The SSRL Injector Beam Position Monitoring Systems *

W. Lavender, S. Baird[†] S. Brennan, M. Borland[‡] R. Hettel, H.-D. Nuhn
R. Ortiz, J. Safranek, J. Sebek, C. Wermelskirchen[§] J. Yang
Stanford Synchrotron Radiation Laboratory, P.O. Box 4349, Bin 69, Stanford, CA 94309-0210

Abstract

This article describes the software and processing electronics of the systems used to measure electron beam trajectories for the new SSRL injector for SPEAR.

I. INTRODUCTION

The beam position monitoring system of the SSRL injector forms a vital component of its operation.[1][2] Several different types of instrumentation are used to measure the position or intensity of the electron beam in the injector. These include current toroids, fluorescent screens, Faraday cups, the "Q" meter, a synchrotron light monitor, and electron beam position monitors. This paper will focus on the use of the electron beam position monitors to measure electron trajectories in the injector transport lines and the booster ring. The design of the beam position monitors themselves is described in another paper to be presented at this conference.[3]

There are three different beam position monitor systems in the injector. One system consists of a set of five BPMs located on the injection transport line from the linac to the booster (known as the LTB line). There is a second system of six BPMs located on the ejection transport line (known as the BTS line). Finally, there is an array of 40 BPMs installed on the main booster ring itself. We will consider first the booster BPMs.

II. BOOSTER BPM SYSTEM

Beam position monitors are located at 40 positions spaced equally around the ring. Of these, 21 are connected to the processing electronics. The connected BPMs are mostly those installed at odd numbered girders of the ring. Extra BPMs are connected at girders 14 and 16, just after the injection point. There is no BPM at girder 13, since its place is taken by a fluorescent screen.

Since the SSRL injector ramps from injection to ejection energy 10 times a second, one of the design criterion for the booster beam position monitor system is that it be able to measure a series of electron orbits during a particular 50 millisecond ramp up cycle. As it would be far too expensive to have dedicated processing electronics for each button of each BPM, the later stages of the processing electronics are shared by multiplexing the signals from the various BPMs down into one four-channel set of electronics with one channel for each button of a BPM.

The multiplexing occurs in two stages. The first stage is handled by a set of 12 ten-to-one multiplexer modules known as R10T modules which use a design[4] developed by SLAC for the SLAC Linear Collider project. The R10Ts are grouped into three banks of four R10Ts each with each R10T in a bank dedicated to a particular BPM button location. The four pickup buttons of each BPM are arranged in an orientation such that they pick up a signal to the upper left from the beam, to the upper right, to the lower left, and to the lower right from the beam. This gives sufficient information to calculate the x and y position of the beam at that BPM. The four cables from a given BPM are routed into separate R10Ts, so that all four buttons of a BPM may be measured simultaneously. Each R10T has one output, so there are 12 outputs to be fed to the next level of multiplexing.

The second level of multiplexing is handled by a device known as the "fast" multiplexer.[3] This is a four channel device which switches any one of four inputs to an output channel. Thus, there are 16 potential inputs and four output channels. Since we currently use only 12 R10Ts, only 12 of the inputs are used and the other four are left disconnected. Each of the output channels of the "fast" multiplexer corresponds to one of the four buttons on a BPM, namely, upper right, upper left, lower right, or lower left.

The electronics that processes the analog BPM signal is a combination of equipment designed and used by SLAC[4] and custom equipment of our own.[3] The typical input signal to our system is a mostly unipolar pulse, 2 ns wide, with an amplitude of 10 to 50 mV. The signal first passes through a 3 pole, 12 MHz high pass filter, which removes the large noise signals generated by the modulators, kickers, and other noise sources in the accelerator. Then the SLAC RF BPM heads stretch and amplify the pulse. The pulses are still the same amplitude, but now 20 ns wide. The final analog stage is an integrating peak detector. Each pulse raises the output by one half the difference between the input pulse amplitude and the current output level. Negative pulses leave the output unchanged. Since the periods of our machine tunes are less than 5 microseconds and we sample each monitor for 25 microseconds, this system integrates out the amplitude modulation caused by the tunes. The voltage put out by the integrator is measured by a CAMAC-based Lecroy 6810 waveform recorder. After a complete series of orbits is recorded, the waveform recorder is read out by the control computer for display and later analysis.

Guard times of 5 microseconds before and 10 microseconds after the bank switching of the "fast" multiplexer are

---

*Work supported by the Department of Energy, Office of Basic Energy Sciences, Division of Material Sciences.

[†] visiting SSRL from CERN

[‡] Now at Argonne National Laboratory, Argonne, Illinois, U.S.A.

[§] Now at Gesellschaft für Mathematik und Datenverarbeitung (GMD), Bonn, Germany

0-7803-0135-8/91$01.00 ©IEEE

added to each BPM measurement for a total measurement time per BPM of 40 microseconds. This guard time is required since the "fast" multiplexer puts out a burst of electronic noise when it switches. The R10T modules also put out electronic noise when they switch, but the software arranges that they are only switched at times when the "fast" mux is looking at an R10T bank other than the one which is switching.

This processing system was chosen because of its accuracy and simplicity to implement. The final stage electronics are matched and linear over a dynamic range of 30 dB. This allows us to use the same electronics on all BPMs, regardless of the differences in signal attenuation from one BPM to another due to signal cable lengths. Our overall system allows us to measure beam positions to an accuracy of a few tenths of a millimeter over an order of magnitude of beam current in the accelerator.

Since the booster BPM system is configured to allow for 30 BPMs to be read during a ramp cycle, the total amount of time required to measure beam positions once from all the BPMs is 30 * 40 microseconds or 1200 microseconds. A dead time of 800 microseconds is appended to each measurement cycle in order to make the measurement interval come out to a round number, namely, 2 milliseconds. After the end of each measurement interval, the CAMAC hardware is programmed to immediately start another measurement cycle, for a total of 33 measurement cycles during a given ramp of the booster. Thus, the BPM system records measurements from 0 to 66 milliseconds into the ramp, which is well past the peak magnetic field point at 50 milliseconds. Reading out the information from the Lecroy waveform recorder, analyzing it, recording it in the control system database, and setting up for the next scan takes about one second. So, in practice, the BPM system measures orbits from a ramp cycle about once every two seconds. This has generally been found fast enough to give good feedback to operators of the machine.

During a ramp cycle, CAMAC instructions must be sent out at precise intervals in order for the measured orbits to accurately reflect the nominal measurement times. Since the main control computer is a multitasking system, it is not well suited to performing this function. Therefore, sequencing of instructions is offloaded onto a Kinetics Systems list sequence processor installed in the BPM CAMAC crate which functions as an auxiliary crate controller. Its function is to ensure that the CAMAC commands are sent out at a constant rate. The central control system computer's function in this case is to program the instruction list in the list sequence processor, enable the BPM system to receive an external trigger, and read out and process the BPM data at the end of the ramp cycle. Once the BPM system receives its external trigger, the list sequencer collects data asynchronously until it has recorded its 33 measurement cycles.

The external trigger for the booster is provided by a peaking strip. This is a device in the booster ring which consists of a magnetic material with a very narrow hysteresis curve and a steep magnetization curve. Thus, a change from a slightly negative magnetic field component in the booster dipole magnets to a slightly positive field causes the peaking strip to switch its magnetization from full magnetization in one direction to full magnetization in the opposite direction. This produces a pulse at the time that the ring magnet's magnetic field is at the field for injection, which is used as a timing trigger by many systems in the booster in addition to the booster BPMs.

The Lecroy waveform recorder in this system is programmed to digitize individual samples in each of its four channels in synchronization with an external clock signal. This clock signal is provided by a device known as the "slow" multiplexer. The "slow" multiplexer is intended for future expansion of the system to record other signals, but it is currently used only to provide the external clock for the Lecroy module. The command to the "slow" multiplexer to provide this signal forms part of the CAMAC list programmed into the list sequence processor. This mode of operation of the Lecroy module is not standard for it, since it normally expect the clock signal to always be present. But with some amount of work, it has proved possible to use the 6810 in this mode.

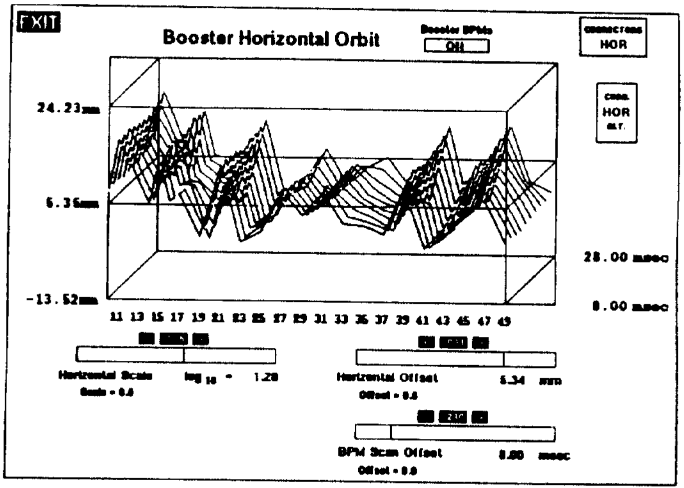
Once the BPM signals are read out of the Lecroy module, the control system takes sums and differences between the four signals, upper right, upper left, lower right, and lower left. These are used to calculate the x and y position of the electron beam at that BPM for that measurement cycle. This information is stored in the form of 33 complete orbit measurements in the control system database. The orbit measurement may be paused at any time to allow the orbits to be recorded to permanent storage. A program also exists that reads a given measured orbit from several ramp cycles and averages them to give better statistics for the orbit measurement.

A sliding buffer of 10 of these measurements is displayed on an operator menu, which allows the operator to see the electron orbit change as a function of time. An example of the appearance of one of these menus is shown in Figure 1, which demonstrates the "waterfall" effect used to achieve an illusion of depth.

III. TRANSPORT BPM SYSTEM

The beam position monitor systems for the injection and ejection transport lines use the same kind of BPMs as the booster BPM system, differing in the processing electronics and the software interface. The transport line BPM system design faces a different kind of challenge from the booster BPM system. Instead of having to make many measurements over a period of tens of milliseconds, the transport BPM system must only make a measurement once every 0.1 seconds or more. However, it is important that the measurement be made at precisely the time the electron beam is passing.

The transport BPM systems also use R10Ts to multiplex signals from multiple BPMs, but since each transport line



Horizontal Scale log₁₀ = 1.20
Scale = 0.0

Horizontal Offset 6.34 mm
Offset = 0.0

BPM Scan Offset 0.00 msec
Offset = 0.0

Figure 1
Injector control system horizontal orbit menu

has less than 10 BPMs, a second level of multiplexing is not necessary. Thus, the outputs from the R10T modules are fed into RF heads and then sent on to a pair of dual track and hold modules built by SLAC[4] which function as peak detectors. The transport BPM systems make use of a feature of the RF heads not used by the booster BPM system. This is the ability to sum the signals from each of its inputs to provide an output trigger signal which is used to reset the dual track and hold modules. Since the dual track and hold modules once triggered will simply store the largest signal they see, it is not necessary to synchronize the operation of the BPM system in any other way. In fact, the R10Ts are multiplexed asynchronously from any external trigger, with the only requirement being that they must dwell on a particular BPM for 0.12 seconds to ensure that the electron beam has passed through the BPM at least once. The control computer computes sums and differences of BPM button signals in a similar manner to the booster BPM system and displays the calculated x and y positions on a computer menu.

Some problems have been encountered in the operation of the transport BPM electronics while the injection and ejection kickers are on. The problem is that the kickers generate RF signals that propagate down the beam pipes to the locations of the BPMs and induce signals in their processing electronics. During normal ramping, this kicker "noise" is sufficient to trigger the dual track and hold well before the passage of the electron bunch, except for the first two BPMs in the injection line. This is not that much of a problem for steering the injection line, since one can turn off the injection kicker until the beam has been well steered. This solution is, of course, not possible for the ejection line, since if the ejection kicker is turned off, there is no beam in the ejection line. In actual operation, the normal practice has been to use the automatic measurement system for the injection line and steer through the ejection line by looking at the BPM signals directly on an oscilloscope.

The fact that the first two BPMs in the injection line are sufficiently far enough away from the injection kicker for its noise to not perturb them is quite fortunate. This is because position information from the second LTB BPM (the BPM after the first bending magnet) is used by the linac energy feedback system as a measure of the current acceleration energy of the linac. This feedback system is described further in another paper to be presented at this conference.[5]

IV. CONCLUSION

The injector beam position monitor systems have successfully been used to measure electron orbits and to diagnose configuration problems. The booster BPM system has proved capable of measuring orbits at intervals of 2 milliseconds during the ramp every two seconds. Further development is in progress to improve the system.

V. REFERENCES

[1] H. Wiedemann, "3 GeV Injector Synchrotron for Spear." At this Conference.

[2] S. Baird et al, "Commissioning the SSRL Injector." At this Conference.

[3] J. Sebek et al, "Diagnostic Instrumentation for the SSRL 3 GeV Injector for SPEAR." At this Conference.

[4] SLAC Instrumetation and Control Division, "SLC Control System Hardware Manual, Release 3.0." SLAC internal document, 1988.

[5] L. Emery, "Energy Feedback system for the SSRL Injector Linac." At this Conference.