EFFECT OF TE MODE POWER ON THE PEP-II LER BPM SYSTEM*

J. Corlett[1], C.-K. Ng[2] and S. R. Smith[2]
[1] Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA
[2] Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309, USA

Abstract

The beam chamber of the PEP-II B-Factory Low Energy Ring (LER) arc sections is connected to an antechamber for the absorption of synchrotron radiation on discrete photon stops. The presence of the antechamber substantially reduces the cutoff frequency of the vacuum chamber and, in particular, allows the propagation of higher-order-mode (HOM) TE power generated by beamline components at the BPM signal processing frequency. Calculations of the transmission properties of the TE mode in different sections of the vacuum chamber show that the power is trapped between widely separated bellows in the arc sections. Because of the narrow signal bandwidth and weak coupling of the TE mode to the BPM buttons, the noise contributed by the HOM TE power will not produce a noticeable effect on the BPM position signal voltage.

1 INTRODUCTION

The LER arc vacuum chamber employs an antechamber with a discrete photon stop for absorption of synchrotron radiation and with pumps for maintaining pressure below 10 nTorr [1]. The horizontal dimensions of the antechambers at the pumping chamber section and the magnet chamber section are larger or comparable to that of the beam chamber. Because of the increase in the horizontal dimension, the cutoff frequency of the TE_{10}-like mode (in rectangular coordinates) of the vacuum chamber is considerably reduced and, in particular, is less than the BPM signal processing frequency at 952 MHz. TE power propagating in the vacuum chamber will penetrate through the BPM buttons and will affect the pickup signal if its magnitude is not properly controlled. It is the purpose of this note to clarify various issues pertaining to this problem.

TE power is generated when the beam passes a non-cylindrically symmetric beamline component such as the RF cavity, the injection region, the IR crotch and the IP region. The beampipes connected to these components have TE cutoff frequencies greater than 952 MHz (for example, the TE cutoff frequency of the RF cavity beampipe is 1.8 GHz), and hence no TE power at this frequency propagates from the component. TE power can also be generated by the scattering of TM power through these beamline components. Since the cutoff frequency of the TM mode is in general higher than that of the TE mode, this mechanism is not pertinent to the problem related to the BPM signal. Consequently, the TE power that needs to be considered is mainly generated by components of the LER arc vacuum chamber, where the TE cutoff frequency is less than the BPM processing frequency.

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2 TE POWER GENERATION

The discontinuities in the arc chamber are the transitions between the pumping chamber and the magnet chamber, the BPM button gaps, the flange tapers and steps, and the transitions between the straight and the arc sections. In the following, we calculate the loss parameters of these components using MAFIA [2] and estimate the TE power generated by them.

(a) Pumping-to-magnet chamber transition The anamorphic schematic layout of the LER arc vacuum chamber is shown in Fig. 1. The magnet chamber is connected to the pumping chamber, which joins another magnet chamber at the downstream after a bellows. The cross sections of the magnet chamber, the pumping chamber and the bellows chamber are shown in Fig. 2. While the beam chamber cross section is the same at different sections, the antechamber geometry varies considerably. The pumping chamber contains a photon stop and pumps, and the magnet chamber and the bellows chamber each has a clearance slot of different horizontal dimension. The slot height (1.8 cm) is the same for all the chamber sections.

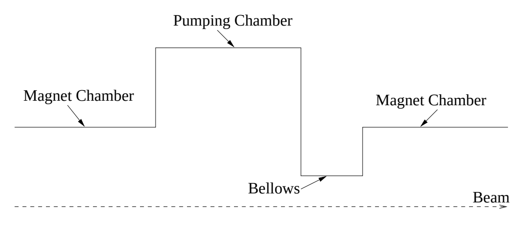

Figure 1: Schematic layout of LER arc vacuum chamber.

Wakefields are generated when a beam passes through discontinuities of a vacuum chamber. The slot of the LER arc vacuum chamber appears as a long continuous groove with discontinuities at the junctions of different chamber sections hidden inside. This is similar to the hidden slots structure introduced in Ref. [3] and follows the design of the ALS vacuum chambers. The beam electromagnetic fields seen by the hidden discontinuities are suppressed because of the exponential drop-off of the fields into the groove, and consequently the wakefield excitation is also reduced exponentially. Thus when the depth of the groove is larger than its height, the vacuum chamber produces very low impedance. This kind of slot structure has been used in the High Energy Ring (HER) arc vacuum chamber, and it was found to have very small impedance [4]. The longitudinal wakefield for one section of the LER arc vacuum chamber (see Fig. 1) when the beam is on axis is shown in Fig. 3. The wakefield is inductive in nature, and the loss parameter is found to be 1.14×10^{-8} V/pC, which corresponds to 0.41 mW for 3 A current and 4.2 ns bunch spacing. The TE power that can propagate at 952 MHz is generated when the beam is offset vertically. Since the loss parameter varies slowly with the beam offset, the generation of TE power at this frequency is expected to be negligible.

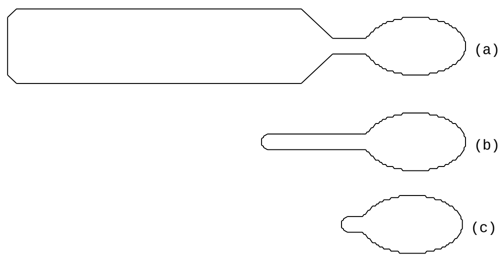

Figure 2: Cross sections of (a) the pumping chamber; (b) the magnet chamber; and (c) the bellows chamber.

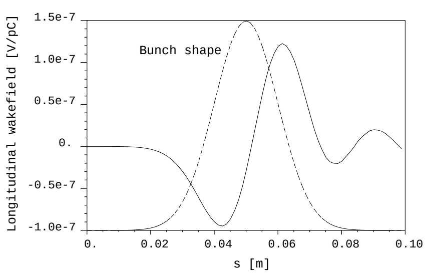

Figure 3: Longitudinal wakefield of the LER arc vacuum chamber. $\sigma_z = 1$ cm.

(b) BPM

The BPM button gaps will produce a larger loss parameter than that from the hidden discontinuities of the arc vacuum chamber. The loss parameter of the BPM in the HER arc vacuum chamber has been calculated before [5]; here we calculate the loss parameter in the LER arc vacuum chamber with the consideration of the side slot of the magnet chamber. The loss parameter is found to be 2.14×10^{-3} V/pC, which is much bigger than the contribution from the chamber discontinuities discussed above. Hence, the TE power generated by the BPM when the beam is off axis may not be negligible.

The TE power generated by the BPM can be evaluated using MAFIA by driving the beam off axis. The electromagnetic fields excited by the beam when it traverses the BPM will propagate along the vacuum chamber or into the BPM button. The fields propagating in the vacuum chamber can be decomposed into the waveguide eigenmodes of the chamber. In particular, we monitor the amplitude of the TE_{10} mode as a function of time. From the Fourier transform of the time variation, we obtain the spectral amplitude $\tilde{a}(\omega)$ of the TE power. The spectral amplitude for 1 cm beam offset is shown in Fig. 4. Since the BPM processes the signal at 952 MHz with a bandwidth of 20 MHz, we need to integrate the TE spectrum within this frequency range to obtain the power, which is given by

$$P = \frac{1}{2\pi} \Delta\omega |\tilde{a}(\omega_o)|^2 \frac{q^2}{t_b},$$

where q is the bunch charge, and t_b is the bunch spacing in time. For a current of 3A, $q = 8.3 \times 10^{10}\, e$, and $t_b = 4.2$ ns, the TE power generated within the bandwidth $\Delta\omega/2\pi = 20$ MHz at $\omega_o/2\pi = 952$ MHz is found to be 3.78 μW.

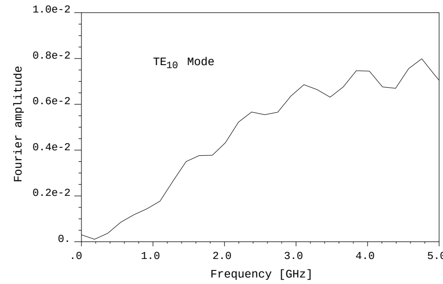

Figure 4: Fourier transform of the TE_{10} mode amplitude generated by the BPM.

(c) Other components

The other components that can generate TE power at around 952 MHz are the arc-to-straight transitions and the flange tapers and steps in the arc vacuum chamber. Since the transition is smooth, the flange taper has a small angle of 20 mrad maximum and the flange step is 0.3 mm or less, the loss parameters generated by these components are expected to be small. We approximate the discontinuities of these components by 2D models. The loss parameters of the arc-to-straight transition and the flange are found to be 6.80×10^{-4} V/pC and 2.38×10^{-4} V/pC, respectively. These are smaller than the loss parameter of the BPM. The TE power generated by these components are expected to be smaller also as the chamber cross sections have similar symmetry to that of the magnet chamber where the BPM is located.

3 TE POWER TRANSMISSION

TE power propagating in the LER arc vacuum chamber has different transmission properties at different sections due to the change in chamber cross sections. For the TE_{10} mode, the electromagnetic field is high in the slot region. The transmission properties of this mode are essentially governed by the slot region at the transition. At the pumping-to-magnet chamber transition, the clearance slot of the magnet chamber matches well with the slot region of the pumping chamber; and therefore the TE power can transmit through this transition with relatively little reflection. At the bellows transition region, the depth of the clearance slot of the bellows chamber is small compared with those of the magnet chamber and the pumping chamber at opposite ends; and thus a substantial amount of TE power will be reflected at this transition. In the following, we calculate the S-parameters for the TE_{10} mode at the pumping-to-magnet chamber transition and the bellows transition. With reference to the signal processing frequency of the BPM, the TE mode frequency is chosen to be 952 MHz.

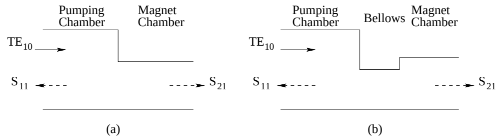

Figure 5: Schematics for S-parameter calculations at (a) the pumping-to-magnet chamber transition; (b) the bellows transition.

(a) Pumping-to-magnet chamber transition

The schematic for the S-parameter calculation at the pumping-to-magnet chamber transition is shown in Fig. 5(a). The cutoff frequencies of the TE_{10} mode of the pumping and magnet chambers are 324 MHz and 748 MHz, respectively, and hence TE power at 952 MHz can propagate through this transition. We drive the TE_{10} mode from the pumping chamber. The transmission coefficient, S_{21} is found to be 0.83. In other words, more than 50% of the power transmits to the BPM region in the magnet chamber.

(b) Bellows transition

The schematic for the S-parameter calculation at the bellows transition is shown in Fig. 5(b). The cutoff frequency of the TE_{10} mode of the bellows chamber is 1662 MHz, and hence TE power at 952 MHz is evanescent in the bellows chamber. The reflection coefficient, S_{11}, is found to be 0.99 at 952 MHz, and most of the power is reflected at this transition. Therefore, the bellows is expected to be shielded from TE power propagating in the vacuum chamber, and to isolate following sections of vacuum chambers from TE power generated prior to the bellows.

4 TE POWER PENETRATION IN BPM

The BPM is located either at the upstream or downstream end of the magnet chamber. The TE_{10} mode couples with opposite sign to the two buttons located at the top and at the bottom of the vacuum chamber as does the beam displacement signal. The vertical position measurement is obtained by the difference of the sum of the two top buttons signals and the sum of the two bottom buttons signals, while the horizontal position measurement by the difference of the sum of the two left buttons signal and the sum of the two right buttons signal. Therefore the coupled TE mode appears predominantly as a displacement error in the vertical direction and does not affect the horizontal measurement.

We carry out an S-parameter calculation to determine the transmission coefficients at the coaxial cables connected to the BPM buttons by driving at 952 MHz the TE_{10} mode of the magnet chamber. Fig. 6 shows the electric field pattern at the steady state of the calculation. It can be seen that the field concentrates in the slot, and hence the coupling of the TE mode to the BPM is small. The transmission coefficients at the left and the right buttons are found to be 1.56×10^{-2} and 7.81×10^{-3}, which correspond to power transmissions of 0.024% and 0.006%, respectively. The left button has a larger transmission coefficient than the right one because of the closer proximity of the left button to the high electromagnetic fields in the slot.

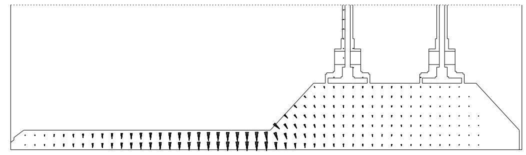

Figure 6: Electric field pattern at the BPM for the TE_{10} mode propagating in the magnet chamber.

As shown in section II(b), the dominant TE power at 952 MHz is generated by the BPM when the beam is off axis; a 3A beam vertically offset by 1 cm induces a TE power of about 4 μW within a 20 MHz bandwidth in the LER arc section. Some of this power couples to the BPM buttons causing an apparent vertical beam offset. A TE mode propagating past the BPM couples 0.03% of the mode power out the top two buttons in the bandwidth of the BPM processor. The attenuation length of the mode in the elliptical beampipe is about 250 m. Because of the large reflection coefficient at the bellows found in the last section, the power is trapped between two bellows 7 m apart, so the TE mode power passes the BPM approximately 35 times before being absorbed by the walls. This means that the buttons absorb approximately 1% (40 nW) of the TE power, which corresponds to a noise signal on the buttons of amplitude ~ 1.4 mV. Comparing with the position signal voltage of 0.7 V at this current times displacement, the TE mode power represents a position error of 20 μm. However, this is a systematic effect; it is a transverse scale error equivalent to an error in pipe radius of two parts in 10^3. Our tolerances in transverse scale are at least 10 times larger.

5 SUMMARY

The LER arc vacuum chamber allows TE power propagating at the BPM signal processing frequency at 952 MHz. We have evaluated the TE power generated by different components of the vacuum chamber and the transmission properties of the TE power at different chamber transitions at this frequency. By calculating the coupling coefficients of the TE mode to the BPM buttons, the noise signal contributed by the TE power within the bandwidth of the BPM processor is small compared with the normal position signal voltage and is within the tolerances of the BPM system.

6 REFERENCES

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