Physics Requirements of Commissioning Diagnostics For SSCL Linac*

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Abstract

Commissioning diagnostics are described in terms of the beam physics requirements of the SSCL linac. Commissioning diagnostics include current monitors, beam position monitors, spectrometer, foil scattering experiment, wire scanners, Faraday cups, and bunch shape monitors. Two DOE integrated contractors, the Superconducting Super Collider Laboratory and Allied Signal, Kansas City Plant, are developing the commissioning diagnostics. The need to measure bright, short linac beam pulses requires special design considerations. High density harps and collectors with up to 50 wires per cm and 128 wires total, and fast, 3.5-MHz amplifiers have been developed. The diagnostics will be first used and tested during beam commissioning of the RFQ.

I. INTRODUCTION

The Superconducting Super Collider Laboratory (SSCL) is currently constructing and commissioning a 600 MeV linac to serve as the injector into a series of synchrotron accelerators [1]. The final structure will be a pair of 53 mile circumference synchrotrons providing colliding proton-proton beams, each at 20 TeV.

The linac [2] consists of an ion source, three distinct accelerator structures, and matching sections to transport the beam between structures. The rf accelerating structures are a Radio Frequency Quadrupole (RFQ), four Drift Tube Linac (DTL) tanks, and nine Coupled-Cavity Linac (CCL) modules, each with eight tanks. The general beam parameters are shown in Table 1. It is important to note the peak current, emittance requirements, and short pulse length of the linac beam. These characteristics, along with the high reliability requirement, provide the unique characteristics for the SSCL linac which drive the commissioning and development program.

Table 1
SSCL Linac Description

Length	143 m
Output Energy	600 MeV
Output Current	25 mA peak
Pulse Rate	10 pulses per second
Pulse Length	2 to 35 μsec
Transverse Emittance	<0.3 π mm-mrad,rms, norm.
Longitudinal Emittance	<7.0 10^{-7} eV-sec
Frequency	427.617 MHz

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II. COMMISSIONING PLAN

The SSCL linac is to be commissioned in stages [3]. The current plans calls for installation and commissioning in a serial approach for each of the following sections: a) Ion Source, b) RFQ, c) DTL Input Matching Section (IMS), d) DTL tank 1, e) DTL tank 2, f) DTL tank 3, g) DTL tank 4 and CCL Input Matching Section (IMS), h) CCL module 1, and i) CCL modules 2-9 and the transfer line to the LEB. Currently, the H^- Ion Source and the RFQ are being operated at the Central Facility laboratory building near Waxahachie. The linac tunnel is near completion and the first DTL tank is scheduled for delivery in January.

III. COMMISSIONING DIAGNOSTICS

Commissioning diagnostics for the SSCL linac consists of a suite of instruments on a diagnostic cart which will be placed at the end of each section as it is being commissioned, and the standard set of operational diagnostics which are located between rf tanks and in matching sections [4, 5]. In addition there are stand alone diagnostics such as the spectrometer and x-ray detector.

Table 2 describes the diagnostic cart instrumentation. The primary function of each type of instrument is indicated. Some diagnostics could measure other variables. For example, a Slit and Collector Emittance Measurement Unit could measure total current if calibrated absolutely, but the SSCL emittance unit measures relative current only. A description of some of the devices and the design considerations for the SSCL commissioning diagnostics follows.

Slit-and-Collector Emittance Measurement Unit - The system measures the phase space distribution of the beam in the x-x' plane and the y-y' plane. A graphite slit measures the position of the beam, and a multi-wire collector measures the angular distribution. The collector is a sandwich design of copper and mica after a design used at LAMPF. The collector has 128 "wires" spanning 24.7 mm (0.13 mm wire width + 0.07 mm mica width).

Each channel of the 128 wires goes to a separate amplifier-ADC-memory array. The amplifier is bipolar and deferential with continuous gain ranges from 10 mA to 10 μA full scale. The amplifier has a 10-MHz bandwidth at the lowest gain and approximately a 1-MHz bandwidth at the highest gain. The ADC digitizes at up to 20 MHz. Each time the board is triggered, 1000 data points are digitized during the beam pulse and stored in memory. Memory for each channel can hold up to 100 sets of data. The board was designed and built by a joint effort between SSCL and Allied Signal, Kansas City [6].

The required dynamic gain range is determined by the following method. Consider a transverse phase space distribution in the x-x' plane given by

$$\rho(x,x') = \frac{I}{2\pi\varepsilon_{rms}} e^{-\left(\gamma x^2 + 2\alpha x x' + \beta x'^2\right)/2\varepsilon_{rms}}, \qquad [1]$$

where I is the total beam current,

α, β, and γ are the standard Twiss parameters,

ε_{rms} is the unnormalized rms emittance,

x is the position coordinate, and x' is the angle coordinate.

The signal on any wire, $I_s(x_0,x'_0)$ is given in terms of the position of the slit, x_0, the angular position of the wire, x'_0, the slit width, Δx, the angular wire width $\Delta x'$, and the secondary electron emission coefficient, C_s, as

$$I_s(x_0,x'_0) = \frac{C_s\, I\, \Delta x\, \Delta x'}{2\pi\varepsilon_{rms}} e^{-\left(\gamma x_0^2 + 2\alpha x_0 x'_0 + \beta x_0'^2\right)/2\varepsilon_{rms}}. \qquad [2]$$

The peak signal is given for $x_0 = 0$, and $x'_0 = 0$, by

$$I_s(0,0) = \frac{C_s\, I \beta_r\, \gamma_r\, \Delta x\, \Delta x'}{2\pi\, \varepsilon_{n,rms}}, \qquad [3]$$

where β_r and γ_r are the standard relativistic notation,

$\varepsilon_{n,rms}$ is the normalized rms emittance.

Table 2

Commissioning Diagnostics and Primary Function

DEVICE \ FUNCTION	Beam Current	Transverse Centroid	Transverse Width	Transverse Phase Space Distribution	Phase Centroid	Energy Centroid	Phase Width	Energy Width	Longitudinal Acceptance Width	RF Field Level
Current Monitor Toroid	X									
Faraday Cup	X									
Segmented Faraday Cup	X	X								
Segmented Aperture		X								
Beam Position Monitor		X			X					
Wire Scanner		X	X							
Slit-Collector Emittance		X	X	X						
Spectrometer						X		X		
Absorber-Collector							X		X	
Bunch Shape Monitor					X		X		X	
Elastic Scattering						X		X		
X-ray Detector										X

Table 3 gives an estimate of some of the peak wire currents expected for the SSCL linac. Table 3 indicates that the highest gain needed is 10 μA. The lowest gain needed is when the collector is run in the beam with no slit in front of it.

Table 3

Peak Signal Level On Collector Wires At Different Locations Along Linac As Indicated By Energy.

Slit Is In Beam.

$I_s(0,0)$ - maximum expected collector wire signal

T - kinetic energy

C_s - estimated secondary emission coefficient

I = 25 mA $\varepsilon_{n,rms}$=0.2 mm mrad

Δx=0.1 mm

$I_s(0,0)$ (mA)	T (MeV)	$\beta_r\,\gamma_r$	$\Delta x'$ (mrad)	C_s
0.015	0.03	0.0086	0.85	1
0.32	2.5	0.073	0.44	5
0.0078	70	0.39	0.10	0.1
0.0054	600	1.3	0.042	0.05

The maximum signal current is then

$$I_s(x=0) = \frac{C_s\, I\sqrt{\beta_r\gamma_r}\,\Delta w}{\sqrt{2\pi\beta\,\varepsilon_{n,rms}}} \qquad [4]$$

where Δw is the wire width.

Table 4 shows the expected peak wire current for various locations along the linac.

The wire spacing, number of wires, and separation between the slit and collector are another important design parameter. The maximum and minimum angular spread of the beam (full width) can be estimated as

Table 4

Peak Signal Level On Collector Wires At Different Locations Along Linac As Indicated By Energy.

Slit Is Not In Beam.

$I_s(0,0)$ - maximum expected collector wire signal

T - kinetic energy

C_s- estimated secondary emission coefficient

I = 25 mA $\varepsilon_{n,rms}$=0.2 mm mrad

Δw=0.127 mm

$I_s(0)$ (mA)	T (MeV)	$\beta_r\,\gamma_r$	β (mm/mrad)	C_s
1.8	0.03	0.0086	0.02	1
8.6	2.5	0.073	0.2	5
0.13	70	0.39	2.0	0.1
0.06	600	1.3	6.5	0.05

$$W'_{max} = 2\frac{\varepsilon_n}{\beta\gamma x_{min}}, \text{ and}$$

$$W'_{min} = 2\frac{\varepsilon_n}{\beta\gamma x_{max}}. \qquad [5]$$

Table 5 shows the values for the estimated maximum and minimum angular spread of the beam along the linac assuming $\varepsilon_n = 0.2$ mm mrad.

Table 5 Estimated Minimum And Maximum Full Widths and Number of Wires Needed						
	W'min (mrad)	W'max (mrad)	n	xmin (mm)	xmax (mm)	$\beta_r \gamma_r$
LEBT	4.6	31.	34	1.5	10.	0.0086
DTL IMS	0.68	11.	78	0.5	8.	0.073
CCL IMS	0.10	2.0	100	0.5	10.	0.39
TRSPT	0.031	0.62	103	0.5	10.	1.3

If one wishes to obtain at least 5 data points across the minimum angular space, than the space between wires is needed is $w' = W'_{min}/5$. The number of wires needed to span the maximum angle space is

$$n = W'_{max}/w' = 5\,W'_{max}/W'_{min}\,. \qquad [6]$$

Based on equation 6, table 5 shows the minimum number of wires, n, needed at various locations along the linac. To make a general wire collector for all regions and assuming a 20% safety factor, the collectors need approximately 120 wires. This is close to the "computer" number 128, which we chose for the design.

The maximum physical size of the collector should be no larger than twice the beam pipe diameter for the case where the collector moves with the slit, and the physical wire spacing is limited by engineering considerations. For the SSCL linac commissioning, copper with a 0.127 mm width and mica with an approximate 0.066 mm width (including packing factor) where used to make the collector. Given the separation, L, between the slit and collector imposed by the linac lattice, a 0.193 mm separation between wires, and a 24.7 mm overall collector width then the actual values for W'_{min} and W'_{max} are shown in table 6. These values compare favorably with the requirements shown in table 5.

Table 6 Actual Values For W'max and W'min				
	L (mm)	W'min (mrad)	W'max (mrad)	n
LEBT	150	1.3	165	128
DTL IMS	300	0.64	82	128
CCL IMS	8800	0.022	2.8	128
TRSPT	30000	0.006	0.82	128

Harp - Harps are multi-wire devices much like collectors, but with high transmission. Harps are better at high energies than the collectors described because harps produce less ionizing radiation. They can be used as collectors for high energy emittance scans as well as fast, accurate position measuring devices. Harps take a full profile in one pulse and at low energies they can be used with a collector downstream to accurately measure the beam position at two points along the beam line. SSCL is working with Allied-Signal to produce high density harps on ceramic boards. The harps will have 128 wires over approximately 48.8 mm with 0.033 mm thick wires. The harps use the same amplifiers as the Emittance Measurement Unit. Details of the SSCL harp are describe elsewhere at this conference [7].

Wire Scanner - Standard wire scanners are being developed for commissioning of the SSCL linac. In the commissioning diagnostics, three wire scanners will be separated by some drift at the end of the diagnostic cart. Each wire scanner will have three wires to reconstruct the RMS emittance of the beam. For more details see [7], [8], and [9].

Bunch Shape Monitor - An important new diagnostic for linac commissioning and operation is the bunch shape monitor. The version for the SSCL will have better than 6 psec resolution. The results for the first version developed by the Institute of Nuclear Research are presented at this conference [10].

Absorber-Collector - The absorber-collector pair is used to measure the beam current above some energy level as an upstream rf module is being scanned. The design of the absorber is such that it will stop the unaccelerated beam, while the beam captured in the acceptance fish will pass through the absorber to the collector. Table 7 shows the basic design for the absorbers. Calculations were done, including the effects of straggling [11], to show the relation of the absorber-collector phase scan measurement data and the phase and amplitude of the rf cavity. This method will be used to determine the course adjustment of the rf cavity.

Table 7 Design Thickness of Absorber			
	Design Output Energy (MeV)	Absorber range (MeV)	Thickness of Cu Absorber (mm)
Tank 1	13.4	12	0.332
Tank 2	32.9	28	1.427
Tank 3	51.6	46	3.396
Tank 4	70.3	64	6.056

VIII. REFERENCES

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