Diagnostics for the MLI Model 1.2-400 Synchrotron Light Source

Dan Y. Wang and Robert Legg
Maxwell Laboratories, Inc., Brobeck Division
4905 Central Avenue
Richmond, California 94804

Abstract

The MLI Model 1.2-400 Synchrotron Light Source is designed for operation at 1.2 GeV at a beam current of 400 mA. An integrated set of diagnostics that meets the needs of all stages of commissioning is required for this commercially produced storage ring. The design of each component will be discussed in light of its use during commissioning, with emphasis on the essential beam position monitoring electronic system.

I. INTRODUCTION

The ring consists of a Chasman-Green lattice with four-fold symmetry. The injector is a 200 MeV linac. The storage ring and linac are connected via a transport line useful for analyzing the linac beam. For a successful and rapid commissioning, it is necessary to have an integrated set of diagnostics which monitors relevant system performance parameters.

Section II contains a diagnostics plan relating key system performance parameters to specific beam measurements, and thence to the particular diagnostic element for performing this measurement. Sections III and IV describe the design specifications of individual diagnostics in the transport line and storage ring respectively and show how these designs are governed by the requirements established in section II. Proceeding from the diagnostic plan, these diagnostics are sufficient for commissioning with minimal frills. Section V is a detailed description of the beam button position monitor electronics system in the ring.

II. DIAGNOSTICS PLAN

The system performance parameters of interest during commissioning, the corresponding beam property to be measured and the diagnostic to be used for this beam measurement are summarized in Table 1.

Table 1. Summary of Diagnostics

SYSTEM PERFORMANCE PARAMETER	BEAM PROPERTY/ MEASUREMENT	DIAGNOSTIC DEVICE
injection efficiency	linac beam intensity within specified energy spread	energy selective slit with current monitor, Faraday cup
transport line transmission efficiency	linac beam emittance	fluorescent screen assembly
	beam positions along transport line	fluorescent screen assemblies (8 total)
ease of finding closed beam orbit	first turn beam position in ring	ring fluorescent screen assemblies (4 total); Sabersky finger
	multiple turn beam survival in ring	single buttons distributed in ring
ease of optimizing closed orbit	beam positions around ring	13 BPM stations distributed in ring
conformity of lattice with theoretical model:		
betatron tunes	beam oscillation frequencies	traveling wave electrodes (coupled to spectrum analyzer) (2 sets)
dispersion function	beam orbit at different rf frequencies	13 BPM stations
lattice Twiss functions	tune change with quadrupole perturbations	traveling wave electrodes
beam lifetime	beam current	dc current transformer (DCCT)
beam emittance	beam size within dipoles	optical monitoring station

III. TRANSPORT LINE DIAGNOSTICS

The transport line diagnostics consist of two slit assemblies (with attached screens), three current monitors, a Faraday cup, and six fluorescent screen assemblies.

Slit assembly
slit jaw thickness: 1 cm
jaw material: heavy metal (tungsten-copper)
slit opening range: 0-50 mm
resolution: < 0.01 mm
alignment of beam: fluorescent screen attached to front of jaws

Toroid current monitor
sensitivity: 10 V/A
risetime: < 2 ns

Faraday cup
range: 0.2 nC to 20 nC (10 Hz rate) (with picoammeter)

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The linac beam has a nominal intensity of 25 mA (100 ns pulse average, 10 Hz cycle) within an energy spread of ± 0.25%. The slit assembly is placed after a 90 degree bend magnet, where the dispersion is 0.71 m and the intrinsic beam width is 0.22 mm (3σ). Thus by opening the slit width to 3.55 mm, the energy spread of the unscattered beam passing through will be ±0.25% with an uncertainty of ±0.03%. Its intensity is measured by the toroid monitor which is interfaced with an oscilloscope and calibrated against the Faraday cup.

fluorescent screen assembly
resolution: 0.25 – 0.4 mm (at 12.5 mA, 100 nsec pulse)
fluorescent screen material: chromox
camera: vidicon/ultricon

With a vacuum chamber aperture of 25–50 mm and beam sizes of a few millimeters, a resolution of 0.4 mm is more than adequate for measuring beam size and position along the transport line in general. However, a better resolution of 0.25 mm is needed for measuring the beam emittance of 0.31 π•mm•mrad.

IV. RING DIAGNOSTICS

The ring diagnostics consist of a Sabersky finger, four fluorescent screens, 13 four-button beam position monitors, two traveling wave electrode stations, a dc current transformer (DCCT), and an optical monitoring station.

Sabersky finger (see figure 1)
width: 1.6 mm
material: heavy metal (tungsten-copper)
location: at injection point, placed to intercept part of injected beam from transport line
min. current sensitivity: 1.5 pA average (with picoammeter)

The stated minimum current sensitivity enables measuring the beam even if the transport line efficiency is only 25%.

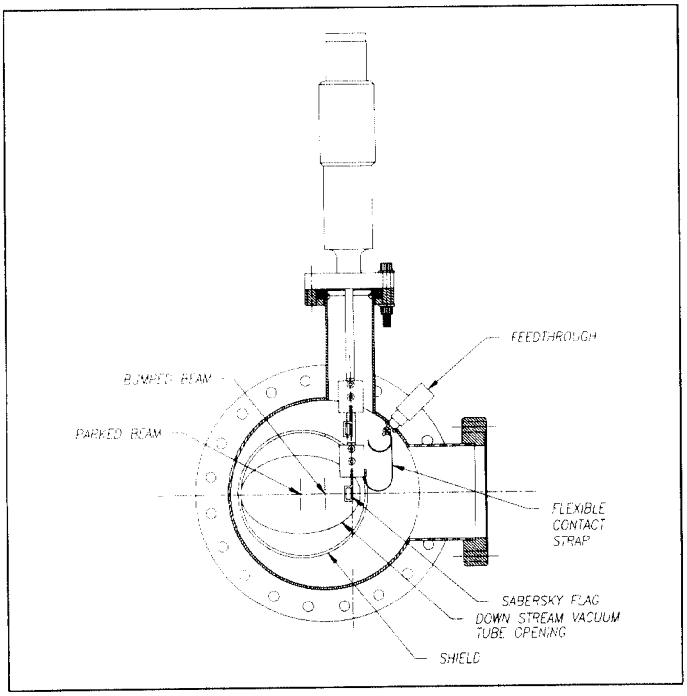

Figure 1. Sabersky finger assembly.

ring fluorescent screens
resolution: 0.7 mm (at 2.5 mA, 100 nsec pulse)
camera: ultricon

The resolution is adequate for viewing the beam on the first turn while it is performing betatron oscillations with a 20 mm amplitude. Use of an ultricon enables viewing a beam which is only 10% of the linac output.

button position monitors
button diameter: 1 cm
capacitance: 11 pF
mount: 4 to a flange assembly

The design specifications are more fully discussed in section IV, which also includes a figure showing the button assembly together with the electronics block diagram.

traveling wave electrodes
length of electrode: 15 cm
angular width of electrode (wide end): 32 deg
frequency response: >1.5 ohms from 0.2 to 1 GHz

The traveling wave electrode station is shown in figure 2. There are 4 electrodes per station. The length of 15 cm is chosen so that peaks in frequency response occur at odd multiples of 500 MHz, which is the ring rf frequency. By using a linear taper, the modulation in frequency response is reduced to less than about 6 db over the bandwidth of more than 1 GHz. These electrodes are coupled to a spectrum analyzer having a noise level of about -100 dbm for monitoring the betatron tunes even when the stored beam is 1 mA.

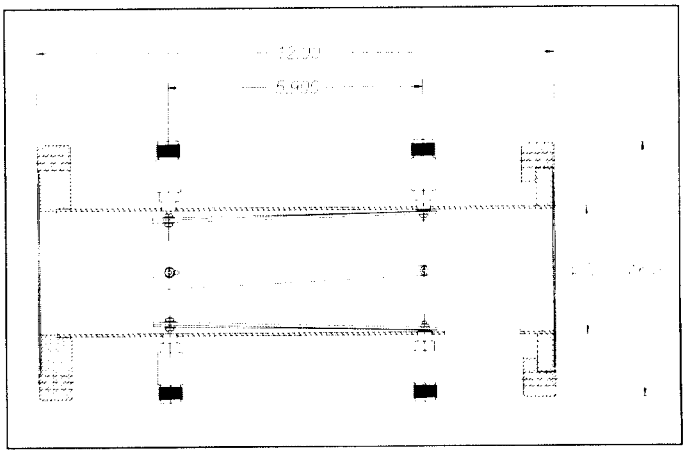

Figure 2. Traveling wave electrode station.

dc current transformer (DCCT)
current range: 0 - 600 mA
resolution: < ±0.016 mA (0.1 sec integration window)
< ±0.005 mA (1 sec integration window)

The DCCT assembly is shown in figure 3. The DCCT core and associated electronics were purchased from Bergoz. The device has an intrinsic di/dt output which can determine beam lifetimes as short as a minute, which is short compared to the expected lifetime of more than eight hours.

optical monitoring station
mirror material: copper with protective coating
system magnification: 1/3.8
resolution at source plane: 0.25 mm

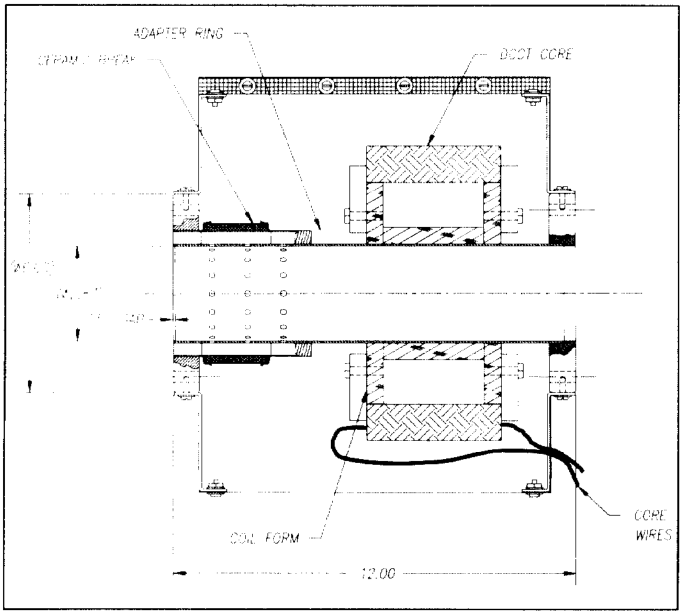

Figure 3. DC current transformer (DCCT) assembly.

camera: vidicon
optics: achromatic lens with a bandpass filter at 5500 angstroms

The optical monitor assembly is shown in figure 4. At 1.2 GeV, the storage ring beam emittance is 2×10^{-7} π•m•mrad, and the energy spread is 6×10^{-4}. For the position imaged, the rms beam sizes assuming 10% coupling are σ_x=0.64 mm and σ_y=0.39 mm. The resolution of 0.25 mm enables an accurate determination of the beam size for measuring the ring emittance.

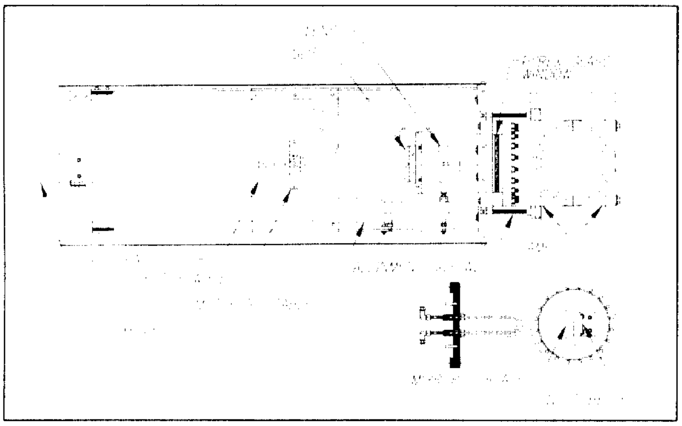

Figure 4. Optical monitor assembly.

V. BPM Electronics System

The beam position monitoring (BPM) electronics system monitors all 52 buttons of the 13 BPM stations, as shown in the block diagram (figure 5). The system consists of a multiplexer controlled by a line sequencer, followed by a signal processing stage that employs a bandpass filter, a gain stage controlled by the line sequencer, and then a diode detector and low-pass filter for signal averaging. The system uses a multiplexed analog switch system like NSLS and a diode detector like CEBAF. The multiplexed system is attractive because it minimizes the number of rf filter/amplifier/detector modules which are needed and thus obviates the need for cross calibration. The diode detector is attractive because its output conforms to a square law device over a 30 dB dynamic range. This reduces the number of steps needed in the gain stage. It also reduces the frequency with which the computer must look at the peak detector output to reset the gain setting. The diode detector is also very accurate. CEBAF is presently using a diode to make 100 ppm measurements with a 35 MHz bandwidth. This makes it possible to do direct measurements with the diode and a filtering system, eliminating the need for more complex signal averaging techniques.

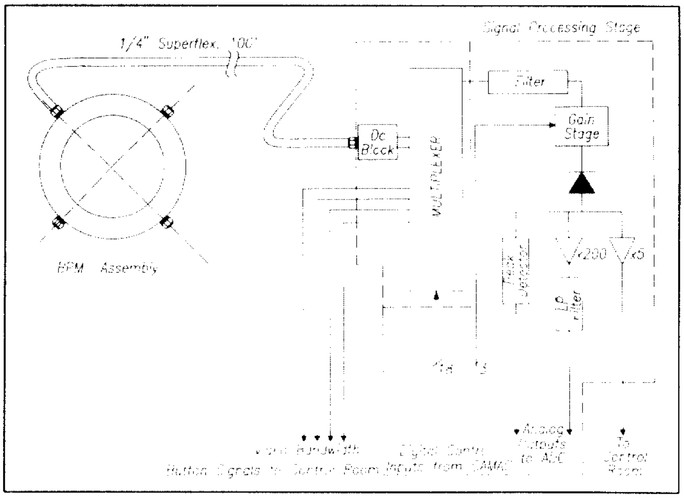

Figure 5. BPM button assembly and electronics block diagram.

When the sequencer is off, the raw signals from four specified buttons are continuously sent to the control room for observation on a fast oscilloscope. This enables monitoring of beam survival on a turn-by-turn basis.

For measuring the beam orbit, the CAMAC line sequencer is turned on so that 52 buttons are scanned. Four signal lines are further multiplexed down to one signal to be fed into the signal processing stage.

An analysis of the gain stage noise floor has been made since this is what ultimately determines the position resolution of the system. The most stringent requirement is to able to measure the beam position to within ±2 mm at a low current of 0.34 mA which corresponds to storing about 5% from one pulse of the linac. It is estimated that the input signal level for this condition is -81 dbm while the noise floor is -107 dbm, which is adequate. At a current of 400 mA, the system should be able to resolve beam positions down to ±0.1 mm.

VI. Conclusion

Testing of the diagnostics is now in progress. Tests on the button assembly are complete. Using a simulated current source, responses from individual buttons were measured with a network analyzer and found to be in good agreement with theory. The frequency response of the traveling wave electrodes has also been found to agree with calculations over 1 GHz. These results indicate that design specifications will be met.