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BEAM COMMISSIONING OF THE PEP-II HIGH ENERGY RING[*]

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Abstract

The PEP-II High Energy Ring (HER), a 9 GeV electron storage ring, has been in commissioning since spring 1997. Initial beam commissioning activities focused on systems checkout and commissioning and on determining the behaviour of the machine systems at high beam currents. This phase culminated with the accumulation of 0.75 A of stored beam—sufficient to achieve design luminosity—in January 1998 after 3.5 months of beam time. Collisions with the 3 GeV positron beam of the Low Energy Ring (LER) were achieved in Summer of 1998. At high beam currents, collective instabilities have been seen. Since then, commissioning activities for the HER have shifted in focus towards characterization of the machine and a rigorous program to understand the machine and the beam dynamics is presently underway.

1 HER COMMISSIONING

The PEP-II [1] High Energy Ring (HER) was completed at SLAC in Spring of 1997. It is located in the PEP tunnel at SLAC, where it is part of the *B*-Factory together with the Low Energy Ring (LER) and the BABAR detector. Beam commissioning of the HER began in earnest in June 1997, and the ring reached 0.75 A of stored beam current—sufficient to achieve the design luminosity of 3×10^{33}— in January of 1998, after 3.5 mo. of running time. Parameters of the Ring are given in Reference [1]. Since July of 1998, HER commissioning work has focused on understanding and tuning of the beam parameters, background measurement and reduction, tuning of the beam feedback systems and understanding of the multi-bunch instabilities and supporting collisions [2] with the completed LER.

Table 1 gives an overview of the commissioning results achieved up to date.

Beam commissioning has been helped significantly by fairly good hardware performance: for the last run, hardware availability was 79% for the PEP-II facility, this includes HER, LER and the Injector.

In this report, we will not cover the rf system [3, 4] or the beam feedbacks [5, 6] since they are described elsewhere.

1.1 Magnet System and Lattice Functions

Alignment of the ring magnets appears to have been within the stated accuracy of 250μm (rms), judged by the ease with which the first turn was achieved and the rms corrector strength needed to reduce orbit excursions to a reasonable level. As of this writing, rms orbit excursions of 0.75 mm rms are routinely achieved. Figure 1 shows a plot of the lattice functions in the vertical plane, together with the design values, measured on-line by phase-advance analysis. The agreement is rather good, but to reach this level of agreement the inner insertion quadrupole had to be tweaked by

Table 1: HER Commissioning results

Parameter	**Unit**	**Design**	**Achieved**
Energy	GeV	9	$9 \rightarrow 9.1 \rightarrow 9$ (ramped)
Current	A	0.99[‡]	0.75
Luminosity	$\mathrm{cm}^{-2}\mathrm{s}^{-1}$	3×10^{33}	5×10^{32}
β_x^*	cm	50	50
β_y^*	cm	2	1.5
Bunch length	cm	1.15	1.15
$\delta p/p$	%	0.061	0.066
ϵ, horiz.	πnmr	48	56
ϵ, vertic.	πnmr	1.9	4
Coupling		0.03	0.0007
Life time	h	12	20 @ 50 mA 2.5 @ 0.75 A

[‡] for β_y^*=2 cm

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[*] Supported by US DOE under contract DE-AC-76SF00515

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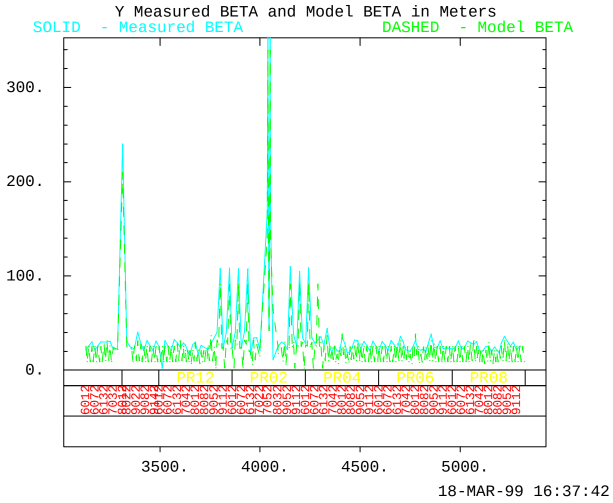

Figure 1: Measured vertical lattice functions

about 0.13%. The amount of correction needed has varied for different lattice configurations and is now thought to arise from a longitudinal position error rather than a calibration error. [7] There are still differences in the details of the lattice functions that remain to be understood.

1.2 Vacuum System

Until early 1998 the vacuum system of the HER has cleaned up according to the schedule outlined in the PEP-II CDR [8], see Fig. 2. With the installation of the final interaction region, beam life times have slid back somewhat due to the extensive vacuum work and the large number of new chambers installed. In the Fall of 1998, however, beam life time recovered and up to 24 h were measured at low beam current.

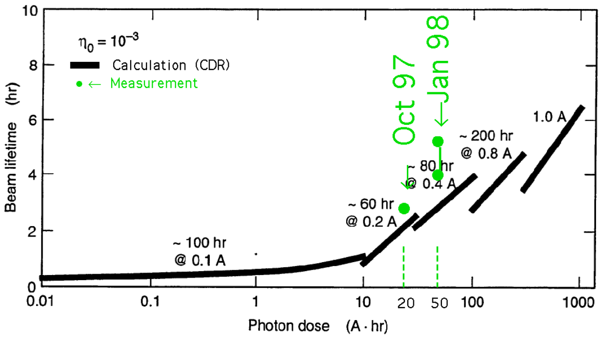

Figure 2: Beam life time *vs* photon dose

In general, the HER has not experienced significant dust trapping. However, in our last run we have seen occasional life-time reductions, mainly at beam currents below 200 mA, which sometimes could only be cured by aborting the beam and reinjecting. Without a systematic study it is not possible to give a cause for this behaviour.

On the other hand, at high residual pressures the beam has been clearly less stable than under good vacuum conditions. Also, the presence of a gap (usually 10%) in the fill is mandatory at high intensity to preserve beam stability. This strongly suggests the presence of ion trapping. The measurement of fill-pattern dependent ion-clearing currents further supports this assertion.

1.3 Transverse Beam Dynamics

Machine resonances have been measured by systematic scans of beam life time *vs* tune and by following an off-axis injected bunch over 1024 turns and Fourier-analysing the result. Identified lines are indicated in Fig. 3.

Transverse beam size has been measured by performing scraping experiments using beam scrapers installed in one of the straight sections. Horizontally, the beam size is within 10% of the prediction, but vertically the results indicate almost twice the beam size predicted. This is to be considered an upper limit, since the measurement of the small vertical extent of the beam by scraping is difficult. There also is evidence for vertical tails.

1.4 Longitudinal Beam Dynamics

Once the rf stations were phased w.r.t. each other, the synchrotron tune was measured at the design value (0.0446 at 14 MV). Beam life time was measured against rf voltage, the result indicates a momentum spread of 0.066% (rms), about 8% larger than the expected 0.0614%. Bunch length was measured using a streak camera and agrees with the predicted σ_l of 1.15 cm at 14 MV.

1.5 Single-Bunch Intensity Related Effects

Tune shift *vs* beam current relates to the broadband impedance in the ring (which is inductive) and was measured several times. The measured tune shifts have increased slightly over time, this is attributed to the changes in the vacuum system made during the various down

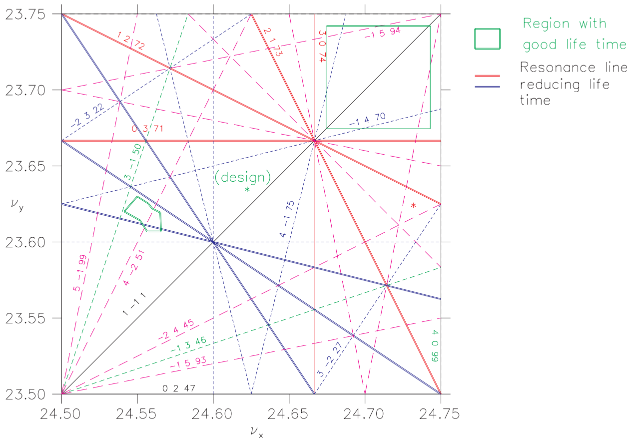

Figure 3: Working diagram of the HER; dark lines reduce beam life time

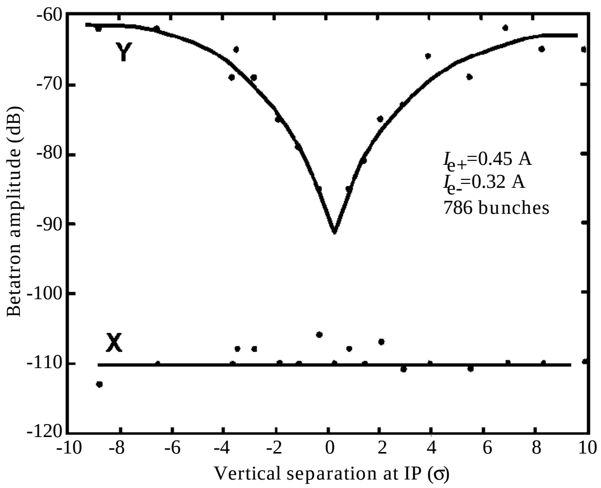

Figure 4: Betatron motion *vs* beam separation

times. In the present configuration the tune shifts are -0.56×10^{-3}/mA horizontally and 1×10^{-3}/mA vertically. The resulting impedance of $>$ 100 nH is larger than predicted by a factor of about 2. However, the max. single-bunch current is limited not by beam dynamics but by hardware considerations and so this is of no consequence. Bunch lengthening up to 2.5 mA bunch current was found to be consistent with potential-well distortion, with no indication for the onset of turbulence.

Excess heating of the shielded bellows close to the beam scrapers was seen and indicates excitation of a localized wakefield. This excitation arises from the step transitions that these experimental scrapers introduce in the vacuum system. These scrapers will be replaced with tapered collimators in the near future.

1.6 Multi-Bunch Effects

Longitudinal Plane Based on the measured HOM spectrum of the rf cavities (which are very well damped) the HER was expected to be stable up to 330 mA, with the longitudinal bunch-to-bunch feedback system designed to be able to stabilise the beam well beyond 1 A current. Grow-damp measurements were carried out demonstrating that the first modes going unstable were a cluster around mode 750…800, with a threshold around 550 mA. The modes agree in frequency with a measured cavity resonance[4]. The increased threshold is thought to arise from the Landau damping introduced by the sizeable synchrotron-tune shift along the fill (due to the 10% ion-clearing gap).

Transverse plane Instability thresholds have been unexpectedly low in both planes in the HER. Even at low beam current coherent bunch motion is detectable. The modal spectrum shows predominantly low-order modes, with indication of a shift from mode 0→1→2…with increasing beam intensity. The instability shows grossly nonlinear growth rates, saturating before the beam is lost unless the beam intensity is several hundred mA. This behaviour is consistent with trapping of heavier ions like CO. However, in a recent run a strong dependence of the growth rate on a vertical orbit wave at a certain phase was observed, which would indicate the presence of a local high-Q impedance.

Bunch-train experiments have shown the instability to be dependent on chromaticity (above $\xi \approx +10$ the beam was markedly less unstable) and on coupling (a fully coupled “round” beam could have about 50% more intensity for the same level of beam motion). These observations were *not* confirmed for even fills with a small gap, indicating that the bunch-train behaves in a way qualitatively different from the even fills.

Improved beam stability was observed during collisions, most likely due to increased Landau damping. A quantitative measure of this effect is the reduction in height of the betatron peak when the HER beam is brought into collision with the LER beam; this is shown in Fig. 4. The damping due to this effect exceeds that obtained from the bunch-to-bunch feedback system.

2 SUMMARY

Beam commissioning of the HER has progressed well, with most of the important commissioning milestones met or exceeded. Multibunch beam operation, however, has uncovered a transverse instability the cause and exact nature of which still remains to be explained. While the excited modes and nonlinear behaviour are consistent with ion trapping, the orbit dependence is not. Preliminary indication from our collision runs is that the Landau damping due to the beam-beam effect will greatly increase the transverse instability threshold, however.

3 REFERENCES

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