SNS FRONT END DIAGNOSTICS*

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Abstract

The Front End of the Spallation Neutron Source (SNS) extends from the Ion Source (IS), through a 65 keV LEBT, a 402.5 MHz RFQ, a 2.5 MeV MEBT, ending at the entrance to the DTL. The diagnostics suite in this space includes stripline beam position and phase monitors (BPM), toroid beam current monitors (BCM), and an emittance scanner. Provision is included for beam profile measurement, either gas fluorescence, laser-based photodissociation, or a crawling wire. Mechanical and electrical design and prototyping of BPM and BCM subsystems are proceeding. Significant effort has been devoted to packaging the diagnostic devices in minimal space. Close ties are maintained to the rest of the SNS effort, to ensure long term compatibility of interfaces and in fact share some design work and construction. The data acquisition, digital processing, and control system interface needs for the BPM, BCM, and LEBT diagnostic are similar, and we are committed to using an architecture common with the rest of the SNS collaboration.

1 INTRODUCTION

The SNS Front End consists of an H^- Ion Source, Low Energy Beam Transport (LEBT), a Radio Frequency Quadrupole (RFQ) with 65 keV injection energy and 2.5 MeV output energy, and a 3.6 m long Medium Energy Beam Transport (MEBT), that matches and chops the 2.5 MeV H^- beam before injection into the remainder of the SNS linac [1].

The extremely compact 65 keV LEBT leaves no room for conventional diagnostics. Only one measurement of beam properties remains, a split-collector current measurement, that goes under the name "LEBT Diagnostic." No beam diagnostic devices at all are included in the RFQ.

Table 1 shows the instruments that will be assembled on the 2.5 MeV, 3.6 m long MEBT. Figure 1 shows their placement along the beam line. This paper will discuss each of these instruments in turn.

2 LEBT DIAGNOSTIC

Beam current will be monitored on a four-way split electrode (LEBT chopper target), placed at the exit of the LEBT. The current balance between electrodes at different times during the chopper cycle can be used to qualitatively determine offsets from the RFQ axis [2]. With appropriate manipulation of the beam steering, some information might be gained about beam size.

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Table 1: MEBT instrumentation summary

Device	Qty.	z extent	Measures
LEBT	1	0 mm	centering
BPM	6	106 mm*	position, phase
BCM	2	59 mm	current
Profile	5	51 mm	x and y profile
Emittance	1	2×51 mm	x-x' and y-y'

* all but 23 mm overlaps with quadrupole magnet

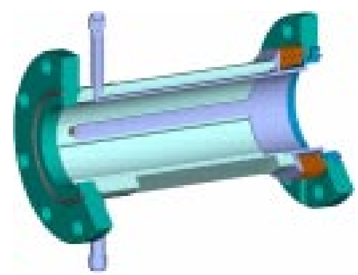

Figure 2: Stripline BPM assembly

3 BEAM POSITION MONITORS

BPMs will be installed in six locations in the MEBT, spaced roughly every 90° of betatron phase advance [3]. The BPMs will primarily be used as a secondary standard for restoring the beam, where the primary standard is the null point for quadrupole steering. The BPMs also serve to measure the trajectory of systematically deflected bunches (this pattern is related to the betatron oscillation of particles in the bunch, but differs due to space charge effects) and to provide beam phase information for tuning the longitudinal optics by way of the rebuncher cavities. Thus, reliability, repeatability and linearity are more important than initial zero set.

To minimize the amount of beamline space dedicated to BPMs, the strips are relatively narrow (22°) so as to fit between quadrupole pole tips.

The electrical processing will use the 805 MHz signal component, since the fundamental 402.5 MHz signal will be contaminated by fringe fields from nearby 402.5 MHz rebuncher cavities.

Since this is a low velocity beam ($\beta = 0.073$) wire-based calibration will not give a proper calibration curve. A simple numerical model will convert electrical signal strengths to linearized position.

Measurements of a prototype show the expected shorted 50 Ω stripline behavior, with no spurious resonances below 8 GHz. Construction of all required BPMs is nearly complete.

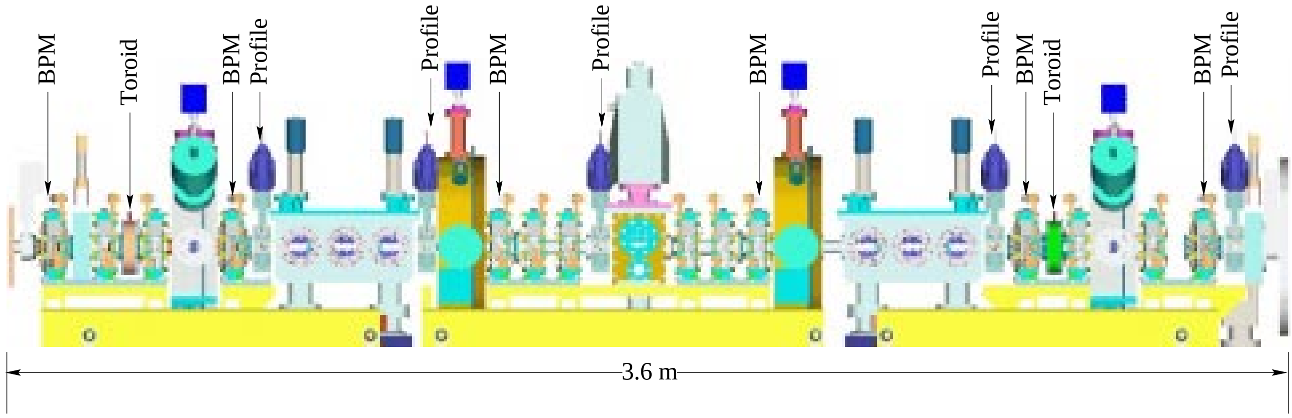

Figure 1: Overview of MEBT.

Electronics to measure longitudinal bunch information now uses the signals coming from the BPM pickup, to avoid the need for separate beamline hardware (see section 6 below). For relative phase measurement with a single BPM, this is fairly easy. For absolute measurement between pairs of BPM's, this requires extra attention to cables and calibration. All BPMs are installed in the same directional orientation, so those phase signals can be compared with no additional sensor calibration term.

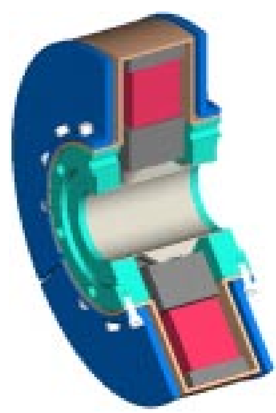

Figure 3: Current transformer assembly

4 BEAM CURRENT MONITORS

The MEBT beamline includes two current transformers to measure beam current, one before and one after the MEBT chopper target. These will be used to measure the current waveforms that are generated by the LEBT and MEBT chopping processes. They also provide the first calibrated measure of beam current and integrated beam charge.

The toroidal transformer is nearly a standard Bergoz FCT-082-50:1 [6], using a high permeability core to keep droop to a minimum during the 0.65 μs chopped beam pulse. These transformers have a measured droop of 0.06 %/μs.

These devices are mounted 37 mm from the main focussing magnet pole tips (1.16 diameter), leading to concerns that the DC magnet fringe field would saturate portions of the toroid core. The result would be a increased droop rate, and sensitivity of the measurement results on quadrupole drive current. Tests have shown this is indeed the case: with the quadrupole running near its design gradient (38 T/m), the current transformer's droop approximately doubles. The design shown above, however, includes a 3.2 mm thick shield made from mild steel. With this field clamp inserted, the droop of the transformer is not measurably affected by quadrupole operation.

The transformers have been delivered, the remaining mechanical beamline parts have been fabricated, and assembly is underway.

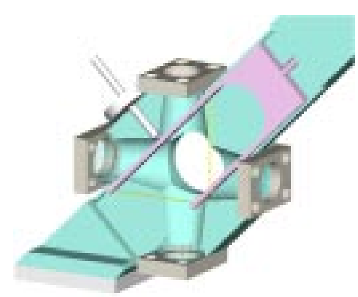

Figure 4: Wire Scanner concept, with provisions for RGF or LP device.

5 BEAM PROFILE MONITORS

Measurements of beam profile in the MEBT are considered essential to check that the transverse beam optics is behaving as intended. In final operation of SNS, these measurements should be made without disturbing the operation of the machine. The two leading contenders to provide such functionality are Residual Gas Fluorescence (RGF) [4] and Laser Photodissociation (LP) [5]. Unfortunately, both of these techniques are considered experimental at this time, and cannot be counted on to deliver reliable profile data for beamline commissioning in 2002.

The current plan is to provide conventional crawling wire scanners, with co-located optical ports, for eventual addition of an RGF or LP monitor. The wire scanners will be used first to commission the beamline, and then to test and commission an optical technique.

Brookhaven Nat. Lab. will provide the flange-mounted wire scanners for the whole SNS project, including the MEBT. That design will be customized to fit the tight space allotment. Unlike the final optical devices, the wire scanner is intended to work only when the beam runs at reduced duty factor. Rather than the full 1 ms pulse at 60 Hz, we expect 100 μm wire to survive 100 μs pulses at 6 Hz (1% of the nominal 6% duty factor). This is adequate to commission, but not operate, the accelerator.

The beam box is designed to accept a wire scanner, plus two pairs (in and out, x and y) of f/2.8 windows on the beam, and a gas jet that could be part of the fluorescence experiments. Space is sufficiently tight that the beam boxes will likely be manufactured as part of neighboring components (chopper electrodes, chopper target, and emittance scanner). We hope that this optical access will be sufficient to deploy a final non-invasive profile measurement.

6 EMITTANCE

The 1999 SNS Beam Instrumentation Workshop [7] strongly recommended that a way be found to measure the emittance of the beam as it leaves the MEBT on its way to the DTL. By subsuming phase measurement into the BPM pickup system, a slit and multisegment collector assembly (at 51 mm each) could be fit into the beamline. Note that the drift space between these devices contains one focussing quadrupole, one BPM, and one profile monitor. The engineering design of this subsystem has started. The slit cannot absorb the full beam power.

For each position of the movable slit, all the beam divergence information is recorded simultaneously by a segmented collector assembly. Each segment has its own front-end electronics equipment, consisting of a charge amplifier and sample-and-hold.

Table 2 shows a plausible parameter set for the MEBT emittance device. With these parameters, the error in reconstructed emittance and the error of the reconstructed Twiss beta function are typically on the order of 2% or less.

Table 2: MEBT Emittance Device parameter set

Slit width	0.2 mm (7.9 mils)
Total slit movement range	5.0 mm
Slit positions for measurement	50
Collector segments	64
Collector size	30 mm (square)
Collector center-center spacing	0.5 mm
Slit-collector spacing	205 mm

7 SIGNAL PROCESSING ELECTRONICS

The signal processing needs for the BPM, LEBT diagnostic, and BCM are similar, both among themselves and with their cousins in the larger SNS project. Collaborative and competitive development of electronics is underway at LBNL, LANL, and BNL.

Most of the relevant information can be collected with a moderate rate (34-68 MHz), moderate resolution (12-14 bit) digitization of a suitably conditioned signal. We are investigating digitization and signal processing platforms that can reliably and cost-effectively deal with this volume of data, and interact with the Global Controls (EPICS). That platform would then be used for all BPM, BCM, and LEBT signal handling, and possibly other uses within SNS.

Each instrument has unique analog signal conditioning requirements. For BPM processing, at least one channel of “vector voltmeter” is required to process beam phase information. This is expected to function with a mixer and direct IF sampling. Such processing can also be used for position readout. Log amp circuitry is also under consideration for the actual signal strength measurements: it has a dynamic range advantage over ordinary linear analog processing.

The BCM signal conditioning requirements for the front end are actually quite modest, essentially a 40 dB amplifier and filter. This simplicity has to be balanced against compatibility with the future BCM signal conditioning for the SNS ring, where the signal has an additional 60 dB of dynamic range, and turn-turn differences are important [8].

8 ACKNOWLEDGEMENTS

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