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Analysis of the wake field effects in the PEP-II storage rings with extremely high currents

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ABSTRACT

We present the history and analysis of different wake field effects throughout the operational life of the PEP-II SLAC B-factory. Although the impedance of the high and low energy rings is small, the intense high-current beams generated a lot of power. The effects from these wake fields are: heating and damage of vacuum beam chamber elements like RF seals, vacuum valves, shielded bellows, BPM buttons and ceramic tiles; vacuum spikes, vacuum instabilities and high detector background; and beam longitudinal and transverse instabilities. We also discuss the methods used to eliminate these effects. Results of this analysis and the PEP-II experience may be very useful in the design of new storage rings and light sources.

1. Introduction

Intensity dependent effects play an important role in the operation of high luminosity colliders. The SLAC PEP-II asymmetric B-factory storage ring collider nominally collided 1700 bunches of 3.0 A of 3.1 GeV positrons on 1.75 A of 9.0 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 $1.2 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ at the Υ (4S) resonance. Achieving this high luminosity was partially due to the increase of operating currents [1]. The high current positron beam holds the record for the number of anti-matter particles stored: 1.5×10^{14}.

Higher current means more power in coherent and incoherent radiation. At the end of the PEP-II run the LER current was increased to a new world record of 3.2 A. During the energy scan, synchrotron radiation power in the high-energy ring exceeded the level of 10 MW in continuous operation, at or near the world record for a lepton storage ring. This large amount of power, produced by 11 RF stations was captured by the wall of the Cu vacuum chamber and then was carefully taken out by a water-cooling system. Additionally to large incoherent radiation, we got bursts of coherent radiation in the form of wake fields.

The design of the PEP-II beam chamber was very challenging. We used shielded bellows and shielded vacuum valves, which had water-cooled flanges. The transitions from elliptical cross-section to circular cross-section were long and smooth. Masks in the interaction region were smoothed. Collimators were designed in a way not to produce longitudinal fields. In order to watch for possible heating of the beam chamber elements, we installed many thermocouples around the ring.

The history of the wake field effects started almost from the very beginning of PEP-II operation.

2. Tiny vertex bellows and a large BABAR detector

High order mode (HOM) heating was observed in the PEP-II interaction region vacuum system [2]. The interaction region vacuum chamber brings the two ring vacuum chambers into a common chamber. In a particular region both beams (LER and HER) excite traveling wake fields or trapped Higher Order Modes (HOMs), which may interfere with each other depending on the beam phases.

The interaction point (IP) has a vertex chamber 50 mm in diameter and 400 mm long. It is a double walled Be chamber with water-cooling to remove induced HOM power. It is connected to a RF shielded bellows that connects to a larger chamber made of Glidcop and Cu. It is also designed to absorb synchrotron radiation with masks that necessitate bumps in the vacuum surface.

One thermocouple (Fig. 1), located near the vertex bellows showed higher readings than expected and caused concern about excessive heating in that region.

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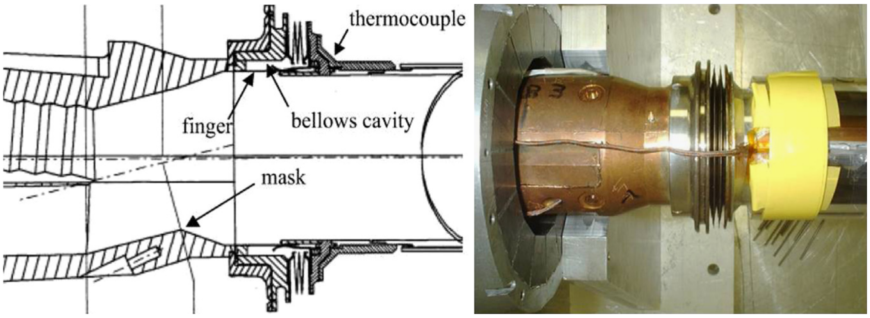

Fig. 1. Vertex bellows in interaction region.

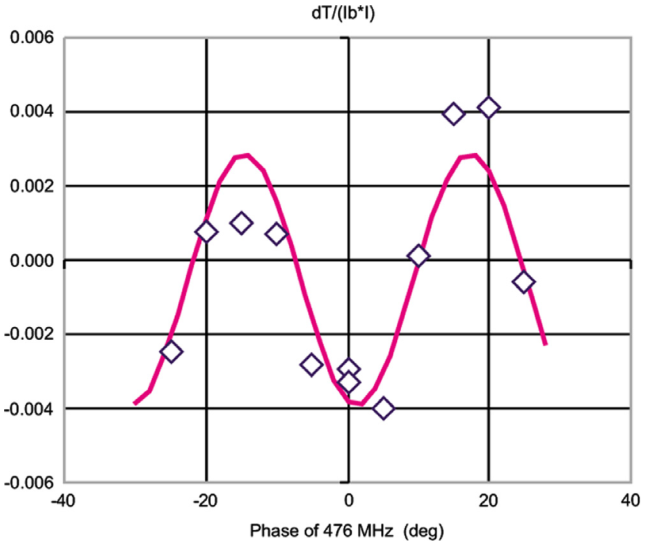

Fig. 2. Modulation of heating by changing the phase of the electron beam. The curve corresponds to 5.4 GHz.

With beam currents of 0.8 A (e^-), on 1.5 A (e^+), at this time, it typically read 150 F, a rise of 90 F above the cooling water temperature. To determine if any single HOM resonance was responsible for the heating, the RF phase of the HER was then moved relative to the LER and a modulation of the temperature was measured (Fig. 2).

We also measured the spectrum of the fields generated in the interaction region using signals from a BPMs located 50 cm from the bellows. We found one mode at the frequency of 5.59 GHz, the power of which was correlated (Fig. 3) with the bellows heating power, which we calculated from the bellows temperature *T*. We estimate the heating power by a formula.

$$P \approx K(T - T_c + \frac{\tau_c \partial}{2\partial t}T)$$

T_c is a bellows temperature at zero currents,τ_c is a cooling time of an exponential temperature decay, measured after the beams abort. *K* is a constant, which can be estimated from the total power, which is removed from the Be beam pipe. The correlation between amplitude of RF mode and estimated power is shown at Fig. 4. The complicated shape is due to the change of the beam (electron and positron) currents.

Thermocouples on the water exit pipes and knowledge of the flow rates gave an estimate of the power removed from the vertex Be chamber. This estimate was around 600 W for the currents noted above. With simple temperature measurements, we were able to determine the nature of heating in a particular region of the interaction region vacuum system. The current dependence identifies HOM as the source of heat. The response to RF voltage shows the expected bunch length sensitivity and quadratic relation with the beam currents.

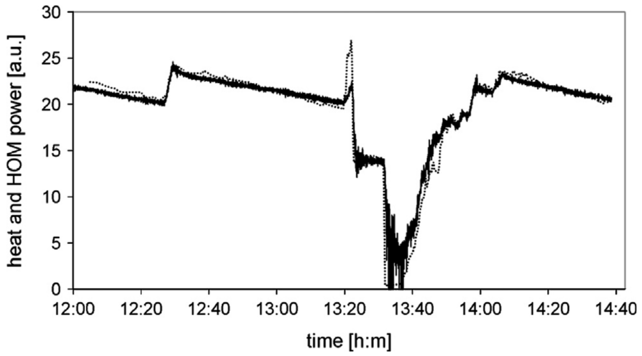

Fig. 3. History correlation of the power of the 5.59 GHz mode (dotted line) and the heat power (solid line), calculated from the bellows temperature.

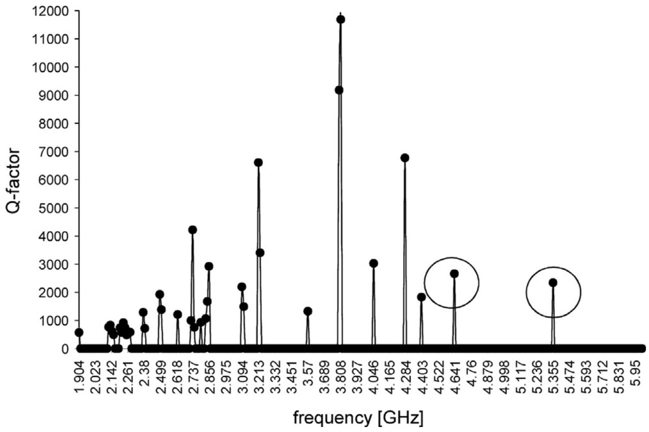

Fig. 4. Q-values of trapped modes at interaction region, measured from the BPM button signal in the time gap between bunch trains. The circled peaks show amplitude correlation the thermocouple temperature.

We also measured the Q-value of HOMs, trapped in the interaction region using a gated spectrum analyzer. The gated signal coincides with the time gap where no beam is present and the amplitudes exponentially decay. To calculate the equivalent Q-factor of the modes we measured mode amplitudes in a small time window at the beginning and the end of the gap. We found a Q-value of the interesting mode of order of 2500. We also found another mode at 4.6 GHz, which may be correlated with a beam chamber trapped mode located near the vertex bellows.

We also did a computer analysis [3] of the cavity behind the fingers of vertex bellows and found a resonant dipole mode of 5.46 GHz, which is very close to the measured value. The calculated field distribution in a cavity is shown in Fig. 5 (left plot). The maximum heating (red color) was at the convolution edges just near the place where the convolutions are welded. We also found