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ANALYSIS OF THE WAKE FIELD EFFECTS IN THE PEP-II SLAC B-FACTORY*

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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; 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.

INTRODUCTION

Intensity dependent effects play an important role in operation of high luminosity colliders. Achieving a luminosity of more than 10^{34} cm^{-2} sec^{-1} in the PEP-II B-factory was partially due to the increase of operating currents [1]. 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, a world record for a lepton machine. This large amount of power, produced by 11 RF stations was captured by the wall of the copper 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 history of the wake field effects started almost from the very beginning of PEP-II operation.

TINY VERTEX BELLOWS AND A LARGE BABAR DETECTOR

High order mode (HOM) heating was observed in the PEP-II interaction region vacuum system [2].

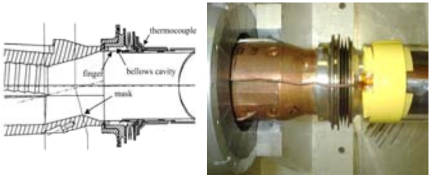

Figure 1: Vertex bellows in interaction region.

One thermocouple, located near the vertex bellows (Fig. 1), showed higher readings than expected and causes concern about excessive heating in that region. With beam currents of 0.8 A on 1.5 A 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, left plot)

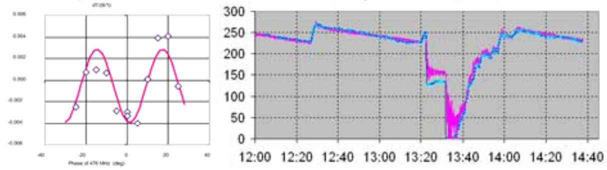

Figure 2: Left plot: Modulation of heating by changing the phase of the electron beam. The curve corresponds to 5.4 GHz. Right plot: History correlation of the amplitude of the 5.59 GHz mode (blue line) and heating power, calculated from the bellows temperature.

We also measured the spectrum of the fields generated in the interaction region and found one mode at the frequency of 5.59 GHz, the amplitude of which was correlated with the heating power, calculated from the bellows temperature T by formula $P \approx K*(T - T_{cool} + \frac{\tau_c}{2}\frac{\partial}{\partial t}T)$, τ_c - cooling time. This correlation is shown in the right plot of Fig. 2. We did a computer analyses of the cavity behind the fingers of vertex bellows and found a resonant dipole mode of 5.46 GHz [3]. In 2003 we opened the BaBar detector and installed more cooling around the vertex bellows. This helped and we did not have further problems in this location at higher currents.

INVISIBLE GAPS IN RF SEALS

During the 2001 PEP-II run an unusual behaviour of a valve body temperature [4] was observed in the low energy (positron) ring. A high positron current elevated the temperatures on different vacuum chamber elements like bellows and vacuum valves. The temperatures, measured by thermocouples, generally varied monotonically in accordance with the positron current. However, thermocouples placed on vacuum valve 2175 showed oscillations of temperature with a period of 3-8 minutes. The amplitude of the oscillations was of the order 5–20 F. The oscillations happened from time to time, when the positron current reached 1000 mA and more. A typical temperature oscillation is shown in Fig. 3. It was assumed that the gasket (RF gap ring), which is

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placed in the joint between the vacuum valve and the vacuum chamber, could have dimensions that are incorrect thereby producing a very small gap. We suspected that the gap size could be of order 100 microns. The positron beam through this size of a small gap could excite a cavity formed by the flange sides and the gaskets. Later we found traces of breakdowns (Fig. 3, right plot).

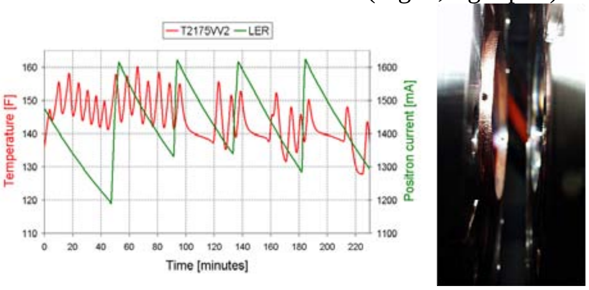

Figure 3: Vacuum valve temperature (red) and positron current (green). Right photo shows traces of breakdowns.

Simultaneously several vacuum valves were destroyed by breakdowns of intensive HOMs excited in a valve cavity (Fig. 5).

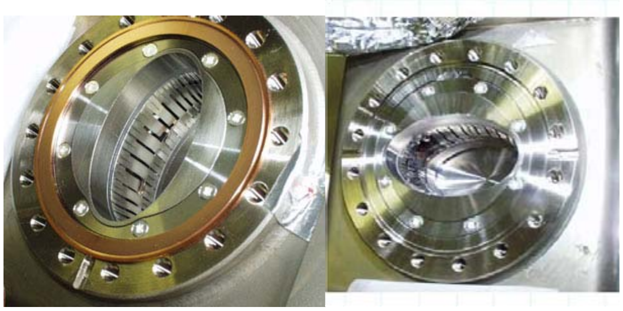

Figure 4: Discharges in shielding fingers of vacuum valves.

We have studied different models to understand how the temperature oscillations could occur. Here we discuss one model. A vacuum valve flange consists of two stainless steel parts, as it seen in Fig. 4. Parts are connected through a circular ring and radial gaps could be from both sides of the ring. When the inner part of the flange is heated, as was discussed before, the size of these gaps decreases with the temperature and thermal contact is improved. The heat energy flows to the outer flange part, which is cooled though with a fan and a copper water-cooled disk. The temperature then goes down and the radial gap opens up once again.

We cured this effect with a better design of the gap rings.

GAP RING, VACUUM SPIKES AND LONGITUDINAL INSTABILITY

We had another experience with a gap ring that was installed incorrectly. At the end of 2005, the beam in the PEP-II Low Energy Ring became affected by an instability with a very fast growth rate, but with a varying threshold [5]. Fig. 5 shows the X and Y position of the beam during this instability. Simultaneously we watched vacuum spikes in the region near one of RF cavities (Fig. 6). The impression was that somewhere we had breakdowns, which disrupted the RF feedback system. We opened the vacuum chamber near this cavity and found a gap ring which was not installed correctly (Fig. 7). We solved the problem by properly installing of a new gap ring. After that we no longer saw this kind of instability.

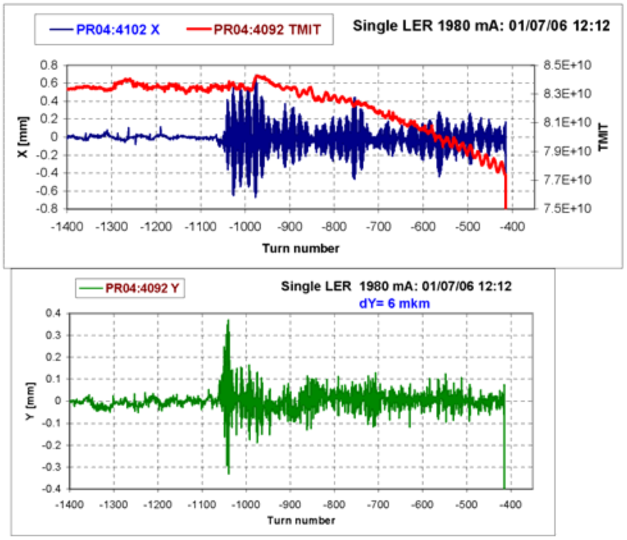

Figure 5: X (blue) and Y (green) beam position during the fast instability. Red line shows bunch charge (TMT).

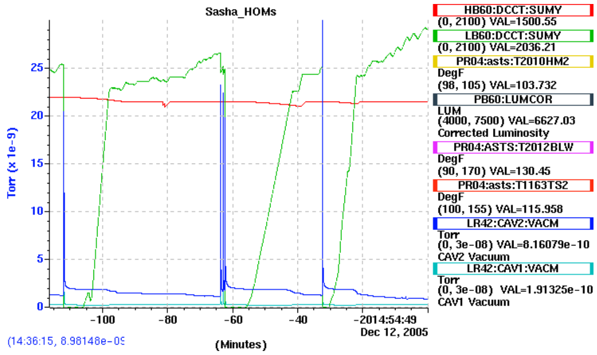

Figure 6: Vacuum spikes (blue line) during each abort. Green line shows LER current.

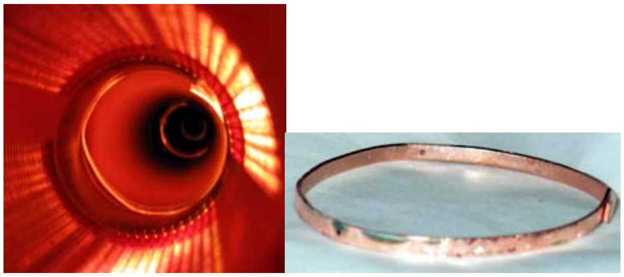

Figure 7: Gap ring in the vacuum chamber and out.

RESONANCES IN HER SHIELDED BELLOWS

There was a very interesting effect we observed while monitoring the temperature of the HER bellows. A typical example is shown in Fig. 8 (left plot). While increasing HER current the temperature of some HER bellows would go up and then go down. We may explain this effect by an excitation of the resonance modes in the cavity behind the shielded fingers. Eigen-mode analyses (S.Weathersby) using MAFIA code showed that several modes can be in resonance with bunch spacing frequencies. One of the modes is shown in Fig.9.

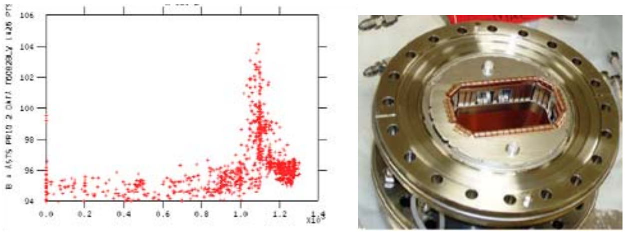

Figure 8: HER bellows temperature as a function of HER current.

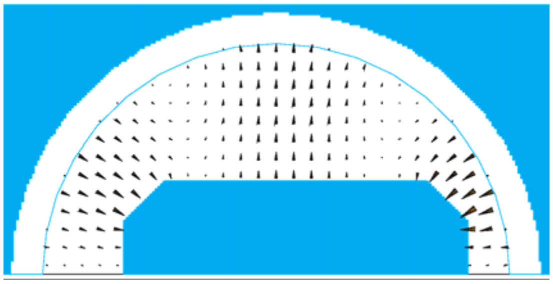

Figure 9: Resonance mode in the cavity behind the bellows shielded fingers.

The bellows are attached to 5 m long chambers, which are heated by absorption of synchrotron radiation. With increasing currents, the chamber temperature increases, and the chamber length changes and bellows has to take this change. In this way, the bellows mode frequency may change be in resonance with the bunch spacing frequencies. As we found later that excitations happen when the bellows fingers are damaged (Fig. 8, right plot).

COLLIMATORS AND BURNING FEED-THROUGH

A temperature rise was found in the LER vacuum chamber elements in one of the 12 junction of straight and arc vacuum chambers. The power in the wake fields in this area was high enough to char beyond use the feed-through for the titanium sublimation pump (TSP). This pumping section is 5.5 m long and consists of the beam chamber and an ante-chamber. Electromagnetic fields, excited in the beam chamber penetrate to the antechamber and then through the filament feed-through. After installing a water-cooled HOM absorber in the pumping chamber, the temperature of the TSP feed-through went down [6]. The HOM power in absorber reached 1.2 kW for a positron current of 2400 mA. We did not find any significant correlations of the HOM power with the beam position in the vacuum chamber, but we found a strong correlation with the vertical beam position near vertical collimators, which are far away from this chamber. Fig. 10 show the HOM power in the absorber (red line) and the vertical beam position near the 15m collimator (blue line) and the 65m collimator (green line). It can be seen that a 10 mm change of the vertical position near the closer collimator reduced the HOM power almost two times. The same (~ 10 mm) change of the beam position in the 65 m collimator changed the power in the absorber by an additional 10%. We subsequently designed some very good HOM bellows-absorberunits [7] and installed them after each collimator (Fig. 11).

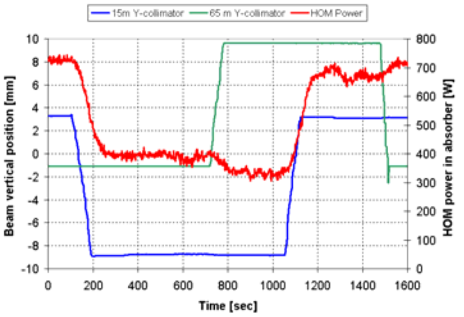

Figure 10: HOM power in absorber (red line) and vertical beam position near 15m collimator (blue line) and 65m collimator (green line).

Some other interesting wake field effects can be found in references [8-12].

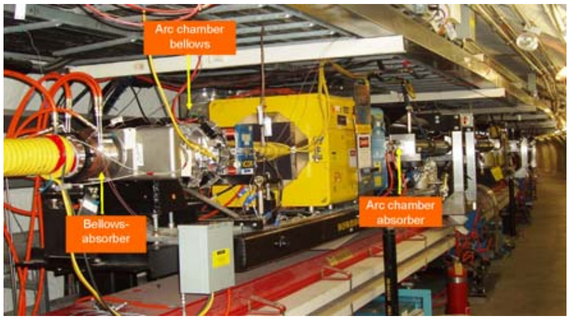

Figure 11: HOM bellows-absorber in PEP-II

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