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Abstract

The higher-order-mode (HOM) heating of the central beryllium beam pipe in the PEP-II B-Factory interaction region is evaluated. Both single and multi-bunch effects are considered. While single-bunch heating is not an issue, resonant heating due to multiple bunch passages is found to be unacceptable. Modifying the IR configuration around the central pipe has been shown to alleviate this problem. Simulation results indicate that the new design is sufficiently effective in reducing possible resonant heating down to a level that is within existing cooling requirements.

1 INTRODUCTION

The PEP-II interaction region (IR) consists of a central beryllium vacuum pipe connected to incoming beamlines through a series of synchrotron masks which are not collinear and vary in dimensions along the beam axis. Fig. 1 shows the IR geometry in the horizontal and vertical planes. The aspect ratio of the structure is very large; the central pipe length is 40 cm while its radius is 2.5 cm. At one end the masks extend to almost a meter from the interaction point. Since there is only vertical symmetry this long structure is numerically challenging to model. Previous studies have assumed a rotationally symmetric mask geometry for simplicity. This work is aimed towards modeling the full 3D effect of the actual IR geometry.

The set of masks and tapers in the IR raises concerns in regard to the impedance it presents to the beam as well as the joule heating generated by the electromagnetic fields that the colliding beams induce. The design as depicted in Fig. 1 has already incorporated smooth tapers with the first concern in mind. Wakefield calculations show that the IR contribution to the ring impedance is not significant. The concern over joule heating is the subject of this paper and the present analysis seeks to determine whether the additional thermal loading will exceed existing cooling specifications.

2 TRAPPED MODES IN BERYLLIUM PIPE

The wakefields generated by the colliding beams at the masks can be trapped in the beryllium pipe due to the constrictions by the masks at both ends of the pipe. These trapped modes do not play a role in the heating incurred in a single bunch transit. However, in multiple bunch passages, resonant heating can occur if the trapped mode is driven by a beam harmonic and its decay time is long compared with the bunch spacing (high Q). This cumulative heating can lead to thermal loading much beyond what the cooling system can handle. To quantify this effect, the identification and characterization of the trapped modes are essential.

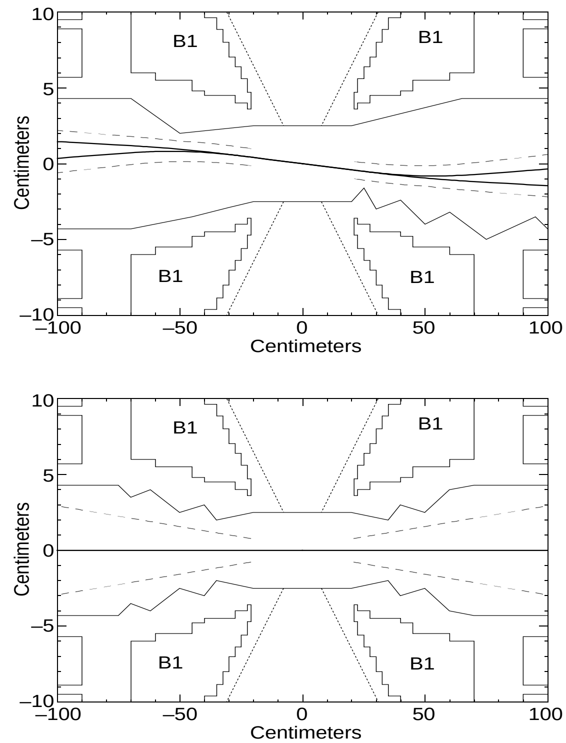

Figure 1: PEP-II IR region: horizontal and vertical plane

Trapped modes are normally best calculated in the frequency domain using cavity codes. These are localized modes below the beampipe cutoff and with low loss (high Q). The central pipe is, in a sense, a quasi-cavity whose beampipes are formed by the masks and tapers that extend out to larger pipes. Seen from the central pipe the beampipe cutoff is effectively changing with distance, first higher then lower as one approaches the larger outer pipes. In this structure some modes can be trapped within the central pipe while others can tunnel through the mask region and propagate in the outer pipes.

Figure 2 sketches the axial electric field of a partially trapped mode. Such a mode would not be determined correctly by a cavity code because there is outflow of energy. Although methods exist that use cavity code data to treat this coupling, they presently cannot handle multiple modes in the external waveguides which is the case here. To circumvent this difficulty we pursue a direct time domain approach in which all the modes are impedance matched at

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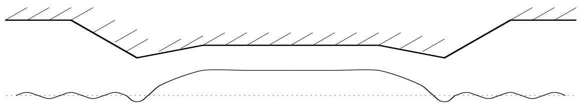

Figure 2: The longitudinal mode pattern in PEP-II IR region

the ends of the larger beampipes.

3 SINGLE BUNCH SIMULATION

The time domain simulation is basically a wakefield analysis whereby one drives a nominal bunch through the structure to find the energy loss and Fourier-transforms the wakefield to obtain the impedance spectrum. For heating calculation, it is further necessary to find the fraction of the energy loss to the pipe wall. We achieve this by monitoring the tangential magnetic field on the wall surface as a function of time (up to 67nsec, 16 bunch spacings). The set of monitors includes 8 locations in the azimuthal direction and 20 in the axial direction. Using this magnetic field data the wall loss can be obtained via perturbation theory. Fig. 3 shows the total heating spectrum within 20 cm of

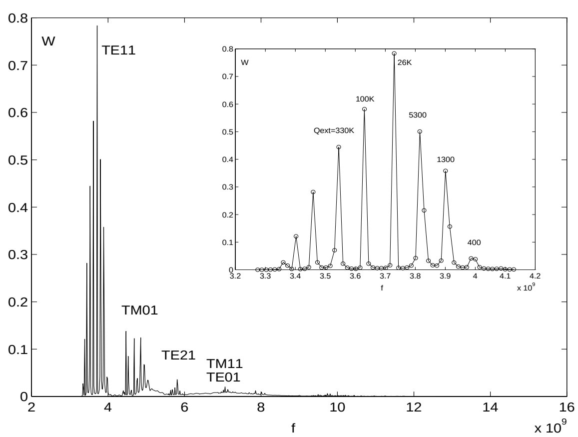

Figure 3: Heat spectrum in the beryllium pipe. The insert lists the Q value of the TE_{11} group of modes.

the IP, which is essentially the beryllium pipe. One can identify the modes by referencing the cutoff frequencies of the central pipe: TE_{11} = 3.5 GHz, TM_{01} = 4.6 GHz and TE_{21} = 5.8 GHz. It is found surprisingly that the dominant modes are from the TE_{11} family. If the IR geometry were treated to be rotationally symmetric (2D) the dominant contributions would have been from the TM_{01} group. TE modes would not be excited by the beam because they have zero electric field along the beam path. However, in the region where the masks intrude into the beampipe in the horizontal plane (right end of the central pipe), The azimuthal symmetry has been broken. The TE modes can have an axial field component and therefore be generated. Fig. 4 shows the dominant mode in the group, TE_{116}, that is well trapped. This is a clear indication that the 3D geometry of the masks is an important effect. Summing all

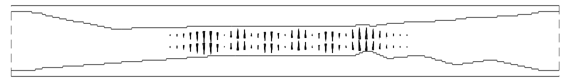

Figure 4: TE_{116} mode pattern

the modes the total heating is calculated to be 9W for a 3A beam.

4 MULTIBUNCH HEATING

When a single bunch passes through IR, it loses energy ΔU_n to the mode n. In the case of a train of bunches passing through IR, each bunch not only interacts with its own wakefield but that of the proceeding bunches[1]. Therefore the energy loss

$$U_n = \Delta U_n\{1 + 2\sum_{l=1}^{\infty} \exp\left[\left(\frac{-\omega_n * t_B}{2Q_n} + i\omega_n t_B\right)l\right]\} \quad (1)$$

contains the summation of all previous wakefield. The factor of 2 comes from the fundamental Theorem of beam loading[2]. The summation at resonance $\omega_n t_B = 2\pi m$, with integer m, is

$$U_n = \Delta U_n \frac{4Q_n}{\omega_n t_B}, \quad (2)$$

when $2Q_n \gg \omega_n t_B$.

In the previous single bunch heating calculation, we have integrated up to $T = 67$nsec, at which time most low Q modes have been completely damped. However, a few slowly decaying modes are still resonating. Thus, we express the multibunch heating

$$\begin{aligned} P_{multi} &= P_{single} \frac{\int_0^{\infty} \exp(-\frac{\omega t}{Q})}{\int_0^{T} \exp(-\frac{\omega t}{Q})} \frac{4Q}{\omega t_B} \\ &= \frac{P_{single}}{1 - \exp(-\frac{\omega T}{Q})} \frac{4Q}{\omega t_B} \end{aligned} \quad (3)$$

to account for finite integration time interval. The mode index n has been dropped to simplify the notation.

Because wakefield calculation requires a much finer mesh and correspondingly more CPU time, a separate MAFIA simulation with a dipole to excite individual modes is performed to calculate the Q_{ext}. A few Q_{ext} values for the TE_{11x} modes are displayed in the insert in Fig. 3. The Q_{ext} of the first 3 modes are so high that we are not able to determine them. Since the metal surface results in a natural Q_0 of 30K, the total Q of TE_{116}, for example, is roughly 14K. From Eq. 3, TE_{116} results in a heating of 4.4 KW if it is on resonance. The other high Q modes contribute even more. The total heating is unacceptable.

5 HEATING REDUCTION

It is seen from Eq. 3 that high Q resonance is highly undesirable. And we have also noticed that the smooth taper, with the aim to reduce the broadband impedance, traps the modes very well. Since wakefield calculation shows that the IR contribution to the ring impedance is not significant, we could use thin irises (See Fig. 5) instead of tapers to increase the tunneling of the trapped mode, thus reduce the Q_{ext}. The vertical mask on the right side is also pushed

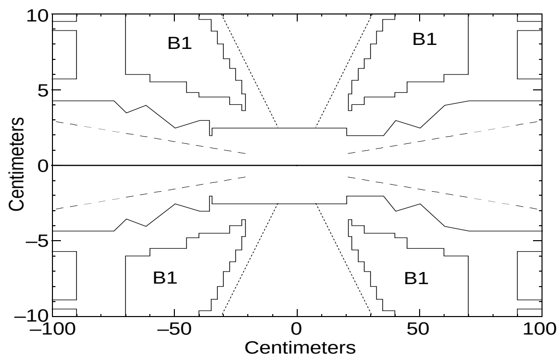

Figure 5: New PEP-II IR region- horizontal plane

in to shield horizontal mask, which induces the dominant TE_{11} contribution. The resulting single bunch heating is shown in Fig. 6. The TE_{11} contribution has been greatly

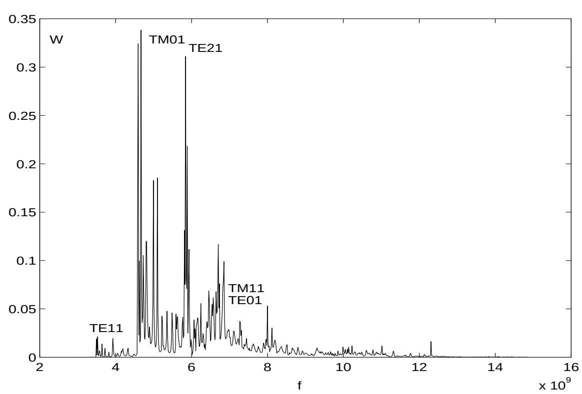

Figure 6: Power dissipation spectrum for new design

reduced at the expense of larger TM_{01} and TE_{21} excitations due to the abrupt geometry change.

We also evaluated the Q_{ext}'s of the modes by the previously mentioned method. Tab. 1 summarizes the multibunch heating if modes are on resonance. The total heating of 242 W assumes a very pessimistic situation where all modes are on the beam harmonics. It is very unlikely because the beam harmonics are 238 MHz apart in the case of nominal 4.2 nsec spacing.

Table 1: Multibunch heating

modes	Q_{ext}	P_{single}	P_{multi}
TE_{111}	3600	0.018	8.32
TE_{112}	1080	0.022	1.38
TM_{011}	4000	0.33	113
TM_{012}	730	0.1	2.58
TE_{211}	8000	0.13	103
TE_{212}	1400	0.32	14.2
Total(W)			242

6 TWO BEAM EFFECTS

For a symmetric mode with respect to IP, its excitation from two colliding e+ and e- beam will be twice as that from a single beam. Correspondingly 4 times the power will be generated. On the other hand, an anti-symmetric mode will have zero excitation (see Fig. 7). Assuming the worst case

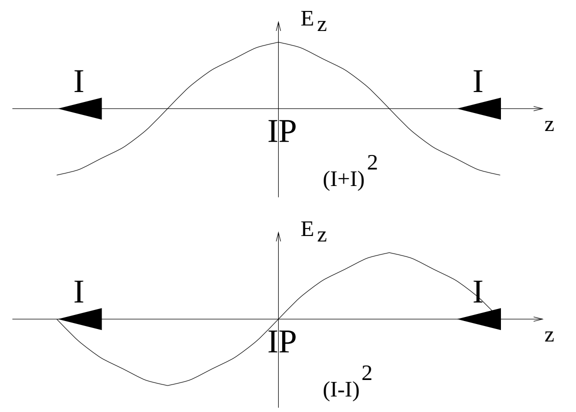

Figure 7: Two head on beams.

scenario with all the modes being symmetric, the HOM heating is $4 \times 242 = 968$W for 3 A beams. In addition to the 30 W image current heating, the total wall heating does not exceed the cooling requirement.

7 CONCLUSION

The PEP-II IR HOM heating has been numerically analyzed. By modifying the synchrotron masks at the ends of the central beryllium chamber, the excitation of TE modes are substantially suppressed and the Q_{ext}'s are greatly reduced. Resonant heating from multibunch on the chamber wall is lowered to within the designed 1 KW cooling capacity.

8 REFERENCES

[1] 'Impedance Study for the PEP-II B-factory', by S. Heifets et al. SLAC-AP-99. March 1995.

[2] 'High Energy Electron Linacs: Applications to Storage Ring RF systems and Linear Colliders' By P. Wilson, SLAC-PUB-2884, Nov. 1991.