DIAGNOSTICS FOR PHYSICS APPLICATIONS AT SPEAR3*

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Abstract

The SPEAR3 light source at SSRL was commissioned in 2004. Since that time the machine has undergone a continual program of improvements that has led to a lowering of the ring emittance, improved injection efficiencies, and the development of specialized operational modes. The effective use of beam diagnostics enabled these improvements to be tested and verified prior to their implementation. To optimize injection we needed to measure the beam position, size, shape, and arrival time of our injected bunch as well as beam losses in the ring. To test new lattices we used these diagnostics to characterize the non-linear resonances in the ring and therefore find operating points that maximized beam stability and lifetime. In this paper we discuss the electrical and optical instruments as well as the experimental methods we used to make these measurements.

INTRODUCTION

Machine studies are done at SPEAR3, as they are done at all machines, to learn about the properties of the ring, both for improving the machine performance and for basic research into the physics of accelerators. Diagnostics are crucial to measure these properties. Our production operational instruments are very effective in measuring static lattice parameters, but we use specialized electronic beam position monitors (BPMs) and fast gated optics to measure dynamic parameters. With the BPMs we can accurately measure the longitudinal and transverse beam centroid parameters for currents ranging from that of a single injected bunch to that of our normal fill. The optical monitors allow us to measure, at a lower precision, the higher moments of the distribution.

In this paper we will give some examples of these measurements and the experiments which they supported. One important example was a study that needed to measure the skew coupling of a septum magnet in order to design a corrector that would reduce the vertical motion of the beam during injection. Another was the use of the instrumentation to properly tune up all phase space parameters of our injection. These diagnostics are also used in coupling experiments to probe the lattice for resonances. And they are used for general diagnostics, such as measuring the amplitude of the longitudinal beam motion, an especially important parameter in our "low α", or short bunch, operational mode.

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MACHINE PARAMETERS

SPEAR3 is a $3\,\mathrm{GeV}$ electron storage ring that operates at currents up to $500\,\mathrm{mA}$. It is $234\,\mathrm{m}$ in circumference giving a revolution frequency of $1.28\,\mathrm{MHz}$. Its harmonic number is 372 so that its radio frequency (RF) is $476\,\mathrm{MHz}$. Beam is injected into SPEAR3 from a cycling injector. One bunch, of about $80\,\mathrm{pC}$, corresponding to $100\,\mathrm{A}$ in the SPEAR3 ring, is injected in each $100\,\mathrm{ms}$ cycle.

DIAGNOSTICS

BPM Electronics

The BPM electronics used for the dynamics mixes the BPM signal from $476\,\mathrm{MHz}$ down to an intermediate frequency (IF) at a revolution harmonic of about $16.6\,\mathrm{MHz}$. The IF is digitized and digitally filtered to give turn by turn information of the signal amplitude and phase [1].

Optical Diagnostics

We use two types of fast optical diagnostics. A streak camera is used to measure longitudinal bunch structure. A fast gated camera, that can be apertured down to $2\,\mathrm{ns}$, is used to measure the transverse structure. Programmable triggers, synchronous to the injected beam, are provided to the cameras to allow them to sample the periodically injected pulses at different delays with respect to the injection time [2].

INJECTION TUNING

Goal

Efficient injection involves the optimization of a number of beam parameters [3]. The transported beam needs to have the correct trajectory in order to place the injected beam onto the correct trajectory in the storage beam. The trajectory is optimized by measuring the oscillations of the injected beam. But in general the injected beam is just a small fraction of the entire beam. It is therefore important to minimize the oscillation amplitude of the stored beam when the injection kickers fire. And it is important to ensure that the horizontal motion induced by the kicker does not couple into vertical beam motion. We used our BPM electronics to measure and optimize our injection configuration.

To maximize injection capture, the injected beam needs to "match" the stored beam lattice as closely as possible. This means that the injected beam energy must be matched to the ring energy, the arrival time of the injected bunch must place it in the center of one of the RF "buckets" of the ring, and the transverse shape of the injected beam must match that of the stored beam at injection.

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Minimizing Vertical Injection Coupling

We used the BPMs to measure the vertical oscillations due to the injection kickers. The kickers are designed to only give a horizontal displacement to the beam. But our injection septum had skew magnetic fields that coupled the horizontal motion of the displaced stored beam into vertical motion. In order to properly design a compensating static multipole magnet, we first needed to measure the coupling.

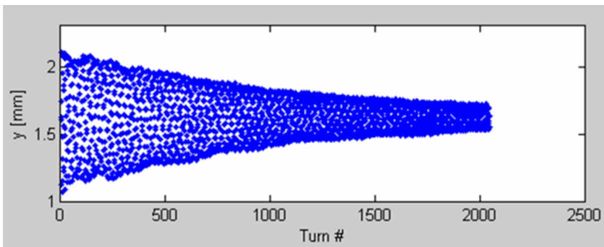

Figure 1: Vertical oscillation amplitudes of stored beam during injection before compensation.

Figure 1 shows the vertical amplitude of the stored beam, about 1 mm peak to peak, before the compenating magnet was installed; Fig. 2 shows that the compenstion magnet reduced the vertical oscillation by an order of magnitude.

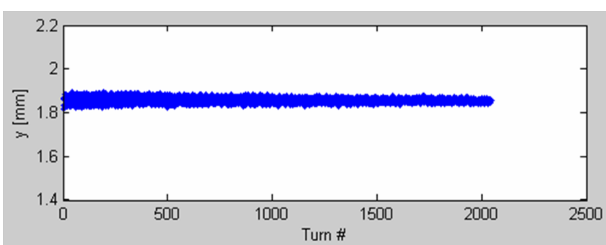

Figure 2: Vertical oscillations after compensation.

Transverse Matching of Injected Beam

The phase space distribution of the injected beam is determined by the lattice paramters of the booster and the transport line. The trajectories of the particles in the injected bunch, once they enter the storage ring, are determined by the SPEAR3 beta functions; the phase space distribution out of the transport line gives the initial conditions for these trajectories. In order to match the initial conditions with the beta functions we took 2 ns gated images of successive injected bunches, delaying the camera trigger for each bunch. Figure 3 is an array of images that shows the quadrupole oscillations of the horizontal beam distribution, the result of a mismatched injected beam.

Longitudinal Matching of Injected Beam

The longitudinal phase space variables of a stored beam are its energy and phase. They are conjugate to each other; for small amplitude oscillations these two signals are in

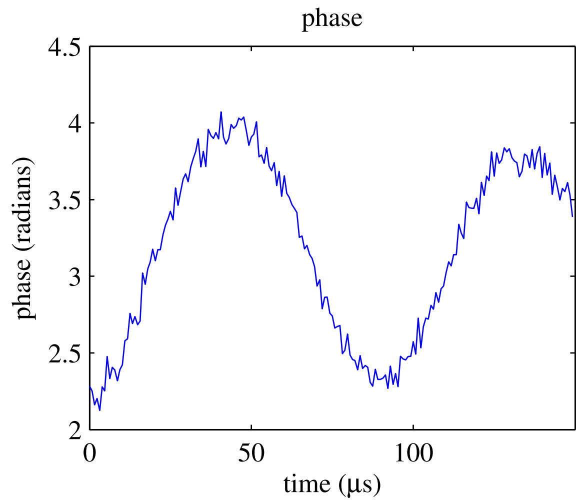

Figure 4: Injected beam with phase error.

quadrature. One can characterize the longitudinal mismatch of the injected beam by its synchrotron oscillation amplitude. If a beam is injected on energy and timed to arrive in the center of the bucket, it arrives on the fixed point of the synchrotron phase space and its oscillation amplitude will be zero.

One can also determine the cause of the mismatch by determining the initial phase of the oscillation. If only the injected energy is in error, the arrival time is correct and the phase oscillation is sine-like. Its amplitude starts from zero and oscillates. If the energy is correct but the arrival time is in error, the oscillation is cosine-like; it starts with a maximum phase offset and oscillates. Figures 4 and 5

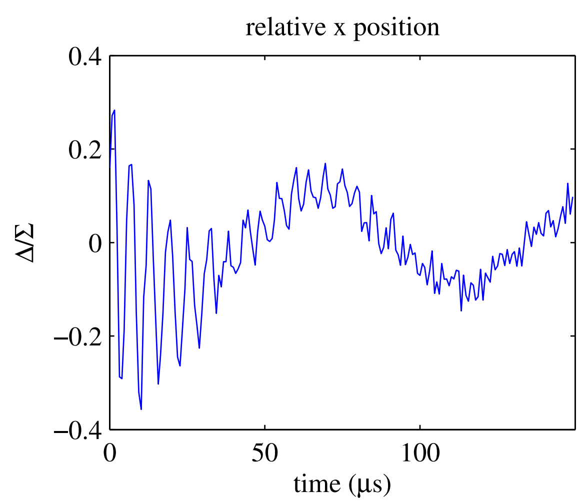

Figure 5: Transverse oscillation of injected beam.

plot the phase and horizontal position, respectively, of a mismatched injected beam. The phase in Fig. 4 is cosine-like, indicating an injection phase error. This error appears

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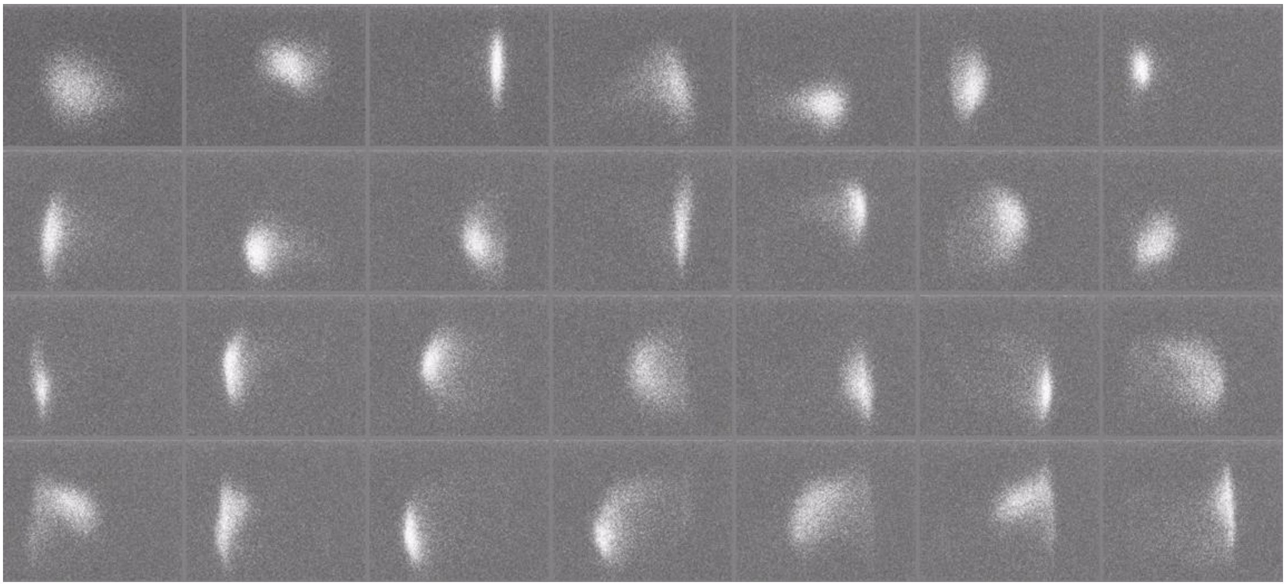

Figure 3: Sequence of photos of mismatched injected single bunch.

on the horizontal position because the BPM is located in a dispersive region. Note that the signals in the two figures are, as expected, in quadrature. The fast motion in Fig 5 is the expected horizontal betatron oscillations due to the kicker acting on the injected beam.

The resolution of the measurement is limited by the low current of the injected bunch, about $50\,\mu\mathrm{m}$ for this measurement. Sixteen successive acquisitions were taken and averaged to quadruple the signal to noise ratio and obtain the required resolution. Our electronics can obtain this accurate phase measurement because we process at an IF that improves our phase sensitivity by almost a factor of thirty.

LONGITUDINAL BEAM STABILITY

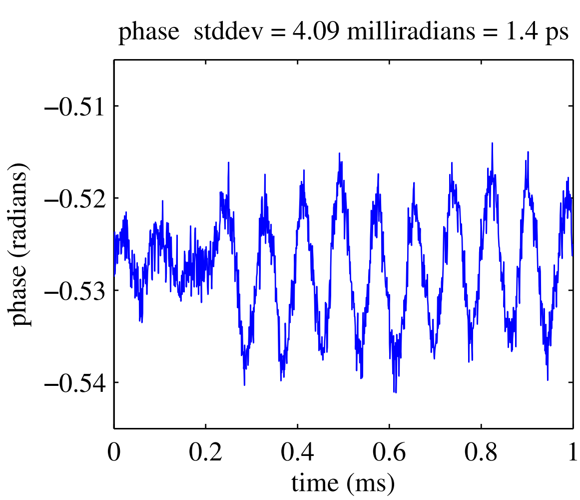

Figure 6: Phase oscillations of beam

SPEAR3 has introduced a "low α" mode of operation for some of the user run. In this mode, SPEAR3 runs with a different lattice in which the longitudinal RMS bunch length is less than $4\,\mathrm{ps}$, compared with $17\,\mathrm{ps}$ in the standard operational mode For low α mode the stability of the RF system must be sufficient to ensure that the longitudinal motion is negligible with respect to the bunch length. Figure 6 shows a typical measurement of the BPM phase. The oscillations are caused by the transients from the SCR firing in the klystron power supply. The feedback gain in the RF system is increased to reduce this oscillation amplitude.

CONCLUSION

HIgh resolution BPM electronics allow precise measurements of dynamic beam parameters, in all three planes of motion. Fast optical diagnostics enable us to measure details of the internal structure of the bunches. These tools are extremely valuable in the machine physics studies required to continually learn about and improve the performance of SPEAR3.

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