrical signals from the enclosed wire planes are passed from this interior space to atmosphere via ceramic coated copper wire and a conventional electrical feedthrough. The vessel is pumped with an 8 l/s ion pump attached permanently to the flange assembly. All materials used in both wire plane designs are vacuum compatible metals (titanium, 304 stainless steel and 6061 aluminum) and inorganic ceramics.

Two wire planes are mounted (one horizontally and one vertically) to the interior surface of one of the vessel flanges (see fig. 3). The mounting apparatus consists of four posts to capture and align the two wire planes to each other without over constraining the planes from thermal expansions and contractions. Surrounding the individual wire planes are 38 μm thick titanium electron collection foils to collect the electrons emitted from the struck wires and close the signal path to the integrating electronics. Mounting mechanisms are similar for both design types.

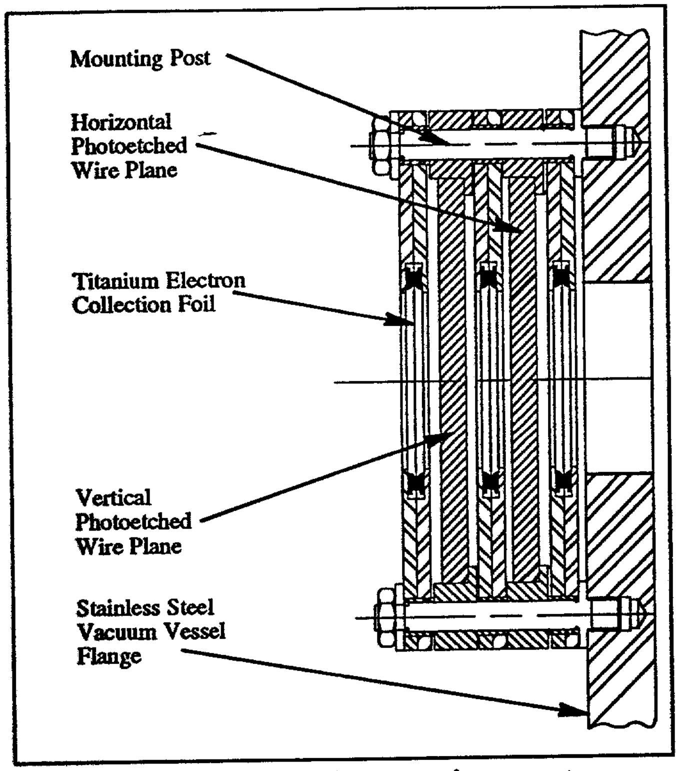

Figure 3. Schematic of wire plane mounting apparatus.

IV. Beam Heating of Wires

Heating of the TSEM's wires by the proton beam is important to investigate for two reasons. Overheating of the wire (near the wire material's melting point) could damage the wire integrity and thermal expansions could cause a wire to bow and short to a neighboring wire.

The instantaneous peak temperature of the section of wire that actually interacts with the proton beam is calculated by estimating the amount of energy deposited in the small volume of wire exposed to beam. If the critical incoming proton beam parameters are assumed to be equivalent to the current predictions of beam on target characteristics after the Main Injector comes on line several years in the future (5×10^{12} protons per pulse, 0.015 cm rms beam size), then for a 50 μm diameter titanium wire ($dE/dx = 1.50$ MeV/g/cm^2), the instantaneous peak temperature can be calculated to be 1270°C.

Assuming a logarithmic transient cooling curve of the form $e^{-t/\tau}$ and assuming the material and geometry are of the photo etched design, then after 1.5 sec (anticipated duty cycle of future Main Injector beam on target) the temperature will cool, by conduction only, to approximately 25°C. After several pulses the wire will most likely only cool to the temperature predicted by averaging the total heat input per pulse over the entire duty cycle, in this case, approximately 350°C.

The above calculations, however do not take into account that some of the energy transferred from the protons to the electrons in the wire material by Coulomb scattering will exit the wire with the higher energy electrons escaping the wires. Rough calculations show that this 'lost' energy is on the order of 51% of the total energy deposited normally calculated for titanium wire [4]. Taking this into account, instantaneous peak temperatures of central TSEM wires should be no more than 620°C and long term equilibrium temperatures should average around 170°C Since the melting temperature of titanium is 1670°C; damaging the wire material by overheating is not a primary concern.

If we assume an average equilibrium temperature of 130°C as predicted above, then the elongation of the 1.6 cm long exposed section of wire (photoetched, untensioned design) is approximately 5.3 μm. If we assume a circular shaped bow in the wire due to this elongation, the amount of sag is 18 μm, more than enough to touch a neighboring wire. This situation should be addressed in future design modifications.

V. Conclusions

Nine photoetched TSEM wire planes have been constructed successfully. All specimens exhibit a high degree of precision wire alignment in a compact, radiation hard form. The wire planes have undergone electrical continuity, conductivity and vacuum compatibility testing without mishap. Future development of this photoetched design will concentrate on further strengthening the sodium silicate bonding techniques and producing a method to tension the unsupported wire lengths if found necessary. This method of wire plane construction offers a simple, radiation hard, one piece design coupled with delicate high precision wire placement.

Two strung wire TSEM wire planes are presently being constructed at Fermilab. The highly accurate wire placement and robust design of this construction technique have been proven through the successful completion of a six wire sample wire plane. Future development of this strung wire design is limited to modifications to improve the ease of assembly. This method of wire plane construction offers precision placed, individually tensioned wires coupled with a durable, radiation hard design.

Both wire plane designs will be mounted in TSEM vacuum vessel assemblies and an installation at the Antiproton Source Target Station will take place later this year. The designs will offer the high resolution and reliability necessary to satisfy the targeting effort requirements not only during the continuing Fermilab collider run but also into the Main Injector era.

VI. References

[1] J. Krider & C. Hojvat, "A Multiwire Secondary Emission Beam Profile Monitor With 20 μm Resolution," *Nuclear Instruments and Methods in Physics Research*, A247, pp. 304-308 (1986)

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[3] Cotronics Corporation, 3379 Shore Parkway, Brooklyn, New York, 11235, USA.

[4] J. Bosser, et al., "The Micron Wire Scanner at the SPS," *European Organisation for Nuclear Research, CERN-SPS Division*, CERN SPS/86-26 (MS), December (1986).