Beam Diagnostic Layout Requirements for SSCL Linac*

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Abstract

A basic set of diagnostics is needed to commission, tune, and monitor the operation of the SSCL linac. This set of diagnostics has been refined in the final stages of design of the linac. Planned diagnostics include current monitors, Faraday cups, beam loss monitors, beam position monitors, wire scanners, absorber-collector phase scan units, slit and collector emittance measurement units, and longitudinal bunch shape monitors. The diagnostics are described and their placement along the linac is given. The use of the diagnostics for tuning the linac is described. The first set of diagnostics will be installed with the RFQ, with additional diagnostics installed with each linac section.

I. INTRODUCTION

The Superconducting Super Collider Laboratory (SSCL) accelerator complex [1] is currently under construction in North-Central Texas, near Dallas. In the first stage an H^- beam is accelerated to 600-MeV by a conventional linac [2]. The beam is then accelerated by a series of synchrotrons to form two counter circulating 20-TeV proton beams that collide at defined intersection regions. The colliding beams produce high energy physics events that act as probes for observing the interaction of the fundamental particles in nature. The linac consists of an ion source, three distinct accelerator structures, and matching sections to transport the beam between structures.

An important aspect of the SSCL linac is the required brightness of the beam and subsequent requirement for low emittance. The design of the linac has been driven by the need to limit the emittance growth. Therefore, the periodic lattice structure and phase advance is held constant as much as possible through the linac. In addition, the beam is accelerated as quickly as possible to limit effective emittance growth at low energies due to space charge. The result is a linac with very short matching sections. Short matching sections are very good for limiting emittance growth, but they do not leave much room for diagnostics. It is difficult to characterize the beam without sufficient diagnostics, and without a well characterized beam, the matching section lenses cannot be adjusted properly to match the beam into the next section of linac. The resulting mismatch leads to an effective emittance growth due to non-linear fields and transverse-longitudinal coupling. To correct this problem, great effort has been expended to justify and develop diagnostics which will fit in the limited matching section region and between accelerator tanks, and to include space where future diagnostics will be located when the need arises.

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II. DIAGNOSTIC LAYOUT

The diagnostics for the SSCL linac are specified in table 1. They consist of the standard linac diagnostics. A brief description follows.

Table 1
List of SSCL Linac Diagnostics

Location	Diagnostic
Low Energy Beam Transport	1 Segmented Faraday Cup
	1 Segmented Aperture
	1 Current Monitor Toroid
	1 Wire Scanner
DTL Input Matching Section	1 Segmented Faraday Cup
	1 Segmented Aperture
	1 Current Monitor Toroid
	1 Wire Scanner
	1 Slit & Collector EMU
	1 Bunch Shape Monitor
	3 Beam Position Monitors
DTL Inter-Tank Spaces	1 Current Monitor Toroid
(per space)	1 Wire Scanner
	2 Beam Position Monitors
	1 Absorber-Collector
CCL Input Matching Section	2 Current Monitor Toroids
	3 Wire Scanners
	3 Beam Position Monitors
	1 Slit & Collector EMU
	1 Bunch Shape Monitor
	1 Absorber-Collector
CCL Inter-Tank Spaces	1 Current Monitor Toroid
(per module of 8 tanks)	1 Wire Scanner
	2 Beam Position Monitors
	8 Beam Diagnostics Boxes
Transport Line	3 Current Monitor Toroids
	8 Wire Scanners
	6 Beam Position Monitors
	1 Bunch Shape Monitor
Transfer Line	9 Current Monitor Toroids
	10 Wire Scanners
	10 Beam Position Monitors

A. Slit and Collector Emittance Measurement Unit

The linac slit and collector Emittance Measurement Unit measures the phase space distribution of the beam in either the horizontal or vertical plane of the beam. The slit measures the position of some fraction of the beam and the collector measures the angular distribution of beam for that particular position. By stepping the slit and collector across the beam, the distribution in position-angle space is measured. The first and second moments of the distribution give the centroids, Twiss parameters, and emittance of the beam in the plane of measurement.

B. Wire Scanner

Wire Scanners measure beam intensity in the horizontal or vertical plane as a function of position. The measurement lacks the angular information the slit and collector Emittance Measurement Unit provides, but wire scanners are less complicated, less expensive, and do not have to completely stop the beam, so they are more useful at high energies. Three wire scanner measurements can be used in series to reconstruct the RMS Twiss parameters and emittance of the beam. Wire scanners can also be used to measure x-y correlations.

C. Beam Position Monitor

Beam Position Monitors measure the centroid of the beam. They are non-intercepting, so they do not interfere with the beam. Transverse and longitudinal centroid measurements can be made with Beam Position Monitors. The beam position monitors will be used to steer the beam, to tune the rf using the Δt method [3] or the least squares method [4], and they will be used as an on-line measure to monitor the beam during operation.

D. Current Monitor Toroid

Current Monitor toroids are also non-intercepting diagnostics which measure the total current passing through them. They are used to measure transmission and monitor the beam during operation. Current monitors with high frequency response can be used to monitor the turn-on transient of the beam. The signal can be fed forward to the rf drive loops to provide additional power for the beam in the rf accelerator loops.

E. Faraday Cup

Faraday cups also give total beam current, and they fully intercept the beam, thus they can be used as beam stops. Care must be take to make the beam stops thick enough to stop all the beam, provide enough cooling to dissipate the average beam power, and select proper materials and shape to handle the instantaneous heat deposited in each micro-pulse.

F. Absorber-Collector

Absorber-Collectors are used to measure the longitudinal characteristics of the beam. The absorber is made to stop all beam below design energy, and the collector measures the beam current that passes through the absorber. In this way the accelerated and unaccelerated parts of the beam can be separated. The acceptance of the upstream rf cavity can be scanned in phase across the beam, and the beam captured in the acceptance fish is measured as a function of phase. The width and relative phase of the acceptance fish is measured and some information concerning the phase width of the beam can be gained by differentiating the signal.

G. Bunch Shape Monitor

A new device being developed at the SSCL and other laboratories is the Bunch Shape Monitor [5]. The Bunch Shape Monitor is analogous to a longitudinal wire scanner. It can measure the longitudinal profile of the beam. A more complete review is given elsewhere at this conference [6].

III. FUNCTION

The primary functions of the SSCL linac diagnostics are to tune and monitor the beam for delivery to the Low Energy Booster and the Proton Therapy Facility. Initially, the diagnostics will be used to commission the linac and carry out linac development necessary to meet full design specifications.

The SSCL linac has a short beam pulse, from 2 μsec to 35 μsec with an expected rise time of up to 100 nsec. The beam tune is space-charge dependent, especially at the lower energies. It is therefore necessary to know the current and longitudinal characteristics as a function of time. Examples of time dependent beam characteristics are given in references [7] and [8]. Averaging over any beam time dependence would smear out the measured emittance. The apparent increase in beam size would cause errors in the estimates of space charge forces. The reduced tune shift would result in errors in the machine simulations. Specifications for most diagnostics call for a frequency response capable of observing 100 nsec rise times on the beam signals, zero to full scale.

A. Transmission

One of the most fundamental characteristics of the linac beam is the transmission. The SSCL linac is designed to deliver 25 mA peak beam with a 30 mA input beam. The RFQ should have a capture of 80% to 100%. Losses along the rest of the linac should be less than a few percent. Current Monitor Toroids along the beam line will be used to monitor beam transmission. During development, they will be used to map out the physical aperture of the linac. Transmission contours as a function of steering and transverse match will be generated using the toroids. Faraday cups are used to stop the beams at low energies. The ion source can be run and its current monitored while downstream linac elements are off.

B. Transverse Tune

To limit emittance growth it is important to keep the beam as small and uniform in size as possible as it traverses the linac. This is done by designing the linac as a periodic strong focusing lattice and matching the beam into the periodic structure. One method of measuring the transverse phase space distribution of the beam is to use the slit-and-collector Emittance Measurement Unit. The unit measures the Twiss parameters and the emittance of the beam. The emittance growth is monitored as a function of some other machine parameter to investigate and optimize the tune space of the linac. The measured beam parameters are used as inputs to tuning algorithms that adjust quadrupoles and match the beam. The slit-and-collector do not give the x-y correlation of the beam. The emittance measurement unit also gives centroid and relative intensity information. Patterns in the phase space distribution can be recognized to help give indications of higher order aberrations, space charge effects, and aperture restrictions.

Wire scanners are used to measure the width of the beam. There is no angular information as with the slit and collector. By measuring the width for three different upstream lens settings or at three different positions along the beam line, one can solve for the RMS phase space parameters of the beam as long as the linear problem is non-singular. For larger numbers of measurements, least squares techniques can be utilized. Wire scanners are more practical at higher energies than slit-and-collector emittance measurement units. Wire scanners do not have to stop the beam. At higher energies, the slit produces ionizing radiation that creates noise on the downstream collector. The drawback to wire scanners is that they integrate over the angle dimension of phase space and the details of the angular distribution cannot easily be recovered except in an RMS sense. At low energies, wire scanners can also be used were there is not sufficient drift to use the slit and collector. At the SSCL, a three wire scanner is being developed, one wire in x, one in y, and a third wire at 45 degrees. The third wire will be used to help measure possible x-y correlation introduced by the Helical Electrostatic Quadrupole[9] or rotated quadrupoles.

Beam position monitors are the third transverse measurement diagnostic. These are non-intercepting devices which makes them the best candidates for on-line beam monitoring. Measurement capabilities are practically limited to centroid measurements only and they are usually less accurate than wire scanner measurements. Because they do not have to be stepped across the beam, beam position monitors can give results on a much faster "real time" basis as the steering is being adjusted. Beam position monitors can also be used to give intensity data. When used at a high dispersion point, the position of the beam is coupled to the momentum, and thus the beam position monitors can be used to monitor the beam energy.

C. Longitudinal Tune

The Bunch Shape Monitor in longitudinal space is analogous to the wire scanner in transverse space. It measures the intensity as a function of phase (proportional to time) along the longitudinal dimension of the micro-bunches. By measuring for three or more different points in longitudinal space, one can reconstruct the longitudinal RMS phase space for the beam. The longitudinal emittance can be measured and the beam matched longitudinally in this manner. The phase of the upstream rf cavity can be scanned and the bunch shape measured as a function of cavity phase. The result gives an estimate of the bucket width from which the cavity amplitude and phase can be inferred.

Another method of measuring the bucket width is by using an absorber-collector. By differentiating the resulting signal an estimate of the bunch width can be made, but this method is not as accurate or as direct as the bunch shape measurement. The absorber-collector phase scan method, along with beam loading measurements, is used to make the course adjustments to the rf phase and amplitudes.

The beam position monitors at SSCL will be used to measure the longitudinal as well as transverse center of the beam. In transverse phase space the beam position monitor signal is proportional to the transverse centroid of the beam. In longitudinal phase space the phase is that of the 428-MHz Fourier component of the beam [10]. Once the rf cavity is set approximately with absorber-collector phase scans or beam loading scans, the classical Δt and least squares phase scan techniques [11] will be used to tune the rf cavities using the phase information.

IV. CONCLUSION

The SSCL linac will have the full suite of diagnostics used at other comparable linear accelerators such as the Moscow Meson Factory and the Los Alamos Meson Physics Facility. To successfully control the emittance growth in the SSCL linac, it is necessary to have a full set of diagnostics to perform measurements outlined. Some restrictions such as permanent magnet quadrupoles eliminate the use of certain diagnostic techniques such as "quad unrolls." To limit emittance growth, transport sections have been made as short as possible, eliminating space for diagnostics. To work in this new and restricted environment, not only must standard diagnostics be made more compact, but new diagnostics requiring less longitudinal space may need to be developed [12]. The short pulse lengths at SSCL force the requirement for diagnostic bandwidths on the order of 3.5 MHz to observe the time dependent behavior of the beam.

VII. REFERENCES

[1] *Site-Specific Conceptual Design Report*, SSCL Report SSCL-SR-1056, July 1990.

[2] L. W. Funk, "The SSC Linac, *1992 Linear Accelerator Conference Proceedings*," Vol. 1, pp. 8-12.

[3] K. R. Crandall, "The Δt Tuneup Procedure for the LAMPF 805-MHz Linac," Los Alamos Scientific Laboratory Report LA-6374-MS, June 1976.

[4] F. W. Guy and T. P. Wangler, "Least-Squares Fitting Procedure for Setting RF Phase and Amplitude in Drift-Tube-Linac Tanks," *Conference Record of the 1991 IEEE Particle Accelerator Conference*, Vol. 5, pp. 3056-3058.

[5] A. V. Feschenko and P. N. Ostroumov, "Bunch Shape Measuring Technique and Its Application for an Ion Linac Tuning," *Proceedings of 1986 Linac Conference*, pp. 323-327.

[6] J. W. Hurd et. al., "Bunch Shape Monitor For SSCL Linac," these proceedings.

[7] E. McCrory et. al., "Observation of Transverse Instabilities in the FNAL 200-MeV Linac," *Proceedings of 1988 Linac Conference*, pp. 182-184.

[8] J. W. Hurd, "Solution to the Transverse Phase Space Dependence Problem with LAMPF's High Intensity H^+ Beam," *Proceedings of 1983 Particle Accelerator Conference*, IEEE Trans. Nucl. Sci., Vol. NS-30, No. 4, pp. 2487-2489, (1983).

[9] D. Raparia, "HESQ, A Low Energy Beam Transport for the SSC Linac," *Proceedings of 1990 Linac Conference*, pp. 405-407.

[10] R. Aiello, "A Digital Approach for Phase Measurement Applied to Delta-t Tuneup Procedure", these proceedings.

[11] F. W. Guy and J. W. Hurd, "Procedures for Setting RF Phase and Amplitude in the SSC Drift-Tube-Linac Tanks," *1992 Linear Accelerator Conference Proceedings*, Vol. 1, pp. 196-198.

[12] D. Swenson and M. Andrews, "Performance of a Wire Shadow Emittance Scanner", these proceedings.