Diagnostic Instrumentation for the SSRL 3 GeV Injector*

J. Sebek, M. Baltay, M. Borland‡ J. Cerino, L. Emery†, R. Hettel, H. Morales, D. Mostowfi, M. Rowen,
J. Safranek, J. Voss, J.N. Weaver, H. Wiedemann, Y. Yin‡ B. Youngman§
Stanford Synchrotron Radiation Laboratory, P.O. Box 4349, Bin 99, Stanford, CA 94309-0210
J.-L. Pellegrin, V. Smith
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309-0210

Abstract

SSRL has built a 3 GeV injector to fill SPEAR. Many types of diagnostic instruments were built into the injector to facilitate and enable commissioning and operation. These instruments were designed to give accurate information for low beam currents seen in the early stages of commissioning [1] as well as for the higher currents in normal operation.

I. INTRODUCTION

SSRL has built and commissioned a 3.0 GeV electron accelerator as a dedicated, full energy, injector for its SPEAR storage ring [2]. The beginning of the injector is a 2856 MHz RF electron gun. This gun emits a peak current of 650 mA of 2 MeV electrons for 2.5 μsec. These electron bunches are compressed in an alpha magnet, and then pass through a pulsed chopper, which selects three of these s-band bunches. These bunches are then accelerated through three 2856 MHz linac sections to an energy of 130 MeV, transported and injected into the cycling booster. Here the bunches are compressed into one bunch at 358.54 MHz, the SPEAR frequency, and accelerated to 3 GeV. Finally, the bunch is ejected from the booster and injected into SPEAR. The injector cycles at a 10 Hz rate and currently delivers greater than 10^8 electrons per cycle to SPEAR.

The diagnostics required for the booster are dictated by the purpose and function of the machine. The low beam currents and single bunch character of the system reduce the need to be able to observe many high frequency phenomena associated with instabilities important at higher beam currents. The fact that the beam stays in the machine for only 50 msec also removes the need for diagnostics that looks for long term drifts in the beam. Also, since the SPEAR injection aperture is reasonably large, the knowledge of the position of the beam does not need to be more precise than a few hundred microns. The diagnostics and associated instrumentation will be discussed with these points in mind. The paper will describe the function of the various devices in three different situations:

- The initial commisioning of the machine when systems were being checked out with very low current.
- Machine physics on and characterization of the injector itself.
- The normal operation of the machine as a dedicated injector for SPEAR.

II. FARADAY CUP

The injector has two Faraday cups for charge measurement. Both are used for machine characterization. The first, located at the entrance to the alpha magnet, is an insertable cup used to measure the charge emitted by the RF electron gun. Since the beam at this point has not yet been chopped, high currents require cooling of this cup. The cup is made of a water-cooled copper bar and serves a double purpose as the support for an insertable screen. Charge here is measured in μC/pulse. The second cup measures beam out of the linac. It is located at the end of a diagnostic beamline into which the linac current can be steered. Because of the higher energies of the beam here, this cup is made of lead. To prevent contamination of the injector vacuum, the lead is encased in stainless steel before it is placed in the vacuum system. This cup receives less than one nC/pulse.

The outputs of both of these cups were fed to general purpose, commercial devices for measurement. One of the most useful tools we have found in commissioning and running the accelerator has been a high bandwidth, fast digital sampling oscilloscope. This scope is used during operation to monitor the many diagnostic signals from the accelerator. During machine physics, these devices can sample signals, such as the current discharge from the Faraday cups, and perform a mathematical calculation, in this case integration, that gives the total charge.

III. CURRENT TOROIDS

Measurement of beam current in many different parts of the injector is required. Current toroids make 8 of these measurements. Preliminary designs had toroids placed inside the vacuum system. Several early experiments showed, however, that toroids external to the beam pipes gave good results. This approach not only saved construction cost and time, but it also allowed toroids to be put in places where they would not have otherwise fit.

Toroid modules were constructed around a vacuum pipe with an inserted ceramic gap that prevented a DC path for the beam-induced wall current from travelling inside the toroid (Figure 1). The toroid itself was placed over this pipe before the end flanges were welded on. A tight fitting aluminum shroud was placed over the toroid assembly to provide a low impedance path for the wall current. Eight turns of wire on the toroid gave reasonable signal amplitudes for our beam currents. This wire was then brought out for detection through Twinax cable. A second, one turn, winding was also put on the toroid for calibration purposes. Although the toroid assemblies were made as compact as possible, the toroid does not have to be directly over the ceramic gap in order to work. As long as the toroid is within the shroud assembly, it functions properly. In one place where space was very tight, we even installed a toroid by first sawing it in two, grinding the faces to insure a smooth fit, and then mechanically joining the two halves around the ceramic gap.

Toroid electrical performance was also very good. Standard commercial magnetics are available with frequency response better than 500 MHz. Since our cables will not pass any greater frequency over the distance between the

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†Now at Argonne National Lab

‡Now at TRIUMF

§Now at SLAC

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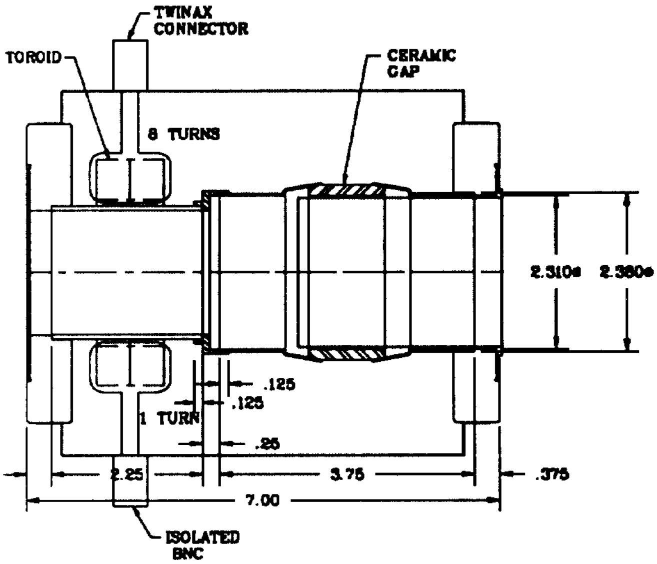

Figure 1
Booster toroid

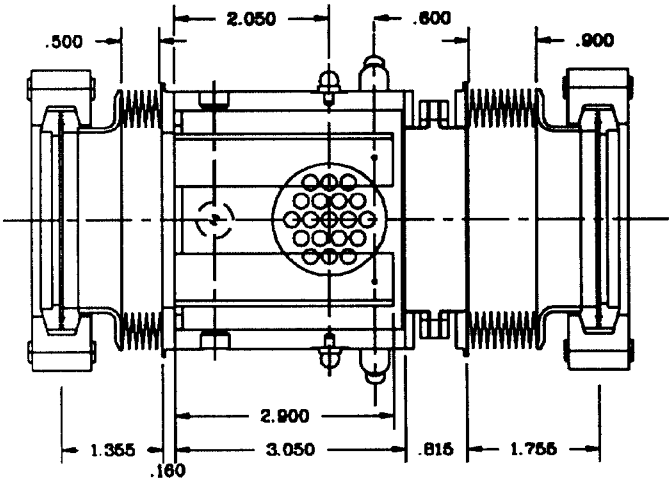

Figure 2
BPM

toroids and the measuring devices, these magnetics were acceptable. A toroid at the exit of the chopper enables us to see, to the resolution of our oscilloscopes, the number of bunches passing through the chopper. Because the toroids perform so well, we chose to use a toroid instead of developing a resistive wall current monitor in the linac. The basic instrument used for looking at these and other fast signals in the ring is a high bandwidth, image intensified oscilloscope, one that enables us to see these fast signals at a 10 Hz repetition rate.

IV. Insertable Screens

Insertable phosphor screens are used throughout the injector, providing valuable information on position and structure of the beam. All screens downstream of the chopper need no special cooling or construction since they see only very low beam currents. The screen which intercepts the largest current, that in the alpha magnet, is made of a more durable material so that it could be attached to a water cooled copper bar that also serves as a Faraday cup.

The screens are routinely used for position information during injection into SPEAR. Standard cameras are positioned outside viewports and bring the image spot back to the control center. Spot position aids beam steering; spot structure aids focusing. Spot intensity is a general machine diagnostic. Machine physics also uses these screens. Energy dispersion and beam emittance can be calculated from measured spot sizes. Quantitative measurements like these are made by analyzing the digitized outputs of an oscilloscope that outputs a standard video raster scan.

V. Beam Position Monitors (BPMs)

Our largest diagnostic system is the beam position measuring system. We greatly benefited from expert consultation from SLAC on the design of the BPMs. Forty modules in the booster ring and twelve in the transport lines provide position information everywhere in the accelerator. The original design called for button electrodes, but tests of prototype modules showed that a 20 dB improvement resulted from the use of shorted 50 Ω striplines in place of the buttons. Each BPM has four striplines 10 cm long, each subtending an azimuthal angle of $\pi/4$ (Figure 2). Even when we have only 10^8 electrons per bunch, the BPM signal is still about 15 mV after travelling through 100 m of RG223 signal cable. With our low normal current, this improvement is very important to maintaining a reasonable SNR for our beam position measuring system [3]. In fact, the BPMs are most valuable in the early stages of commissioning when the beam current is only a fraction of its final operating value. Without the added signal the striplines provide, the BPMs would have been useless during this time. The four striplines in each module allow us to measure both x and y position at each BPM. These modules are oriented azimuthally so that the striplines straddle the horizontal plane of the beam. This minimizes the synchrotron radiation received by any electrode. The BPM positional sensitivity has been measured to be about .6 dB/mm.

The fabrication of the modules was also crucial to their success. For cost reasons, the BPM is a welded assembly, not machined from a single piece of metal. The striplines are made from sectors of a machined tube with an inner diameter of 6 cm. Careful construction techniques and good quality control held the shape and position of the striplines to .1 mm after assembly. The center conductors of 50 Ω ceramic feedthroughs were welded to the striplines to insure a good electrical connection. Electrical center was tested on a fixture that was repeatable to .02 mm. A machined mounting bracket positions the BPMs to an accuracy of .1 mm with respect to the girder. After all tolerances are accounted for, the BPMs are aligned to within .5 mm of the neighboring quadrupoles.

The instrument module also serves as a vacuum pump out port to which a 20 l/sec ion pump may be attached. Good vacuum practice requires a large orifice for the port, while good electrical practice requires an electrically continuous wall for the image current. The compromise that was reached was a circular sieve-like hole pattern for the orifice. Bench tests showed no noticeable degradation of the electrical signal from these ports.

VI. Q Meter

The Q meter is a large, cylindrically symmetric capacitor that converts image current from the beam to a voltage that can be monitored (Figure 3). Because of its cylindrical

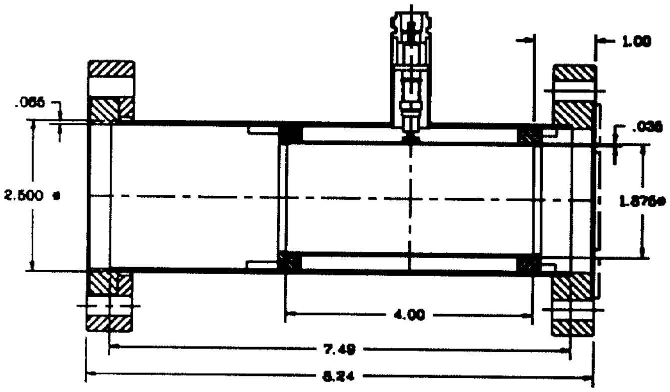

Figure 3
Q Meter

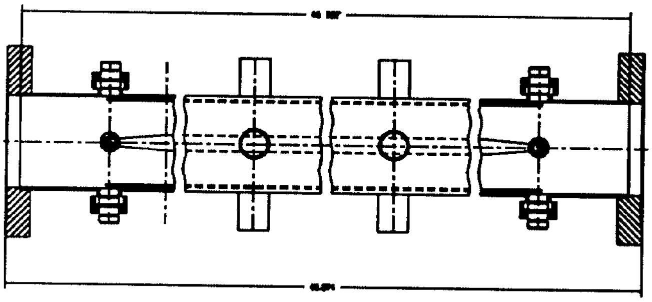

Figure 4
Stripline

symmetry, the Q Meter output is independent of beam position through first order. Its capacitance is about 40 pF, so its frequency response is more than adequate for our needs. The signal from the Q Meter gives the main diagnostic signal for the booster. Displayed on a high bandwidth, image intensified scope, this signal shows the instantaneous current in the booster. The quadrupole tracking supplies are adjusted so as to minimize the step losses from this signal. Since the magnitude of this signal, combined with the low loss cable that carries it to the control console, enables bunches of millions of electrons to be seen, the Q Meter was also very valuable in the early stages of commissioning.

VII. STRIPLINE

One of the by-products of replacing the SLAC to SPEAR injection line was the acquisition of two, one meter striplines units (Figure 4). These units each have four 50 Ω striplines with connections on both ends of each line. We have currently installed one of these units in our booster. Although its signal is comparable to that of the Q Meter, its design gives it great value in allowing us to measure the tunes of the system. This unit is mounted so, like the BPMs, its striplines straddle the horizontal plane. By driving a pair of diagonally opposed striplines with a few watts of power near the tune frequencies, we can excite both the horizontal and vertical tunes of the beam. This is a much less invasive technique than exciting the tunes with large impulses from a kicker, for example. With this technique, one can observe the tunes without dramatically changing the stability or character of the beam. The unused striplines of this unit can then be used to observe the tunes. Coupling between striplines is less than 40 dB, so that the signal due to the beam can be clearly observed. Using a crude, homemade AM detector and a very nice spectrum analyzer that updates at audio rates, we were able to easily measure the tunes and use that information to set them at the design value. A future development project for the injector, using these striplines, is the implementation of a tune feedback system. This system will control the quadrupole supplies that control the tunes, keeping the tunes at the desired value. This system has already undergone preliminary tests at SPEAR.

VIII. CONCLUSION

The diagnostic instrumentation that was designed and installed at the SSRL injector has proved more than adequate to commission and run the machine. Careful testing of critical components to insure maximum signal output of these devices insured their usefulness and aided in the successful commissioning of the accelerator.

IX. REFERENCES

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