SLAC-PUB-12076
August 2006

A NEW HOM WATER COOLED ABSORBER FOR THE PEP-II B-FACTORY LOW ENERGY RING*

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Abstract

At high currents and small bunch lengths beam line components in the PEP-II B-factory experience RF induced heating from higher order RF modes (HOMs) produced by scattered intense beam fields. A design for a passive HOM water cooled absorber for the PEP-II low energy ring is presented. This device is situated near HOM producing beamline components such as collimators and provide HOM damping for dipole and quadrupole modes without impacting beam impedance. We optimized the impedance characteristics of the device through the evaluation of absorber effectiveness for specific modes using scattering parameter and wakefield analysis. Operational results are presented and agree very well with the predicted effectiveness.

INTRODUCTION

The SLAC PEP-II asymmetric B-factory 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 luminosty of $1.08 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$. At such high currents intense scattered beam fields from collimators propagate some distance and couple RF power into nearby vacuum chamber structures such as shielded bellows and pump ports causing undesirable heating.

To reduce the heating effects of HOMs it would be desirable to couple out scattered beam fields near their source before they reach sensitive components and then dissipate this power in a controlled way. Introduction of such a device in the beam-line can result in added impedance to the beam therefore any design must consider this consequence.

Studies were done to understand the nature of scattered beam fields from a collimator in a straight section of LER. It was determined that such fields take the form of dipole and quadrupole propagating modes.

Based on these studies a device was designed to specifically couple out and damp dipole and quadrupole modes while leaving the monopole mode untouched[2]. The monopole mode is geometrically similar to the beam field. The coupled mode power is concentrated and dissipated in absorbing media of high permitivity $\epsilon_r = 30$ and large loss tangent $\tan\delta = 0.11$. Absorber power is extracted with water cooling lines.

HOM EFFECTS IN LER

Temperatures in a several meter vicinity of a collimator straight section were elevated in comparison with those in other areas of the low energy ring. Some of these exhibit strong dependence on the transverse position of the beam with respect to the collimator[1]. Of particular concern were anomalously high temperatures observed on a bellows in a straight section of LER, located 15 meters downstream of a fixed vertical beam collimator. Thermocouples mounted on the exterior of the bellows within the convolutions were registering a temperature rise of 80^0 reaching 180^0F at nominal LER currents of 2500 mA even after the installation of cooling fans. Internally, sensitive bellows fingers can reach much higher temperatures.

COLLIMATOR WAKE FIELDS

A collimator presents a strong scattering source for beam fields. We perform a wakefield analysis using MAFIA[3] to show how scattered beam fields give rise to propagating electromagnetic waves which transport power to other parts of the machine.

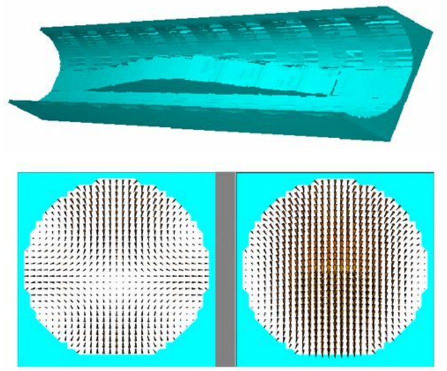

Figure 1: Collimator generates dipole and quadrupole fields after the passage of a 1.3 cm long Gaussian bunch. These are two snapshots at the same location separated in time.

Figure 1 shows the LER collimator structure and field snapshots downstream from the collimator a few nanoseconds after the passage of a 1.3 cm long Gaussian bunch which have a dipole and quadrupole field pattern. The dipole mode predominates at the longer time scales.

The HOM power generated at the collimator mostly follows the beam with a small fraction propagating in the opposite direction. Figure2 plots the Poynting vector flux

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* Work supported by Department of Energy Contract DE-AC02-76SF00515

Presented at European Particle Accelerator Conference (EPAC 06), 26-30 Jun 2006, Edinburgh, Scotland

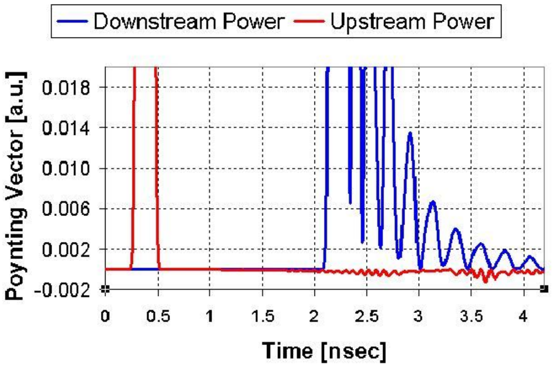

Figure 2: Poynting vector flux through upstream (red) and downstream (blue) locations vs. time. Initial red and blue signals indicate the passage of the beam. Negative values correspond to propagation in the upstream direction.

through a beam pipe cross section recorded upstream (red) and downstream (blue) from the collimator. A positive Poynting flux indicates energy flow in the beam direction. Negative flux is the upstream direction. The upstream propagation signals originate at the two sloped faces of the collimator.

Collimator loss factor

We performed loss factor wakefield calculations. The dependence with transverse beam position offsets is shown in figure 3. Loss factor exhibits a quadratic dependence with bunch length as shown figure 4. These results agree qualitatively with experiment[1]. Based on these analysis, it appears that a reduction of HOM heating can be achieved if dipole and quadrupole propagating HOMs can be intercepted before reaching beamline components. This suggests a beamline device which selectively couples to dipole and quadrupole modes along with a means to dissipate the coupled power, such as in a water cooled absorbing media with a high loss tangent.

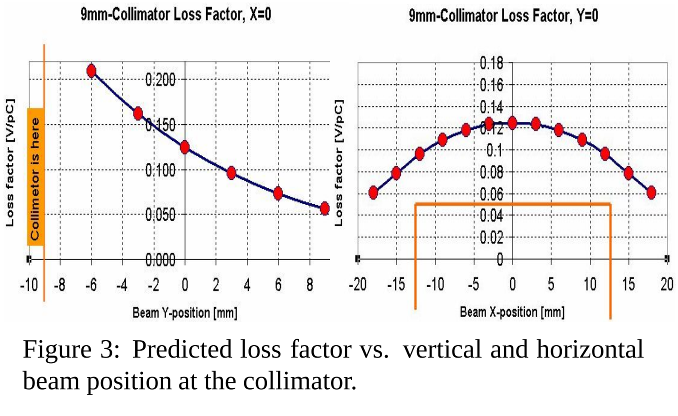

Figure 3: Predicted loss factor vs. vertical and horizontal beam position at the collimator.

STRAIGHT BELLOWS ABSORBER

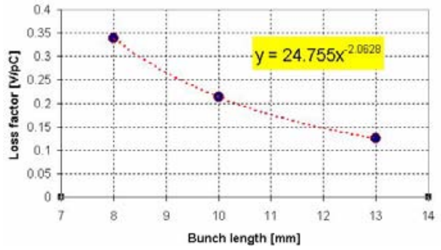

Figure 4: Collimator loss factor predicts a quadratic dependence on bunch length.

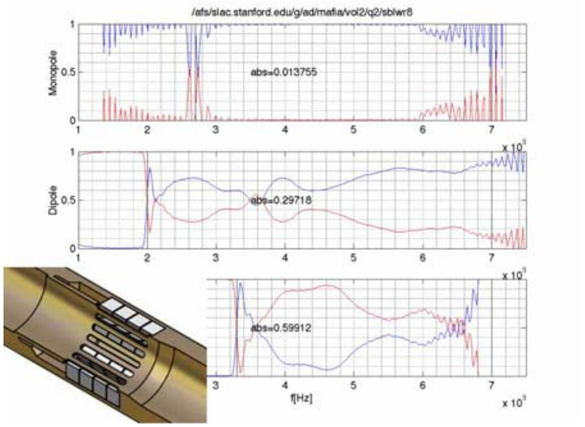

Figure 5: Scattering parameter analysis for configuration sblwr8 for three waveguide modes: monopole (top), dipole (middle) and quadrupole (bottom). Slot dimensions are 70 mm by 6.0mm with absorber thickness of 16.7 mm. The inset is the computational model. The gray tiles behind the coupling slots are modelled as a dielectric: relative electric permitivity $\epsilon_r = 30$, loss tangent tan$\delta = 0.11$. Blue trace is transmission. Red trace is absorption.

We consider a device with coupling slots and a cavity containing a high loss tangent ceramic absorber which is situated just downstream of the collimator straight section. Scattering parameter analysis is used to characterize the response to specific propagating modes. The goal is a design which maximizes dipole and quadrupole mode power absorption while allowing monopole mode power to pass without disruption. Monopole mode impedance can contribute to beam instability.

Scattering parameter analysis

Scattering parameters for each of three circular waveguide modes (monopole, dipole and quadrupole) are computed with MAFIA using a mode excitation in the time domain over a given frequency range with mode matched ports. Reflection and transmission scattering coefficients s_{11} and $s_{21}$are used to calculate a fractional power transmission and absorption given by $s_{11}^2 + s_{21}^2$ and $1 - \left(s_{11}^2 + s_{21}^2\right)$ respectively. Results for the sblwr8 configuration are shown in figure 5 .

This configuration was best at absorbing dipole and quadrupole modes while leaving the monopole mode unaffected. Dipole mode absorption is important since this is the main mode generated by the collimator. In the 2-5 GHz range we can expect 40% of the dipole mode power to be absorbed.

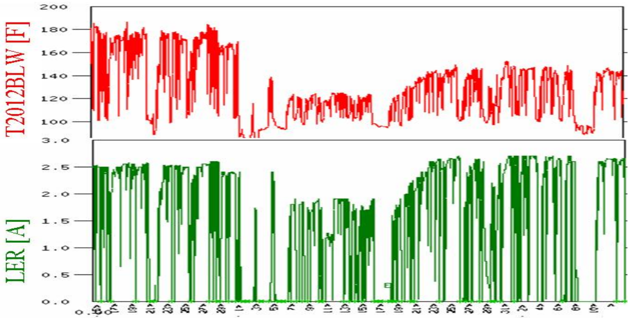

Figure 6: Temperature (red) of a bellows downstream of a LER collimator and LER current (green) before and after installation of the HOM absorbing device on May 1, 2006

A Selective HOM absorbing device

The device consists of a series of longitudinal slots which expose a cavity containing ceramic absorbing medium to beam induced fields. This provides continuity for monopole image charges to traverse the device, while coupling to the dipole and quadrupole modes. This coupling occurs because of the geometry of TE dipole and quadrupole electric fields which have nonzero transverse components at azimuthal directions near the beam pipe walls. This together with a longitudinal magnetic field results in a Poynting vector radially oriented and thus power is coupled out of the beam pipe at the slot. The monopole TM mode magnetic field is purely azimuthal.

Once coupled out of the beam pipe, the HOMs are exposed to absorbing ceramic tiles of high permittivity and high loss tangent. Electromagnetic energy is dissipated in the tiles. The tiles are brazed to a copper block with cooling water pipes to extract the heat.

The design process involved variation of slot, absorber and cavity geometry to optimize absorption characteristics using scattering parameter analysis. The slot length affects the degree of dipole and quadrupole coupling but is limited by mechanical constraints. Longer slots increase coupling. The absorber thickness affects the absorption spectra. Thicker absorbers tend to lower absorption peak frequencies. Wider slots tend to spread out the absorption peaks. An optimal configuration is found with a slot length 70 mm, slot width of 6 mm and absorber thickness of 16.7 mm.

The absorber and an adjacent bellows cavities are consolidated to expose the bellows cavity to the absorber and help damp any modes which may have infiltrated the bellows.

RESULTS

The device was built and installed during the last major maintenance period and has experienced high current running. Figure 7 shows the completed device just prior to and after installation.

Reduction in temperature rise by about 50% is observed at comparable currents before and after the installation in a nearby bellows as shown in figure 6. Other nearby bellows, pump ports, vacuum valves and anti-chambers see a similar reduction.

Figure 7: Straight absorber device before and after installation. Absorbing tiles are seen behind coupling slots. Copper water cooling lines remove absorber HOM power.

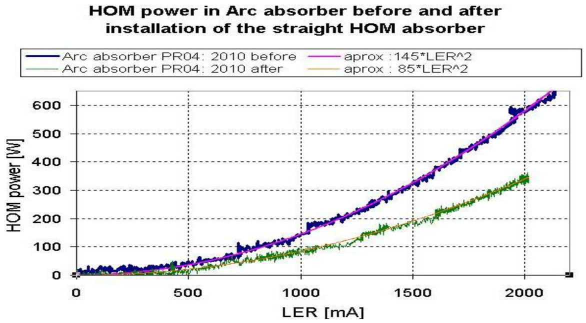

Figure 8: Effectiveness of straight bellows device is evaluated from a power estimation from cooling water flow and temperature in a downstream LER arc antichamber.

Figure 8 shows a power estimation from cooling water temperatures and flow in a nearby water cooled arc antichamber HOM absorber. The dependence is quadratic with current. A fit for the coefficient with data from before and after the installation gives 145 and 82 W/mA^2 respectively. The ratio of the coefficients indicate a 42% reduction in power extracted from the arc anti-chamber.

CONCLUSION

A new HOM absorbing device is implemented in a straight section of the PEP-II LER demonstating the capabilty to remove and damp undesirable dipole and quadrupole propagating HOMs produced at an upstream collimator with mimimal impedance to the beam. As a result HOM contribution to beam line heating is reduced without impacting beam stability, allowing higher currents for increased luminosity.

REFERENCES

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[2] S.Weathersby et al, “A Proposal for a New HOM Absorber in a Straight Section of the PEP-II Low Energy Ring”, PAC ’05, p. 2173.

[3] The MAFIA collaboration, “User Guide” CST GmbH, Darmstadt, Germany.