HOM SENSITIVITY IN THE PEP-II HER VACUUM CHAMBER*

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Abstract

Synchrotron radiation is the main source of vacuum chamber heating in the PEP-II storage ring collider. This heating is reduced substantially as lattice energy is lowered. Energy scans over Υ energy states were performed by varying the high energy ring (HER) lattice energy at constant gap voltage and frequency. We observed unexpected temperature rise at particular locations when HER lattice energy was lowered from 8.6 GeV ($\Upsilon(3S)$) to 8.0 GeV ($\Upsilon(2S)$) while most other temperatures decreased. Bunch length measurements reveal a shorter bunch at the lower energy. The shortened bunch overheated a beam position monitoring electrode causing a vacuum breach. We explain the unexpected heating as a consequence of increased higher order mode (HOM) power generated by a shortened bunch. In this case, temperature rise helps to identify HOM sources and HOM sensitive vacuum chamber elements. Reduction of gap voltage helps to reduce this unexpected heating.

INTRODUCTION

The SLAC PEP-II asymmetric B-factory storage ring collider nominally collides 1700 bunches of 3.0 A of 3 GeV positrons on 1.75 A of 9 GeV electrons consisting of a low energy positron storage ring (LER) situated above a high energy electron storage ring (HER). The rings intersect at an interaction point (IP) within the BaBar detector sustaining a luminosity of $1.2\times10^{34}\text{cm}^{-2}\text{s}^{-1}$at the $\Upsilon(4S)$ resonance. The last PEP-II run concluded with an energy scan spanning several of the Υ energy states in which the HER energy was varied from 8 to 10 GeV. The energy scan was implemented entirely through varying HER magnet strengths. While transitioning to a lower energy at the 2S resonance (HER energy 8 GeV) from a higher energy 3S resonance (HER energy 8.6 GeV), a vacuum breach occurred caused by an overheated beam position monitoring (BPM) electrode at 1500 mA of beam current. The origin of the heating is determined to be increased higher order mode (HOM) power caused by a shortened bunch. The bunch length change is a consequence of the energy change with constant RF gap voltage and frequency.

Subsequently, the RF gap voltage was reduced by 15% from 16.5 to 14 MV in order to lengthen the bunch and prevent excessive HOM heating, allowing 2S runs to continue at nominal currents.

A history of some relevant parameters are shown in figure 1. The upper plot is a time history of HER lattice energy

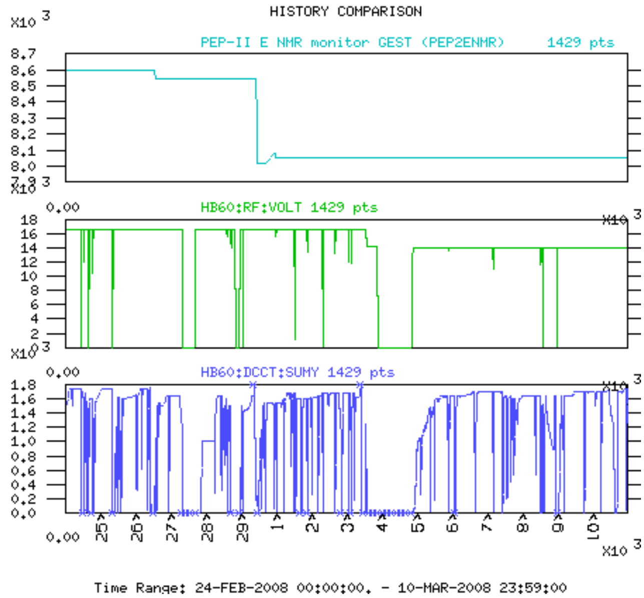

Figure 1: Energy, RF gap voltage and beam current during 3S to 2S transition. Energy (top plot) in MeV is calculated from HER magnet strengths. Middle plot shows the RF gap voltage remained at 16.5 MV until three days after the energy change. Bottom plot shows beam currents maintained at 1700 milli-amperes.

derived from measurements of magnet strengths from Feb 24 through March 10 of 2008. The middle plots shows that the total HER RF gap voltage at 16.5 MV was not changed until three days later. Thus, for three days HER was run with a shorter bunch length at more or less constant current. The current is shown in the bottom plot. The vacuum breach occurred during this period on March 3. Repair took about one day and HER was restored to nominal 1700 mA current but at a lower 14 MV gap voltage.

SYNCHROTRON ENERGY LOSS

Synchrotron energy loss can be measured from RF balance [2]. The RF energy contribution to the beam is determined from forward and reflected energy measurements at the RF cavities. The beam loses this energy in the form of synchrotron radiation and HOMs. Figure 2 shows that as a function of beam energy the synchrotron radiation energy loss obtained in this way fits the expected 4th power dependence.

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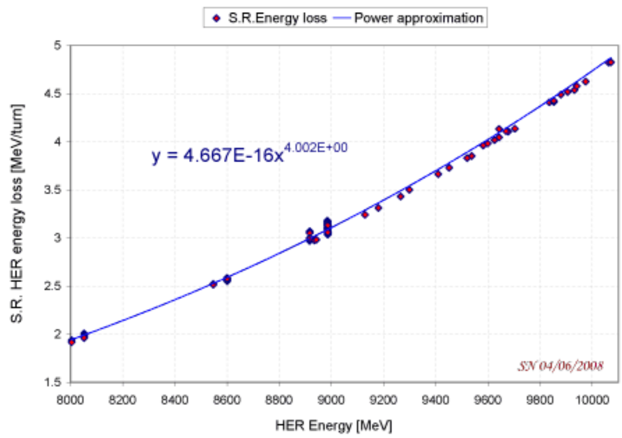

Figure 2: Synchrotron energy loss per turn determined from RF ballance at several beam energies for a current of 1700 mA and 16.5 MV RF gap voltage.

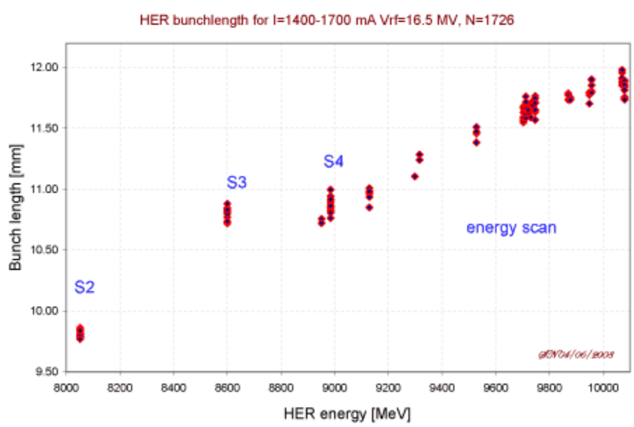

Figure 3: HER bunch length vs HER lattice energy derived from measured BPM spectra at constant RF gap voltage of 16.5 MV at currents of 1400-1700 mA.

HER BUNCH LENGTH MEASUREMENTS

Bunch length is measured the from the spectrum of BPM electrode beam signals[1]. Measurements performed for several HER lattice energies at constant 16.5 MV RF gap voltage and currents of 1400-1700 mA are shown in figure 3. Bunch length decreases more or less linearly with HER lattice energy. HOM power heating is then expected to increase with lower energy.

Measurements of bunch length were performed during the time period of the 3S to 2S energy transition and during subsequent running at the 2S lattice energy at a lower gap voltage. Figure 4 displays bunch length vs bunch charge for these configurations. The bunch current at 1700 mA of HER current is about 1 mA. At a constant 16.5 MV gap voltage, the 3S to 2S transition dropped the bunch length from 10.8 to 9.8 mm. To mitigate associated HOM effects, the gap voltage is lowered from 16.5 to 14 MV in the 2S lattice configuration, lengthening the bunch to 10.6 mm.

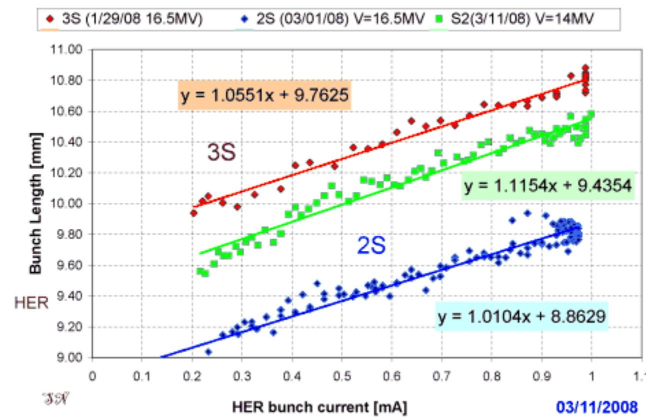

Figure 4: HER bunch length vs bunch current at various HER lattice energies as determined from BPM spectra. The red and blue data points represent respectively the bunch lengths at the 3S (8.6 GeV) and 2S (8 GeV) HER lattice energies at constant 16.5 MV gap voltage. The green data points show bunch lengths at the 2S (8 GeV) HER lattice energy with a lower gap voltage of 14 MV.

HOM HEATING IN HER

We observe HOM heating in pump chambers, in bellows, and gaps formed between vacuum flanges. Wake fields are known to penetrate bellows through shield fingers. Pump chambers are infiltrated through pump screen apertures[4]. BPMs have a known impedance at 7 GHz [5]. Temperatures of pump chambers, bellows and flanges are monitored during the energy scan. HER BPMs, however, were not instrumented with temperature monitoring.

The variation in bunch length served as a means of identifying HOM sensitive components in the HER vacuum chamber. Since synchrotron radiation heating is expected to decrease at the lower 2S energy, HOMs from a shorter bunch are the only other source of heating. A temperature increase in this case signals HOM activity.

Figure 5 shows temperatures for affected bellows and quadrupole pump chambers as a function of time during the period February 24 to March 10, 2008 (upper 3 plots). The bellows with the largest temperature excursions are located adjacent to RF cavities. The period of elevated temperatures occurred during three days marked by low beam energy (8 GeV) and high gap voltage (16.5 MV). After repair of the damaged BPM, beam is recovered and running continues at 8 GeV beam energy but with a lower RF gap voltage (14 MV) from March 5-10. Temperatures during this time period returned to the levels typical of the previous higher energy 3S running. Since the energy and beam current were not changed, synchrotron radiation has no role in the temperature reduction. The decreased heating is attributed to reduced HOM intensity by virtue of a longer bunch length. The lower plot correlates gap voltage and energy over the same time scale. Currents remained at around 1700 mA throughout most of this time period.

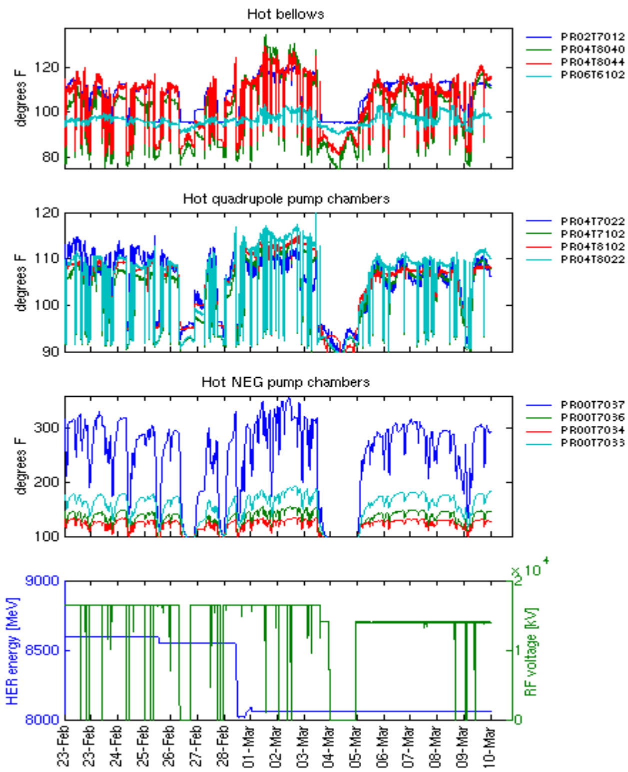

Figure 5: Elevated HER pump chamber and bellows temperatures correlate with low beam energy and relatively high gap voltage. Bottom plot shows HER beam energy (blue) and RF gap voltage (green). Beam current was relatively constant during this time. Temperature reduction during March 5 through March 10 operation correlates with lower beam energy and lower gap voltage at the same current.

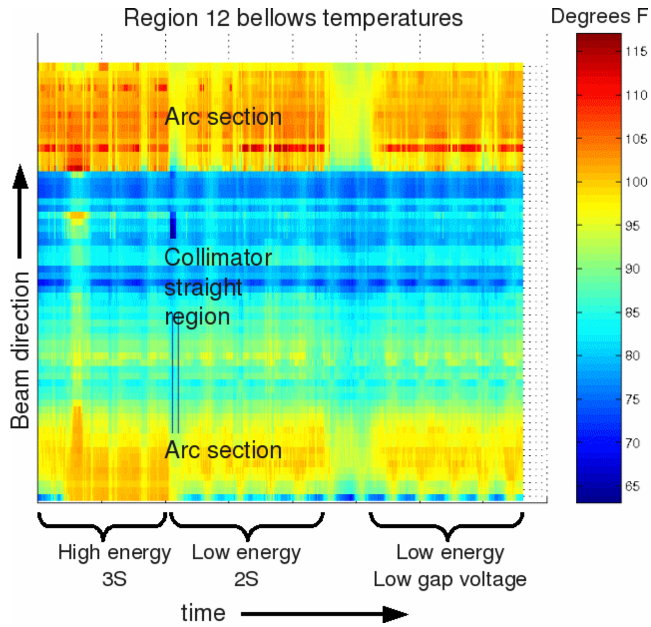

Figure 6: Temperatures at bellows location near the collimator region as a function of time. Hot arc bellows are downstream of the straight collimator section.

At the interaction region (IR) where the two beam lines intersect, the vacuum chamber profiles change dramatically, providing a significant source of wake fields. Some non-evaporable getter pump chambers (NEGs) in this area exhibit increased HOM heating. Others are not affected.

Collimators are known sources of HOMs [4]. In figure 6 arc bellows downstream of straight section collimators show the bunch length dependent HOM heating pattern.

CONCLUSION

Heating in the PEP-II storage ring collider vacuum chamber has two main contributions: synchrotron radiation and HOMs from wake fields. As the beam energy is lowered, synchrotron heating decreases. Bunch length measurements indicate an increasing linear dependence with energy. HOM heating increases with lower energy due to the shortened bunch length for constant RF gap voltage and frequency. At constant gap voltage and currents temperature elevation at lower lattice energy represent the increased presence of wake fields. There are roughly 300 bellows and over 90 quad chambers in the HER and not all show signs of HOM heating. The observed HOM heating of affected components can help identify nearby HOM sources or indicate damage from manufacture or installation.

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