WAKE FIELDS IN THE SUPER B FACTORY INTERACTION REGION*

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Abstract

The geometry of storage ring collider interaction regions present an impedance to beam fields resulting in the generation of additional electromagnetic fields (higher order modes or wake fields) which affect the beam energy and trajectory. These affects are computed for the Super B interaction region by evaluating longitudinal loss factors and averaged transverse kicks for short range wake fields. Results indicate at least a factor of 2 lower wake field power generation in comparison with the interaction region geometry of the PEP-II B-factory collider. Wake field reduction is a consideration in the Super B design. Transverse kicks are consistent with an attractive potential from the crotch nearest the beam trajectory. The longitudinal loss factor scales as the -2.5 power of the bunch length. A factor of 60 loss factor reduction is possible with crotch geometry based on an intersecting tubes model.

INTRODUCTION

A viable Super B factory[2] must sustain low emittance beams with intense currents of short bunches to reach the necessary high luminosities. The design calls for a 2.5 Ampere 4 GeV low energy positron ring colliding with 1.9 Ampere electrons from a high energy 7 GeV ring with bunch lengths of 5 mm. Experience with high current short bunch operation of the PEP-II B-factory[1, 3] underscores the need to control and mitigate the detrimental effects of intense beam generated electromagnetic fields, particularly in the interaction region, where both beams contribute wake fields. Wake field calculations for the current design estimate at least a factor of 2 lower loss factor than the PEP-II case. Averaged transverse kicks are computed, which show kicks directed towards the crotch nearest the offset beam trajectory. A factor of 60 further improvement in loss factor reduction can be achieved by a modification of the crotch geometry such as that formed by two intersecting tubes.

THE SUPER B INTERACTION REGION

Figure 1 is a cutaway orthographic view of the model of the Super B interaction region used for this study. The geometry spans 0.11 by 0.04 by 1.5 meters. One of the beam chamber axis is oriented along the z-axis, the direction with which the simulated bunch propagates. This model is meshed with up to 40 million points. The chamber material is considered infinitely conductive. Field solvers Gdfidl[4] and MAFIA[5] are used to evaluate wake field loss factors and averaged transverse kicks.

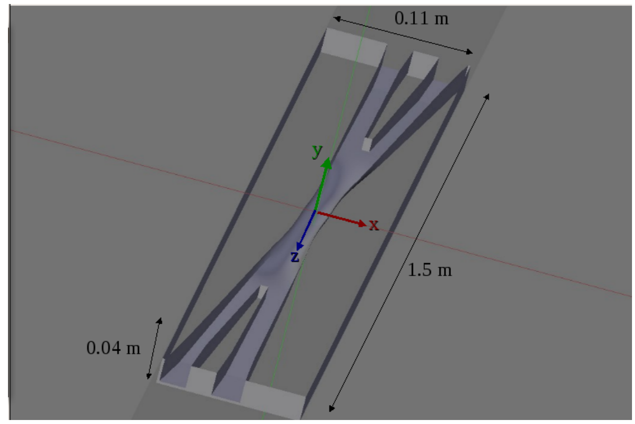

Figure 1: Cutaway model of the Super B interaction region. Dimensions in meters. Beam direction is along the z-axis.

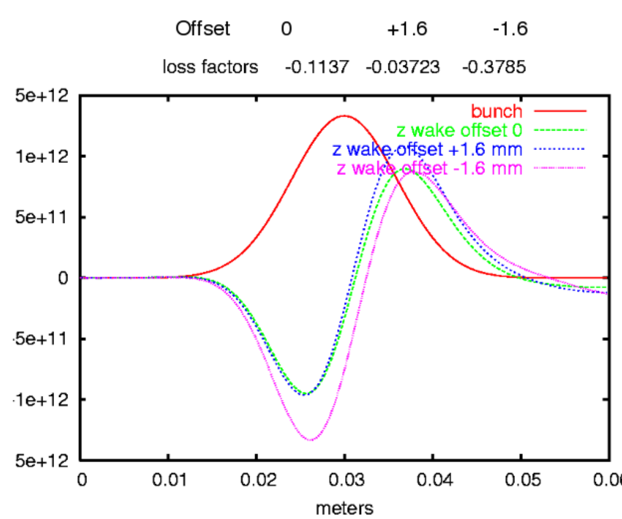

Figure 2: Longitudinal wake fields and loss factors for a 6 mm long bunch at various horizontal beam trajectory offsets from the ideal beam path: -1.6 mm, 0, and +1.6 mm.

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LOSS FACTORS AND BEAM TRAJECTORY

HOM generation is affected by beam trajectory. This is investigated by computing the loss factors for horizontally displaced beam trajectories. Figure 2 displays the calculated longitudinal loss factors, wake potentials, and the bunch profile for horizontal displacements of 1.6, 0 and + 1.6 mm from the nominal beam trajectory for a 6 mm long bunch. Longitudinal loss factors are respectively -0.379, 0.114 and 0.037 V/pC, decreasing with positive offset. With reference to the geometry of figure 1, a positive horizontal offset brings the beam closer to the upstream crotch. A negative offset means a trajectory closer to the downstream crotch. Loss factors increase with proximity to the downstream crotch.

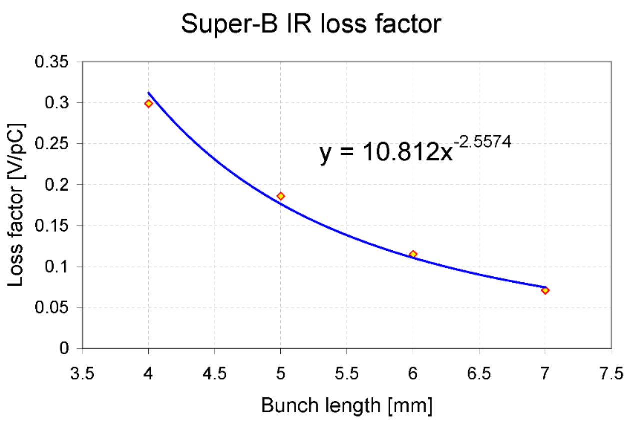

Figure 3: Loss factor dependence on bunch length is nonlinear.

BUNCH LENGTH

For a given total charge shorter bunch length increases the peak current and excites higher frequencies in the wake field spectrum. In general this leads to higher loss factors. Loss factor vs bunch length is shown in figure 3 for the case of the Super B interaction region. This increase in loss factor is nonlinear and varies as the -2.55 power of the bunch length.

For one 5 mm long bunch the Super B interaction region loss factor is $\kappa = 0.186$ V/pC. Both beams contribute to wake field generation under nominal colliding conditions. For a 5 mm bunch length the wake field power generated with both positron and electron beam currents of $I_+ = 2.5$ Amperes, $I_- = 1.9$ Amperes, and bunch spacing of $\tau = 4.2$ ns is

$$P_{beam} = \kappa\tau \left(I_+^2 + I_-^2\right) \sim 7.7\ \mathrm{kW}$$

AVERAGED TRANSVERSE KICKS

Wake fields from interaction region crotches affect particle trajectory. Figure 4 shows the wake potential seen by a 6 mm bunch for different horizontal bunch offset through the Super B interaction region. The wake potential is seen to reverse polarity on either side of the nominal trajectory. For the positive horizontal offset of +1.6 mm the beam is closer to the upstream crotch and the wake potential is positive, indicating a kick towards the upstream crotch. For the -1.6 mm offset case, the beam passes closer to the downstream crotch and the wake potential is negative, indicating a kick towards the downstream crotch. These observation are consistent with the crotches providing an attractive potential.

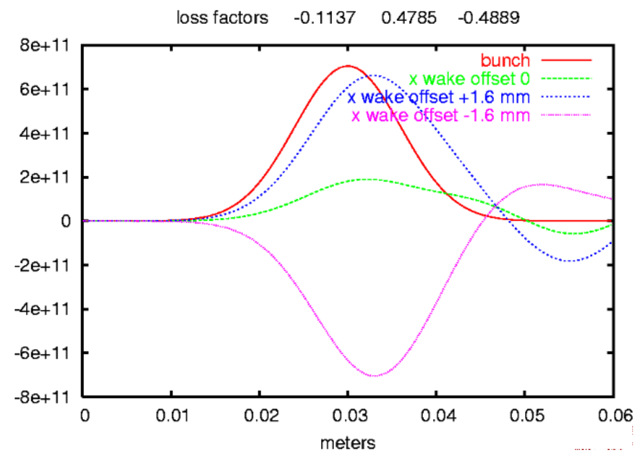

Figure 4: Horizontal integrated wake fields for various horizontal beam trajectory offset of a 6 mm bunch.

COMPARISONS WITH THE PEP-II B-FACTORY

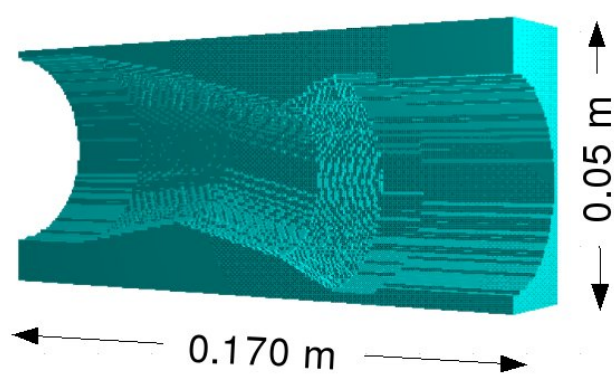

Figure 5: Section of PEP-II interaction region used for loss factor comparison.

The PEP-II interaction region model in figure 5 is considerably smaller and does not include the crotch regions. Tapers, masks and offsets are the dominant contribution to wake field generation in this case. For a bunch length of 13 mm in this PEP-II interaction region the loss factor was computed to be $\kappa = 0.060$ V/pC. Scaled to a 5 mm bunch length with both low energy ring and high energy ring current I±=2.12 Amperes, and bunch spacing of 4.2 ns, this small part of the PEP-II interaction region generates P_{beam}= 14 kW, which is a factor of two larger than wake field power generated in the entire Super B interaction region for the same operating parameters.

Based on this comparison with PEP-II, the Super B interaction region design presents a smaller impedance to the beam. This helps preserve emittance and allows the Super B-factory interaction region to sustain the short bunches at the currents required to produce high luminosity.

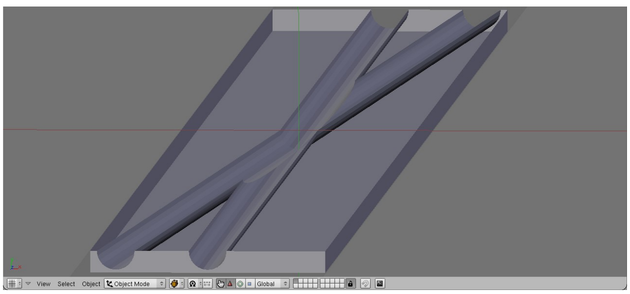

Figure 6: Cutaway view of an interaction region composed of two uniform 20 mm diameter tubes intersecting at an angle of 66 mr.

INTERSECTING TUBES

Loss factors can be further reduced by minimizing beam chamber contour variation seen by the beam fields. This suggests an optimal interaction region composed of two uniform tubes. Such an arrangement is shown in figure 6. This geometry offers an extended tapering crotch which allows surface currents to flow with less impedance compared with the abrupt crotch transition of figure 1. For a 5 mm bunch at the nominal trajectory the loss factor for intersecting tubes is κ= .0028 V/pC compared with κ= 0.186 V/pC for a Super B 5 mm bunch. For nominal Super B operating parameters the intersecting tube interaction region generates only P_{beam}= 116 W. Figure 7 shows the wake potential for this case.

CONCLUSION

We conclude based on the comparision with PEP-II that wake fields are not an issue in the present Super B interaction region design, providing that beams remain on or near the nominal trajectory between the two crotches. The loss factor displays a nonlinear -2.55 power dependence on bunch length. A crotch modeled on a simple intersecting tube geometry promises a further factor of 60 reduction in loss factor for the case of a 5 mm bunch length.

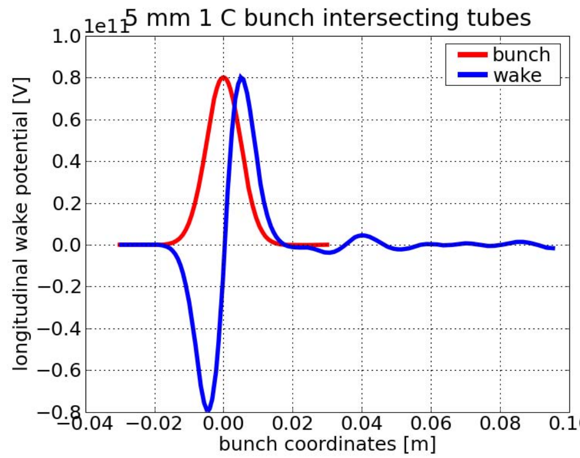

Figure 7: Wake potential (blue) of an on-axis 1 C 5 mm bunch (red) for two tubes of radius 20 mm intersecting at 66 mr.

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