

# TRAPPED MODES IN THE PEP-II B-FACTORY INTERACTION REGION\*

E. Henestroza  
Lawrence Berkeley Laboratory  
University of California  
Berkeley, California 94720

S. Heifets and M. Zolotarev  
Stanford Linear Accelerator Center  
Stanford University  
Stanford, California 94309

## ABSTRACT

The design of the PEP-II B-Factory Interaction Region is based primarily on beam-stay-clear requirements and on synchrotron radiation background considerations (masks are required to shield the detector beam pipe from all sources of synchrotron radiation). A complicated 3-dimensional structure results from these requirements. A high intensity beam traversing this structure will generate wake fields that lead to energy deposition on the beam pipe, as well as to decelerating and deflecting forces acting back on the beam. Computation of wake fields and impedances in frequency-domain and time-domain using 2-D and 3-D electromagnetic codes revealed the existence of trapped modes in the interaction region, which if not controlled could enhance the higher order mode heating of the beam pipe. We will present the simulation results and the design strategy to avoid resonant conditions between these trapped modes and the bunch train frequency.

## I. INTRODUCTION

The PEP-II B-Factory, a high-luminosity, asymmetric electron-positron collider that will operate in the 10 GeV center-of-mass energy regime, is under construction at SLAC. The collider consists of a 9 GeV high-energy storage ring (HER), and a 3.1 GeV low-energy storage ring (LER). The average currents in the rings are 1 Amp. for the HER and 2.14 Amps. for the LER. The storage rings are designed to accommodate a large number of bunches, up to 3316 in buckets separated by 2.1 ns (476 MHz RF).

To achieve high luminosities in an asymmetric collider the beams have to collide head-on and be separated magnetically afterwards. Separating the unequal-energy beams by the use of bending magnets

and offset quadrupoles generates several fans of synchrotron radiation.

Several sources must be considered in the investigation of synchrotron radiation background including direct synchrotron radiation (primary masks must be placed to prevent such radiation from striking the detector beampipe, at the same time keeping the number of photon striking their tips to an acceptable level), photons that scatter through a mask tip, sources of synchrotron radiation from elements far upstream of the interaction region, and sources of backscattered photons from downstream surfaces.

Since the collider has to maintain an acceptable detector background condition, the design of the PEP-II B-Factory Interaction Region (IR) is based primarily on beam-stay-clear requirements and on synchrotron radiation background considerations. A complicated three-dimensional structure results from these requirements.

## II. THE INTERACTION REGION

The proposed dimensions [1], in the horizontal and vertical planes, for a beam pipe design  $\pm 1$  m from the Interaction Point (IP) are shown in Figs. 1 and 2, in a reference frame in which the collision axis of the beams is the primary axis. The masks (highlighted in those figures as shaded areas) must shield the detector beam pipe from all sources of synchrotron radiation.

The interaction region (IR) is a three-dimensional structure, composed of a number of offset tapers with elliptical cross section, asymmetrically placed in the horizontal and vertical planes. A high intensity beam traversing this structure will generate wake fields that lead to energy deposition on the beam pipe, as well as to decelerating and deflecting forces acting back on the beam.

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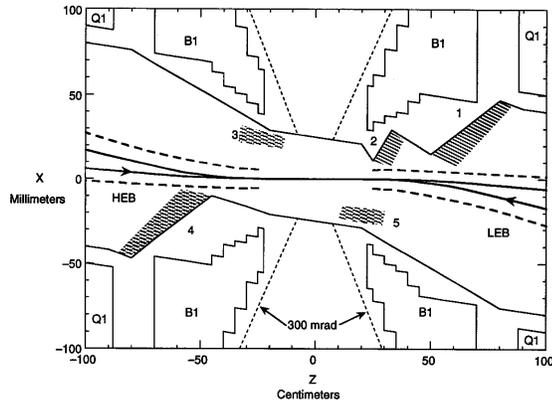


Figure 1: Horizontal plane, for a beam pipe design  $\pm 1$  m from the Interaction Point, in a reference frame in which the collision axis of the beams is the primary axis.

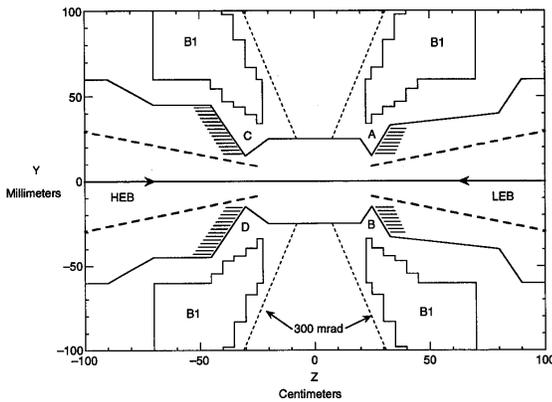


Figure 2: Vertical plane, for a beam pipe design  $\pm 1$  m from the Interaction Point, in a reference frame in which the collision axis of the beams is the primary axis.

### III. WAKEFIELDS

The wakefield and impedance of the IR were calculated with the time-dependent electromagnetic codes MAFIA [2] and ABCI [3].

MAFIA calculations in three-dimensions showed that to a good approximation one could consider the interaction region as an axisymmetric structure, neglecting the beam pipe offsets and deformations, as well as the beam offsets from the main centerline. A cylindrically symmetric structure was obtained by rotating the layout of the real structure in the vertical plane.

The wake potentials for a gaussian bunch ( $\sigma = 1$  cm), calculated for the real (3D) structure, are shown in Figure 3. The transverse wake is due to the asymmetry of the structure in the x-direction. Similar longitudinal

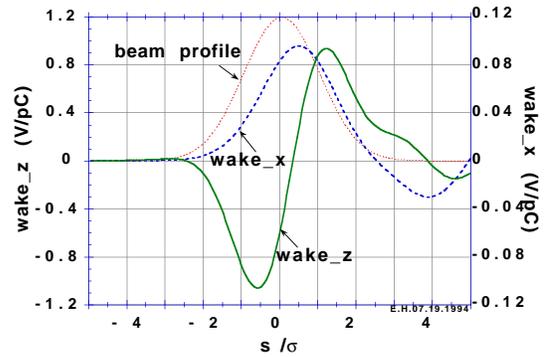


Figure 3: Wake potentials for the B-Factory Interaction Region. The distance is in units of the bunch length.

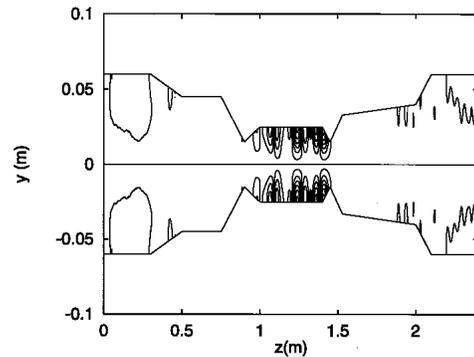


Figure 4: Electric field lines left by the beam in the IR after several beam transit times.

wake potential is obtained for the axisymmetric case. The broadband impedance is approximately inductive with  $L \approx 5$  nH, corresponding to a  $Z(n)/n \approx 5$  m $\Omega$ . The narrow-band impedance has a resonance at a frequency around 6 GHz. The loss factor of the total structure is  $k_l = 0.12$  V/pC. Most of the lost power propagates downstream and is absorbed outside the IR.

The effect of the IR discontinuities on beam dynamics is negligible. The main issue for the IR is heating. The heating from the propagating high order modes (HOM) is small and the potential problem comes from the trapped modes in the central Beryllium pipe,  $\pm 20$  cm from the IP. The energy deposition could be enhanced substantially if there were trapped modes in the IR, provided their wave length were a multiple of the bunch spacing.

As shown in Fig. 4, the existence of trapped modes in the Be pipe is suggested from a long term calculation of the wake fields by the ABCI code.

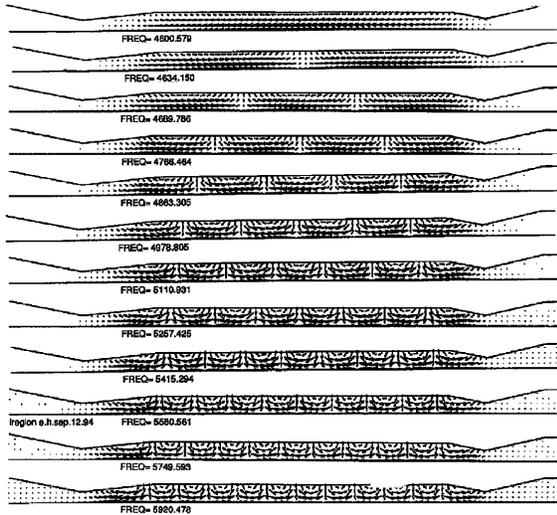


Figure 5: Electric field configuration of the trapped modes in the Be pipe of the B-Factory IR.

#### IV. TRAPPED MODES

The resonant modes of the axisymmetric structure, obtained by rotating the layout of the real structure in the vertical plane, were calculated using the frequency-domain code SUPERFISH [4]. A number of trapped  $TM_{01}$  modes, with frequencies ranging from 4.60 to 5.92 GHz, were found in the cavity-like confinement formed by the Be pipe and the adjacent masks. As expected, all these modes are the  $TM_{01}$  eigenmodes of a cylindrical pipe of radius  $a=2.5\text{cm}$ . The frequency interval at the low frequency end is about 50 MHz and increases to 150 MHz at the upper frequency end. Figure 5 shows the electric field configuration of the normal modes. The total contribution to the loss factor from all the modes shown is  $k_l = 0.012 \text{ V/pC}$ .

Both beams excite the modes simultaneously. The power deposition within the Be pipe depends on the  $Q$ -factor of the modes. The  $Q_{\text{ext}}$  is due to the coupling of the trapped modes to the propagating modes in the adjacent beam pipes with larger radii. We estimate  $Q_{\text{ext}} \approx 1200$  for a typical  $f_m = 5.7 \text{ GHz}$ . Since the resistive wall  $Q \approx 12000$ , only 10% of the power loss goes to the Be pipe wall.

The total power deposition in the IR by two beams is given by  $P_{\text{tot}} = ek_l(I_1 N_1 + I_2 N_2)$ , where  $e$  is the electron charge,  $k_l$  the loss factor, and  $I$  and  $N$  are the current and number of particles for each bunch respectively. With the average currents specified for the two rings we get  $P_{\text{tot}} = 480 \text{ W}$ . In principle, detuning from a resonance can be done by heating the Be pipe. The frequency shift for the mode at the upper end of the frequency range is comparable with the width of the resonance.

The power loss is enhanced for a train of bunches depending on the detuning of the mode frequency from the resonance frequencies:  $\omega_{\text{TSB}}/(2\pi c) = \text{integer}$ . If only 3 out of every 12 trapped modes are resonant, the power loss is  $P = 3 * (1/12) * 480 \text{ W} * D_{\text{max}} = 1.92 \text{ kW}$ , where we have estimated an enhancement factor  $D_{\text{max}} \approx 16$ . The power dissipated into the wall itself in this case is  $P_{\text{wall}} = 192 \text{ W}$ .

The Ohmic loss is much smaller. It depends on the rms bunch length, the skin depth of the wall, and the conductivity. For the B-Factory IR parameters, the power deposition per unit length is of order of 10 W/m, for a total of 4 W of ohmic loss into the Be pipe.

The frequency spectrum of a train of bunches also has frequencies at the multiples of the revolution frequency  $\omega_0$  but the total loss of the coherent modes is smaller than the uncorrelated power loss  $P_0$ .

#### V. CONCLUSION

The total loss factor of the IR is relatively small and, by itself, is not a problem. The main concern for the HOMs at the IR is heating of the central Be pipe due to the localized trapped modes. Simulation shows that such modes indeed exist in the range between 4 and 6 GHz being separated by 50-100 MHz. A potential enhancement of the energy loss in a bunch train under resonance conditions is a problem but may be avoided by careful choice of the geometry and by controlled heating of the Be pipe, which detunes the modes differently for low and high frequency modes. Further 3D numerical calculations of the  $Q_{\text{ext}}$ , and measurements with a prototype structure are needed to study and to avoid the resonances.

#### VI. ACKNOWLEDGEMENTS

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#### VII. REFERENCES

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