Overview and Status of Beam Instrumentation at the SSC

Robert C. Webber
Superconducting Super Collider Laboratory*
2550 Beckleymeade Avenue, Dallas, Texas 75237 USA

Abstract

An overview of beam instrumentation requirements at the SSC and a status report on work progress is given. Small transverse emittance beams, ranging in energy from 30 KeV to 20 TeV, must be commissioned, measured, and diagnosed. Instrumentation plans and current design and development efforts for BPMs and other systems are presented. Monitors and electronics soon to be delivered for use in the Linac are described. Design of the Linac systems has been done with requirements and applications in the synchrotrons in mind and thus should provide a basis for design of much of that hardware. The useful commonality of design across the machines is discussed.

I. INTRODUCTION

Instrumentation for one Linac, three booster synchrotrons, the two Collider rings, associated transfer lines, and the test beams facility must be provided to commission and operate the Super Collider [1]. With the wide range of beam energies encountered within the SSC complex, nearly every imaginable type of instrumentation has potential application, from the traditional slit and collector emittance measuring unit for 2.5 MeV H-minus ions to exotic schemes for profile measurement of the 20 TeV proton beams. The many kilometers of accelerator and beamline ensure that all types of traditional instrumentation will exist in large quantities. Yet, budgetary limitations and the sheer magnitude of the task require concentration on a sound baseline suite of instrumentation. Table 1 provides an approximate instrumentation count.

II. PLANS, ACTIVITIES AND STATUS

A. BPM Mechanics

BPM designs are a focus of current activity. Open-circuited microstrip type designs are planned for use through the drift tube section of the Linac and center-tapped 'button' style monitors for the side-coupled Linac sections. External mechanical constraints, rather than beam or signal characteristics, drive the choice of two different design styles. Linac BPMs are in fabrication at this time.

Throughout the synchrotrons and transfer lines, plans call for stripline type pick-ups which are shorted at one end. The stripline design has been chosen to obtain adequate signal strength for low intensity commissioning of the superconducting rings, while maintaining well controlled impedances presented to the beam. The shorted-end design halves the number of signal feedthroughs required relative to an externally terminated design and eliminates reliability concerns of an internally terminated design. Additionally, the shorted-end pick-up exhibits no directionality, permitting it to be used in the HEB where beams circulate opposite directions from one cycle to the next and in the LEB where mechanical constraints require pick-up installation in alternating longitudinal orientations.

The HEB and Collider BPMs, located within the cryogenic spool pieces, must be designed to operate reliably and predictably at 4°K and through numerous temperature cycles [2]. It is anticipated that a common design will satisfy the requirements and constraints of those two machines, though plans call for both two and four electrode versions in the Collider. An early version prototype Collider BPM exists and procurement of prototypes of the current design is underway. The possibility of a warm beam tube liner for synchrotron radiation absorption within the cold Collider vacuum tube strongly impacts aspects of BPM design. Efforts are underway to identify a design that satisfies beam impedance and heat leak requirements without sacrificing position measurement performance.

B. BPM Electronics

Considerable development effort has been expended toward the use of logarithmic video detecting amplifiers in beam position processing circuitry [3]. Current plans are to use such circuits, operating in the 47-60 Mhz band, for Linac and LEB BPMs. Identical circuitry will form the core for both systems, though the Linac signals first require a 428 to 60 Mhz frequency conversion stage. Experience acquired during development of the log-amp electronics for those applications will determine its suitability for use in the common BPM electronics design required for the MEB, HEB, and Collider. A prototype of this circuitry has been tested with real beam signals at the FNAL Booster and its performance [4] compares favorably with the AM-PM circuits employed there. The log-amp processing method offers the wide instantaneous dynamic range and "automatic" normalization provided by the AM-PM method, while offering advantages including simplicity of implementation, relaxed phase matching requirements of the input signals, and wider input signal bandwidth acceptance. Signals from BPM pick-ups in the Linac will also be used as beam phase and time-of-flight monitors. A novel phase measurement method has been developed to meet the accuracy

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Table 1
Quantities of Beam Instrumentation Required in SSC Accelerators

Instrument	Linac	LEB	MEB	HEB	Collider	Transfer and Test Beam Lines
Planes of Beam Position Measurement	78	180	218	330	2320	142
Beam Loss Monitors	22	90	206	330	3000	175
DC current monitor	-	1	1	1	2	-
Wideband and Fast (video bw) current monitor	20	2	2	3	4	37
Beam Phase Monitor	39	1	1	1	2	8
Diagnostic Kickers	-	H&V	H&V	H&V	2 X H&V	-
Wire Scanners	32	-	1	-	-	10
Assorted Profile Monitors	2	3	9	6	6	36
Assorted Misc. Monitors	-	-	-	6	12	20

and dynamic range requirements demanded in this application [5].

Turn-by-turn position data acquisition is planned for each BPM location in each synchrotron. A VXI circuit board has been designed to provide the required digital processing and interface circuits and to accommodate a plug-in module for the log-amp analog signal processing circuitry [6]. A single board is designed to process two planes of position measurement. It digitizes both position and sum signals for each plane and has on-board memory to store up to 64K samples of each signal. Programmable averaging capability of up to 2048 turn-by-turn positions is also featured for closed orbit measurements. Memory freeze capability is included for quench and beam abort post-mortem analysis.

The concept of a plug-in module for the analog circuitry permits the same board to be used with little modification for other applications, such as beam loss monitors. Discussions have been held with numerous electronics manufacturing companies, large and small, in preparation to contracting for design assistance with this board. The quantities required force us to address industrial production and quality issues, especially in the areas of manufacturability, reliability, and testing. The plan is for development of a product suitable to our needs which may be made commercially available.

C. Profile Monitors

The small beam emittance, 1π mm-mrad normalized rms, and tight budget for allowable emittance growth through the accelerators make transverse beam size and profile measurements both essential for diagnosis of emittance blowup problems and difficult to accomplish. Accurate determination of beam sizes as small as 100 microns must be made in the high energy machines.

In the Linac and up to the LEB, traditional stepper motor driven wire scanners will be used [7]. They will be mounted at 45° to allow both horizontal and vertical measurements to be made at one location with a single device. Such instruments are already in use on the ion source and RFQ [8]. For longitudinal profile measurements in the Linac, a 'Feschenko style' bunch length monitor is being built [9].

Multi-wire harps are expected to be used as transverse profile monitors in most transfer lines, where single pass profile measurements are required due to long machine cycle times. The HEB to Collider transfer lines may be exceptions where required beam size resolution is difficult to achieve with harps. Also, the tolerance of the Collider superconducting magnets to energy deposition from scattered particles from such intercepting monitors may limit their usefulness in those lines. Ionization monitors, optical transition radiation monitors, and monitors employing a transverse probe beam have been suggested as possible solutions for this application. Little concentrated effort has yet been spent considering the merit, feasibility, or design of such devices.

In the synchrotrons, the baseline method for profile measurement is envisaged to be the flying wire. Design details for flying wire systems at the SSC have not yet been addressed. Such a device is believed to be quite adequate for the MEB and HEB rings. In the LEB there is concern that the fly time of the wire through the beam is unacceptably long compared to expected dynamic variation of beam parameters. Some effort has been spent investigating a suitable design for an ionization profile monitor for that application. In the Collider, the wire-beam interaction time can be shorter than a single turn. However, there are concerns there about emittance growth, energy deposition effects of scattered particles, and luminosity lifetime degradation if the wire is used with a full intensity beam during a colliding beams store. There have been efforts in the Collider group to assess the relative merits of numerous other, less obtrusive methods for continuous emittance monitoring in the Collider [10]. Schemes utilizing synchrotron light, ionization, and both neutral and electron probe beams have been considered [11], [12], [13]. The current view of that group is that an electron probe device is the most attractive alternative. Efforts are underway to initiate an R&D project for such a device.

D. BLMs

Reliable beam loss monitoring systems are required for commissioning, operations, and diagnostics purposes, as well as for machine protection and quench prevention in the superconducting rings. The baseline design is still use of FNAL style ion chambers or BNL style proportional chambers regularly spaced around the rings, typically near the quadrupole locations. There has been some investigation of solid state detectors, including PIN diodes and HgI_2 and CdTe based devices, as possible alternatives. Of these, the HgI_2 device offers the highest radiation damage threshold and lowest leakage current.

III. COMMONALITY ACROSS MACHINES

The goal of commonality of design across machines is a necessary and desirable objective in a project of SSC scale. Manpower resources, budget, and schedule all contrive to limit the number of unique designs that may be produced. Yet, performance requirements, space constraints, and aperture requirements demand that the individual details, especially of the mechanics, of each application not be ignored. This is especially true in the low energy end of the Linac, which is now being designed, where space is scarce and instrumentation performance requirements are exacting.

Each of the synchrotrons has a unique beam tube aperture and/or cross-section resulting in different BPM pick-up designs, except perhaps for a common HEB / Collider design. Differences of beam size, relevant measurement time scales, and machine operating tolerance for beam loss and emittance blowup all affect instrumentation design decisions.

Signal processing electronics is an area in which we find more practical commonality over larger scales. System functional requirements, as well as beam bunch intensities and time structures, throughout the MEB, HEB, and Collider rings are quite similar, permitting use of a single BPM electronics design throughout. We also expect beam loss monitoring electronics hardware to be common across at least the high energy machines.

Resources are stretched much more by the number of designs than by the production quantity of any one design. Nevertheless, final designs must be compatible with mechanical reality, and provide credible and useful information on the beam parameters they are intended to measure. This forces the need for continual compromises.

IV. SUMMARY

Many activities covering a broad range of beam instrumentation issues and designs are underway at the SSC with contributions from various corners of the laboratory organization. There are simultaneous efforts to design and build the 'bread and butter' instrumentation essential to any accelerator and to develop strategies for coping with the unique instrumentation problems posed by the small emittance and high energy beams of the SSC. There is a continuous struggle to achieve the economy of scale possible by commonality of design while sacrificing as little performance as possible in any particular application.

V. REFERENCES

[1] Superconducting Super Collider Laboratory Site-Specific Conceptual Design Report, SSC Laboratory Report No. SSCL-SR-1056, (1990).

[2] D. Martin, "Instrumentation Issues at the SSC," Proceedings of the Second Annual Accelerator Instrumentation Workshop, Batavia, Illinois, AIP Conference Proceedings No. 229, ISBN 0-88318-832-1 (1990).

[3] R. Aiello, "Log-ratio Technique for Beam Position Monitor Systems," to be published in AIP Proceedings of the Fourth Annual Accelerator Instrumentation Workshop, Berkeley, California (1992).

[4] R. Aiello and M. Mills, "Test Results of the SSC Log-Ratio Beam Position Monitor Electronics," to be published in proceedings of 1993 Particle Accelerator Conference.

[5] R. Aiello, "A Digital Approach for Phase Measurement Applied to Delta-t Tune-up Procedure," to be published in proceedings of 1993 Particle Accelerator Conference.

[6] A. Jones, "VXIbus Register Based Beam Position Monitor," SSCL Pre-print 153, 1992, to be published in AIP Proceedings of the Fourth Annual Accelerator Instrumentation Workshop, Berkeley, California (1992).

[7] J. Hurd, et al., "Beam Diagnostic Layout Requirements for SSCL Linac," to be published in proceedings of 1993 Particle Accelerator Conference.

[8] R. Aiello, et al., "Beam Instrumentation for the SSC RFQ," to be published in proceedings of 1993 Particle Accelerator Conference.

[9] J. Hurd, et al., "Bunch Shape Monitor for SSCL Linac," to be published in proceedings of 1993 Particle Accelerator Conference.

[10] W. E Nexsen, et al., "Minimal Interference Beam Size/ Profile Measurement Techniques Applicable to the Collider," draft SSCL note, April, 1993.

[11] E. Tsyganov, et al., "Electron Beam Emittance Monitor for the SSC," SSCL Pre-print 179, December, 1992, to be published in proceedings of 1993 Particle Accelerator Conference.

[12] R. Richardson, et al., "Beam Profile Measurement Using Thin Molecular Beams," to be published in proceedings of 1993 Particle Accelerator Conference.

[13] E. Tsyganov, et al., "Limitations of a Residual Gas Ionization Beam Profile Monitor for the SSC Collider," SSCL-602, November, 1992.