# A Beam Position Detector for SSC Collider Rings

Donald J. Martin
SSC Laboratory*
2550 Beckleymeade Avenue
Dallas, Texas 75237

## *Abstract*

A short-circuited stripline position detector which would operate in flowing liquid helium has been prototyped for the Supercollider main rings. Each sensing device, at 968 locations in each ring, consists of four 15 cm long, 50 Ω strip transmission lines. To maximize signal-to-noise ratio and reduce orthogonal sensitivity, each electrode subtends 70 degrees of the 37 mm aperture. Electrical to mechanical centers are proposed to be maintained within 0.15 mm radius by accurate tooling, so individual calibration would not be required. A radiation resistant, impedance matched vacuum feedthrough which is integral to the output signal cable is being considered. Because of the large quantity of detectors and inherent difficulty of replacement, reliability and manufacturability received the greatest concern during the design.

## I. Introduction

A Collider position detector design was needed early in the SSC project, since the detector resides within the cryogenic helium and vacuum environment of the spool piece. The detector design therefore preceded the existence of a comprehensive Beam Position Monitor (BPM) plan. Nonetheless, an early detector design proved useful in several ways. The design addressed space allocation for position detectors, mechanical tolerances of the BPM relative to the magnetic correction elements, and a host of cryogenic issues, such as heat leak, thermal expansion, and thermally induced changes in material properties. The design and fabrication of the devices also tested the entirely new procurement, drafting, and mechanical design departments within the laboratory. SSCL competitively bid the task of fabricating two detectors, and the component parts for two more. The shell and electrodes were fabricated by a precision machine shop in the Dallas, Tx. area. The feedthrough cable assembly, itself the subject of intense investigation, was made by a specialty cable house and installed at detector assembly. The result of this early design work is shown in Figure 1.

The BPM system must provide accurate position and coarse intensity signals under the various operating conditions of the Collider: during machine commissioning, at Collider design intensity, in fault diagnosis, and during specialized accelerator studies. The system may also be called upon to help protect superconducting magnets by reflexively sending abort signals if the closed orbit at any detector exceeds a preset limit. The detectors will be located at the sextupole end of each magnet correction package, every 90 m half-cell length. Each sensing device measures both horizontal and vertical position. Strips short-circuited at one end may be used since directionality is not required in the Collider, and this measure also saves cost, reduces heat leak, and improves reliability.

## II. Detector Design

Beam current in the machines is characterized by individual bunches, nominally 14 cm FWHM and separated by 5 m intervals. The stripline area must be sufficient to produce at least -40 dbm signal power at the Collider commissioning levels of $2 \times 10^8$ protons per bunch (ppb). This is about the minimum signal power required by AM/PM or log ratio processing.

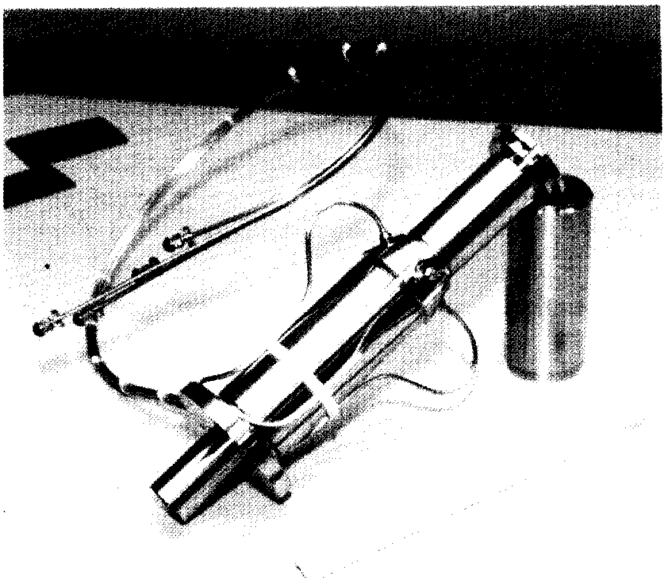

*Figure 1. Collider Beam Position Detector*

As the desirable properties of stripline monitors are well known, standard design equations from various sources are available [1]. The 5 m bunch spacing suggests strips of 15 cm length and a characteristic impedance in the 50 Ω to 75 Ω range. So that the electrodes will not be aperture defining elements, and to maintain the selected impedance, the beam tube bulges out around them. See Figure 2. The electrodes are also recessed 2 mm outside the aperture so that synchrotron radiation cannot strike them. (Synchrotron radiation impacts the detector design by its ability to produce noise in the electronics). Both the body of the detector and the strip are gradually tapered, up to the point where the coaxial pin and strip connect, to improve the electrical transition between the two geometries. The final geometry of the connection is expected to be determined empirically using TDR. The downstream end of the detector will be rigidly attached to the sextupole support plate, although the method is not resolved. In the present design, each detector is located by two 0.25 in. diameter pins on the cold mass end

---

*SSC operated by the Universities Research Association Inc., for U.S. Department of Energy under Contract DE-AC02-89ER40486.

plate. One pin is diamond shaped so that a bit of clocking on the round pin is possible. Three machine bolts tighten the detector flange to the spool piece plate. The flanges may then be tack welded together to fix the transverse alignment indefinitely. Advantages to this method are that the distortion of a heavy vacuum sealing weld are avoided, disassembly for repair is easy, and the bolt arrangement allows easy installation on a test stand. The detector is designed with a tailpiece section of beam pipe, which will be robot welded to the beam tube during spool manufacturing. This weld is readily inspectable before the detector assembly is butted against the cold mass end plate.

## III. Materials

Ionizing radiation will be present in the Collider and other circular accelerators, with the position detectors duly exposed. Estimates of energy deposition in devices close to the beam pipe have been made by several authors [2,3,4]. Radiation exposure results from beam scattering on residual gas, beam scraping on the beam tube, and catastrophic beam loss. The lifetime radiation dose of beam detectors in the Collider arcs will probably fall in the range 30 to 300 Mrads. A small number of detectors near the Interaction Regions may see doses up to 30 Grads. This radiation restricts the choice of materials that might be used in the detector. Some organic dielectrics, used in high frequency work, must be excluded from consideration as mechanical support materials. Materials that possess radiation hardness, low outgassing rate, maintain dimensions over life, have good RF properties, such as low loss and reasonable permittivity, are few. Ceramics are cautiously being considered in the 4K design, as brittleness and dielectric constant are of concern. A ceramic ring on the stripline upstream end is part of the present design, making the strip about 9% longer electrically, and causing an impedance bump. Detector mechanical pieces are taken from the 300 series of austenitic Stainless steels, which are frequently used in cryogenic engineering for their strength and corrosion resistance. However, some of these metals tend to be unstable at low temperatures, undergoing thermal or stress - induced martensitic transformation, leading to loss of ductility. This effect is of greatest concern in the vacuum feedthroughs. There is some evidence that this transformation caused insidious failures in the cryogenic feedthroughs used in the Fermilab Tevatron [5]. Among the Stainless steels, types 310 or 316LN are a good choice for cryogenic applications.

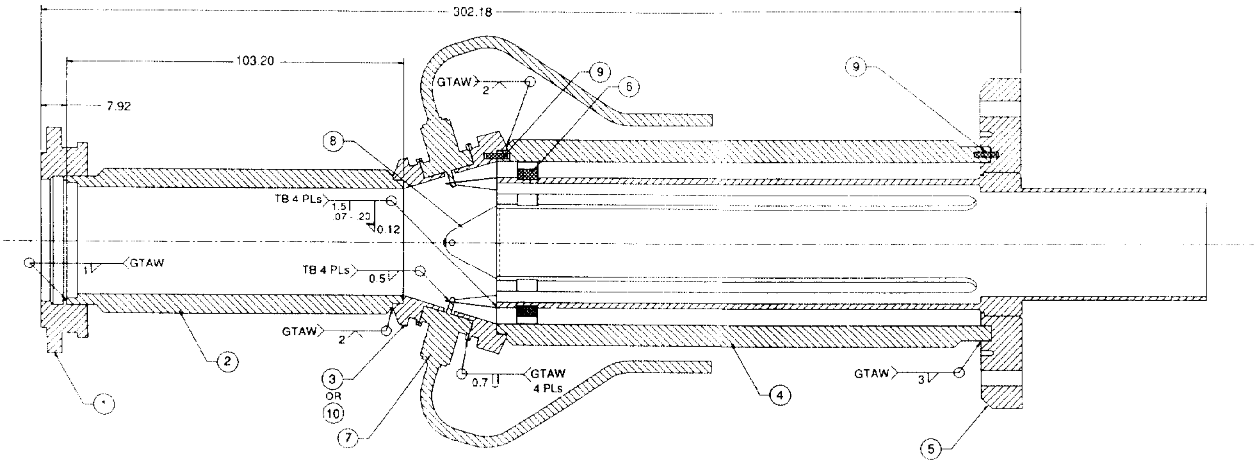

*Figure 2. Collider Beam Position Detector Assembly Drawing*

## IV. Vacuum Feedthroughs

Each position detector requires four vacuum feedthroughs, so 7,744 are required by the two Collider rings. Because of the great quantity of feedthroughs, and the inherent difficulty of replacement, these components must be very reliable. A detector MTBF of about $10^9$ hours keeps the downtime of the Collider to one week of every five years operation, from BPM failures alone. Detector failure is defined as that failure that prevents machine operation. It could result from a helium to beam vacuum leak, a stripline electrode collapsing into the beam aperture, or other unforeseen mode. In this early design, the feedthrough and signal cable to the outside of the cryostat are an integral assembly. The feedthrough is not the usual demountable connector, such as SMA. This is done because the outer body of the detector is exposed to LHe, so a leaking feedthrough would allow LHe into the beam tube. If a connector like SMA were used, it would need to be sealed by a metal sheath, making the connector pair all but inaccessible. Therefore, the connector is eliminated in favor of an all - welded stainless steel assembly. A 0.142 in. diameter solid jacketed cable is commercially available. At the 4K end of the cable, a seal separates beam vacuum from the cable dielectric. This seal will be of the brazed ceramic - to - metal type. If the ceramic develops small cracks, the cable dielectric would be exposed to beam vacuum, but not helium. For a while, the failure would likely be transparent to operation. The 25 cm of cable closest to the beam detector is at 4K. The dielectric would outgas into beam vacuum, but slowly, since most gases trapped there would be solidified. The room temperature end of the cable is hermetically sealed using glass or ceramic. This is done for redundancy, and to keep moisture from entering the cable dielectric. Silica in a finely powdered state is proposed for the cable dielectric, which is highly radiation resistant and largely inert. The silica is vacuum baked at 800°C during cable fabrication, so it is unlikely that significant outgassing through a cracked ceramic would occur. If either cable seal fails, a potential risk to the cable is absorption of water, as powdered silica is slightly hygroscopic.

Isolation between cryostat guard vacuum and air is maintained through an SMA jack-to-SMA jack coaxial feedthrough. This is done to avoid having the signal cable terminate into the tunnel environment, so that were the end damaged, the entire detector assembly would not have to be replaced. Because the detector is at the end of the cryostat, it is susceptible to handling damage, particularly the signal cables. An option being considered is a sheath covering the four cable bundle, and forming an extra shield against LHe exposure. In this scheme, the signal cables do not seal LHe, so a wider range of coaxial cable types may be considered.

## V. Reliability

How often will vacuum feedthroughs fail catastrophically, causing seven to ten day shutdowns of the Collider? A feedthrough may be more likely to fail because an adjacent one failed and the two had to be warmed to room temperature to make the repair. Failure rate may depend upon the number of temperature cycles each feedthrough experiences. It can easily be shown that the average number of lifetime thermal cycles for vacuum feedthroughs is not expected to exceed about 40, making worst case estimates. This suggests a methodology for accelerated life testing of this component.

## VI. Conclusion

A prototype Collider ring position detector was designed and fabricated. To date, the device has neither been mechanically inspected or electrically tested. However, a number of design difficulties were uncovered by the exercise. Stress relief of the feedthrough to prevent loading caused by differential expansion was not adequate. The semi - rigid cables, though rugged, may pose an installation problem within the spool piece, since they lack flexibility. Schemes for locating the vacuum feedthroughs outside the liquid helium are being considered, and alternate radiation resistant materials are being investigated for the cable dielectric. An improved set of prototypes are now being designed for use in ASST, the Accelerator Systems String Test, scheduled for late 1992.

## VII. Acknowledgment

The author gratefully acknowledges the many useful suggestions provided by R. E. Shafer, which concerned the theoretical and practical design of stripline detectors. The author thanks Richard Talman for valuable discussions on the synchrotron radiation issue. Useful suggestions on mechanical implementation were given by Dan Hutton, Leon Jemes, Jim Hahn, and Charles King. All fabrication drawings were created by Charles King.

## VIII. References

[1] R. E. Shafer, R. C. Webber, T. H. Nicol, "Fermilab Energy Doubler Beam Position Detector", IEEE Transactions on Nuclear Science, Vol. NS-28, No.3, June 1981.

[2] I. S. Baishev et al, "Beam Loss And Radiation Effects In The SSC Lattice Elements", Institute For High Energy Physics, USSR, 7/28/90.

[3] T. A. Gabriel, "Preliminary Simulation of the Neutron Flux Levels in the Fermilab Tunnel and Proposed SSC Tunnel", SSC - 110, 8/20/87.

[4] Gilchriese (editor), "Radiation Effects at the SSC", SSC - SR - 1035, 6/88.

[5] R. E. Shafer, personal communication to author.