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FIRST BEAM-COMMISSIONING RESULTS FROM THE PEP-II *B*–FACTORY HIGH ENERGY RING: BEAM OPTICS.*

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ABSTRACT

Construction of the PEP-II *B*–Factory High Energy Ring has been recently completed at SLAC. In two beam commissioning periods, stored beams of up to 300 mA intensity have been achieved with good beam lifetimes. The Ring hardware systems have worked very well and in general are performing to the specifications. All beam diagnostics systems are working. Three of five rf stations have been run, which is sufficient to support beam currents in excess of 500 mA. By mid-October 1997 the Ring has accumulated 20 Ah of stored beam intensity and the vacuum system has cleaned up (due to synchrotron-radiation "scrubbing") according to plan.

1 Introduction

The High Energy Ring (HER) of the PEP-II *B*–Factory is a 9 GeV electron storage ring designed for 1 A circulating beam current in 1656 bunches with the option of upgrading to 3 A in the future. The HER [1)] has been under construction in the existing PEP Tunnel at SLAC since early 1994. It is complemented by the 3.1 GeV, 2.1 A Low Energy Ring (LER) for positrons presently being installed in the same tunnel and by the BaBar detector scheduled to roll in early in 1999.

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Construction of the HER was completed at the end of May 1997. In March 1997, a sector test with beam was performed taking the beam from the injection point to a temporary beam dump at the beginning of IR 2 (the detector region). This test confirmed correct operation of the magnet system and allowed us to commission and calibrate the BPM system using the injecting beam. Corrector-response measurements (R_{12} and R_{34}) verified the Ring optics in the sectors tested and the injection kicker was timed in and calibrated.

During the course of a 4-week commissioning run in June beam was stored and the life time was increased to ≈ 10 h at low intensities. Two rf stations were used at that time. Both the transverse and the longitudinal feedback systems began commissioning. Towards the end of the run, maximum beam intensities of 60 mA were reached. In a second, 6-week long run in September and October 1997 one more rf station was brought on line and commissioning of the various low-level rf loops was begun in earnest. Both transverse and longitudinal beam feedbacks were put in operation and the synchrotron light monitor (SLM) was commissioned. [2]

2 Accelerator Systems

2.1 Magnet system

During construction, the quadrupoles were sorted to minimize deviations within each magnet family and the dipoles were sorted into three groups by their BL/I value and placed in a specific pattern to minimize orbit excursions. During early beam commissioning we found the machine orbit (Fig. 1) to be well centered even when using only a small fraction of the available correctors. The lattice functions showed some deviations from the design, this was traced to a 0.5% error in the calibration of the insertion quadrupoles (see Fig. 2).

2.2 Vacuum System

The vacuum system uses both discrete and distributed ion getter pumps in the arcs of the Ring, discrete pumps of a larger capacity in the straight sections where—due to lack of synchrotron radiation—there is less outgassing from the walls. The performance of the system has been as expected and pressure levels and lifetimes are consistent with the design parameters as set out in the original design report. [3]

2.3 Rf System

The HER has a 476 MHz rf system with five stations, each having four cavities and powered by a single 1.2 MW klystron. [4] Three stations were operational during the September-October run, although at times we ran with only two stations. The rf cavities not actively running were “parked” by moving their resonant frequency to a value in between the 2^{nd} and 3^{rd} orbit harmonic of the beam, thus avoiding strong coupling of the fundamental frequency to the beam. The rf stations were run at 3.2 MV each for most of the running time, compared to 2.8 MV/station nominally.

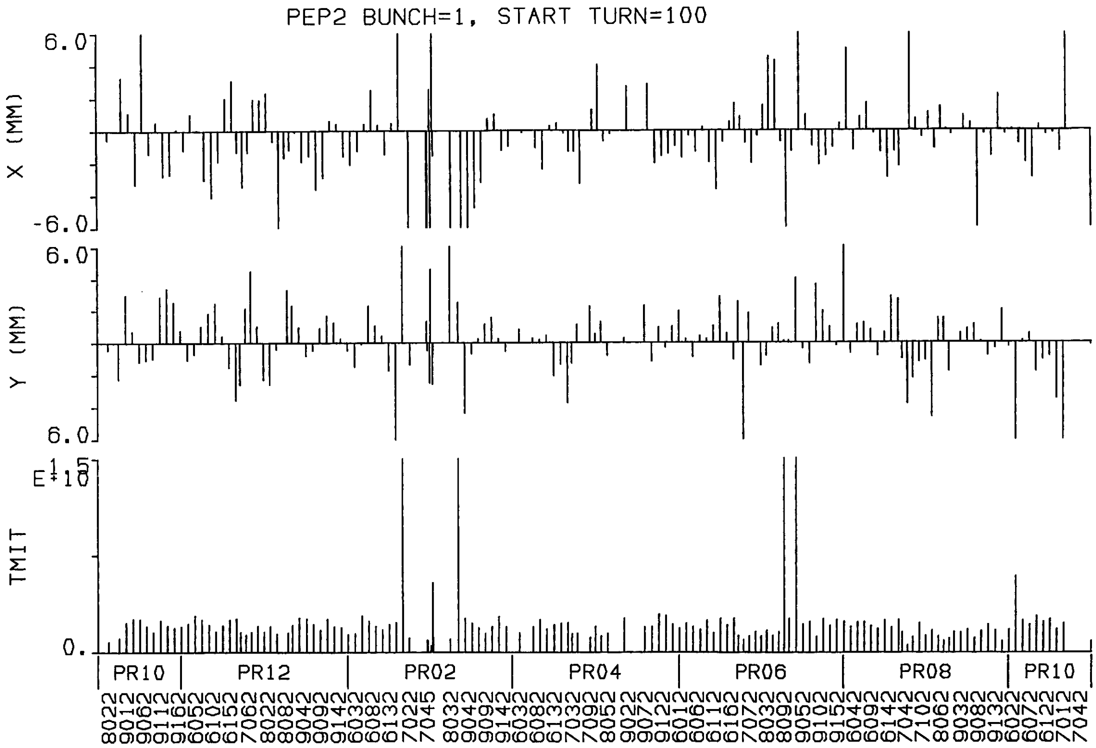

Figure 1: *Typical closed orbit in the High Energy Ring*

During early running, the rf system was operated essentially open-loop with only the tuner loop operating. Commutating noise on the 90 kV klystron power supply caused a noticeable amplitude and phase ripple on the rf voltage, which was detectable in the longitudinal spectrum of the beam. In the course of commissioning, the phase-stabilizing dc loop around the klystron as well as the fast, direct rf feedback loop were brought into action, noticeably reducing the amount of noise injected into the beam. An "ac" ripple loop—a filtered loop with high loop gain at specific strong lines in the spectrum of the rf voltage—was put into operation as well but turned out to require more commissioning effort in later runs.

2.4 Beam Diagnostics

2.4.1 BPM system

About 300 single-turn beam position monitors (BPM) are used to diagnose beam orbits and transverse motion. They have the capability of recording up to 1024 turns consecutively or spaced several turns apart. Time resolution is about 20 ns (5 bunches). Initially, electronic noise limited resolution to about one mm; subsequent modifications to the DSP firmware reduced this noise to the point where the BPMs are almost meeting the design requirements, although further efforts are under way to eliminate this problem completely.

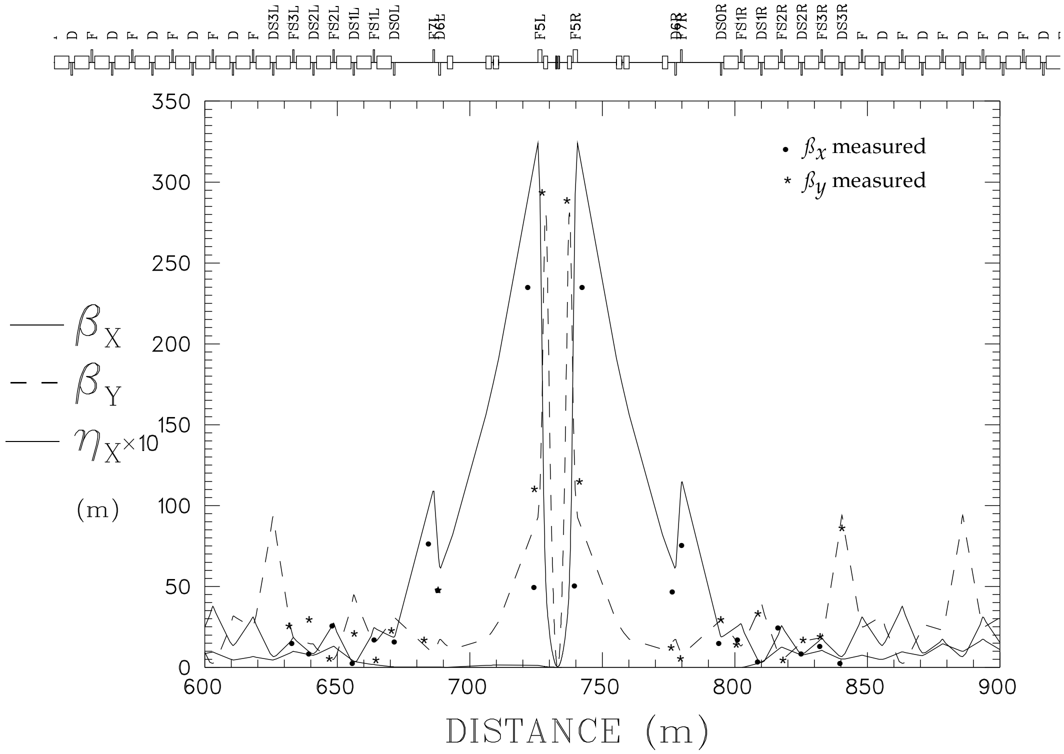

Figure 2: *Lattice functions in IR 2 and adjacent arc regions*

2.4.2 Synchrotron light monitor

The synchrotron light monitor (SLM) captures light from a dipole in the middle of Arc 7 and guides it onto an optical bench underneath the dipole where the optics and TV cameras are located to align the system and observe the beam spot. 60-Hz TV frames are being read out to the site-wide TV distribution and also to a digitizer connected to the control system.

Commissioning the SLM was straightforward, except for difficulties in focusing the beam image onto the camera. Subsequent investigations showed that the mirror was distorted, apparently during attachment of the cooling tubes. This currently limits our ability to assess the transverse size of the beam.

3 Optics and low-intensity studies

In the early days of beam commissioning, beam dynamics work focused on orbit determination and steering of the machine, especially in the Interaction Region, IR 2. The lattice functions (Fig. 2) were analysed both on-line using the traditional method of varying the quadrupole strengths as well as using the corrector-response matrix method. [5] There is a clear deviation from the design values of the lattice functions at the insertion quadrupoles. The vertical beta functions also deviate significantly in the arc upstream of the interaction region. It should be noted that the lattice configuration used during these runs had "relaxed" peak beta values of about 1/2 of the design values. Dispersion (Fig. 3) was well controlled. The natural chromaticity was found to be (-34,-39) in reasonable

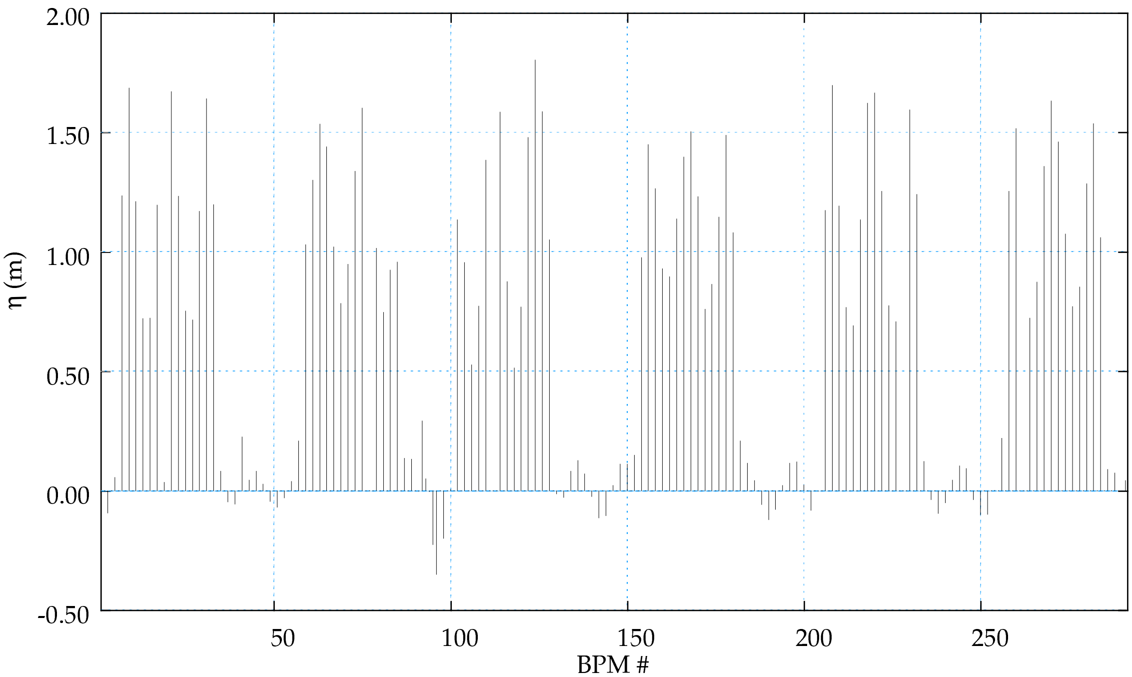

Figure 3: *Measured horizontal dispersion*

agreement with the design values of (-35,-41) for this lattice configuration. Measuring the chromaticity for various settings of the sextupoles we found an average offset of the orbit in the sextupoles of about one mm. Assuming that the sextupoles are not systematically misaligned, this would indicate an excess in length of the Ring of about 4 mm. This is consistent with a tendency of the horizontal orbit in the arcs to mostly deviate to the *inside* of the Ring.

Tune scans (Fig. 4) were performed that showed the expected betatron resonances. In particular, all nearby third-integer resonances were seen with some indication for the presence of higher-order resonances.

Machine coupling and the efficacy of the global skew quads were studied using the tune-crossing method and found to be as expected, with the machine coupling being about 5 % before decoupling and < 1% after empirical decoupling.

4 Summary

The HER has had two tremendously successfull beam commissioning runs, achieving almost one-third of the nominal beam current of 1 A. No major setbacks or technical problems have arisen so far. The maximum intensity reached to date can easily be explained by the state of the feedback and rf systems, both of which have made great progress dur-

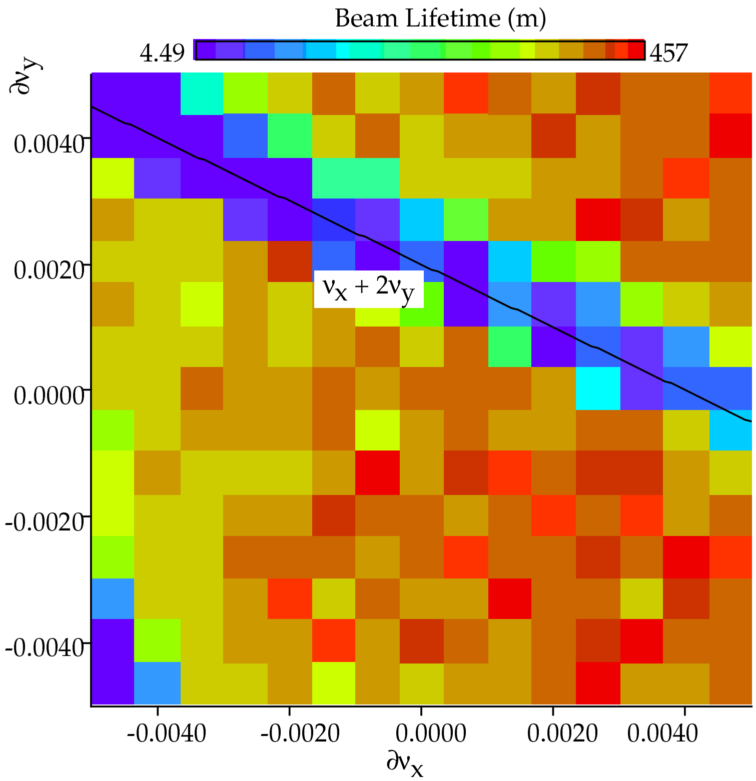

Figure 4: *Tunescan around* $(\nu_x, \nu_y) = (24.72, 23.62)$

ing these runs but are not yet fully commissioned. (As of this writing (Jan 98) the max. injected beam current was 0.75 A).

Acknowledgments

Successfull beam commissioning of the HER would have been impossible without the participation of the enthusiastic and capable operations staff and support staff of SLAC.

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