TE WAVE MEASUREMENTS OF THE ELECTRON CLOUD IN THE CESR-TA RING*

S. De Santis#, LBNL, Berkeley, CA 94720, U.S.A
J. Sikora, M. Billing, M. Palmer, Cornell University, Ithaca, NY 14850, U.S.A.
B. Carlson, Grove City College, Grove City, PA 16127, U.S.A.

Abstract

The CESR Damping Ring Test Accelerator collaboration (Cesr-TA) utilizes the CESR e+/e- storage ring at Cornell University for carrying out R&D activities critical for the ILC damping rings. In particular, various locations have been instrumented for the study of the electron cloud effects and their amelioration. In this paper we present the results obtained using the TE wave propagation method to study the electron cloud evolution and its dependence on several beam and machine parameters. Although the method's formulation is not particularly complex, a quantitative estimate of the electron cloud density from the TE wave data requires corrections for a number of error sources, which can potentially affect actual experimental measurements. The most prevalent of theses sources, and their remedies, are discussed in this paper.

INTRODUCTION

One of the leading R&D issues for the positron damping ring of a future linear collider is to ensure that the density of electron cloud build-up in the vacuum chambers can be kept below the levels at which beam instabilities and incoherent emittance growth will occur. In the present ILC damping rings (ILCDR) design, the presence of the EC in the positron ring limits the maximum current that can be stored and hence the minimum circumference of the ring that can be employed. As such, it is a significant cost driver for this accelerator system as well as being a major source of concern for whether the design can reach its performance goals.

Characterization and mitigation of the electron cloud effect constitutes one of the main activities in the Cesr-TA research program [1]. Several different techniques for electron cloud diagnostics have been developed in the past few years and are currently used in the program. In particular, the TE-wave transmission method [2] can be easily implemented on any section of the accelerator where BPMs are available and therefore can quickly provide measurements without the need of any hardware installation on the vacuum chamber and therefore is used in several sections of Cesr-TA. While conceptually the method has a relatively simple formulation, we have observed that in practical measurements a number of effects can compromise a quantitative evaluation of the electron cloud density if a certain degree of accuracy is desired. In this paper we present a selection of measurements on Cesr-TA and show how we compensate for some of the most common of such effects. Additionally we present data showing how, in some circumstances, the TE wave can itself perturb the electron cloud distribution.

* Work supported by the U.S. Department of Energy under Contract Nos. DE-AC02-05CH1123 and DE-FC02-08ER41538 and by the National Science Foundation Grant PHY-0734867

EXPERIMENTAL SETUP

Table 1: Cesr-TA Parameters

Energy [GeV]	2, 4, or 5
Circumference [m]	768
Revolution frequency [kHz]	390
Harmonic number	1281
Bunch length [ps]	30 to 52
Bunch current [mA]	up to 8
Bunch spacing [ns]	14 or multiples of 4

The relevant parameters for the Cesr-TA ring are summarized in Tab.1. For machine operations at all energies it is possible to select either electrons or positrons beams, although the two species circulate in opposite directions.

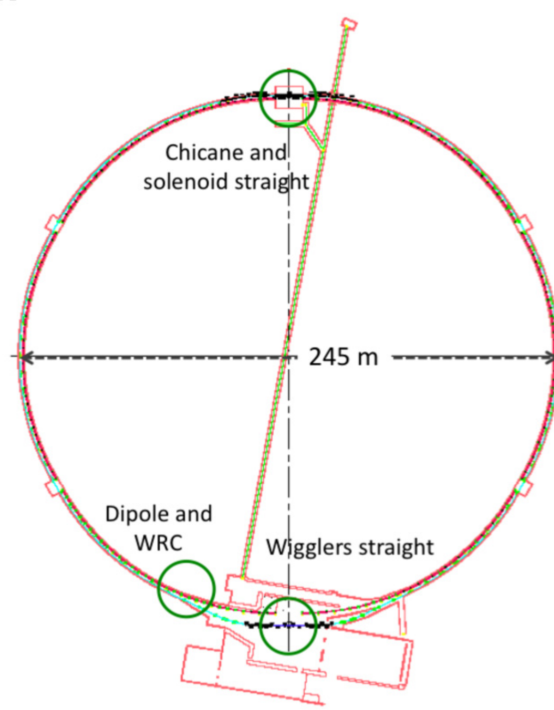

Figure 1: TE wave measurements locations in the Cesr-TA ring.

Useful comparisons can be obtained, although the differences in the synchrotron radiation patterns have to be taken into account. The TE wave technique has been implemented in different location along the ring, as shown in Fig.1. In each of those areas a few BPMs can be used to excite and detect the wave. At present, the chicane and the wigglers regions are constantly monitored: Any change in the beam or machine conditions automatically triggers a measurement, which is archived in a dedicated database.

EXPERIMENTAL RESULTS

In order to derive a value for the electron cloud density from the observed modulation sidebands amplitude we have observed a number of potential sources of error. In particular we can single out a few rather common effects introducing errors in the phase shift determination from the measured amplitude of the modulation sidebands. In this section we discuss the remedies adopted at Cesr-TA, which can be exported to other machines in most cases.

Influence of the gap length in the fill pattern

The TE wave method is intrinsically only sensitive to changes in the electron cloud density: a constant density would not produce any modulation sidebands. Also, if the length of the gap in the beam pattern is not long enough to completely dissipate the cloud, that portion constantly present in the machine would not be measured leading to underestimate its total density.

Theoretical considerations and simulations can be used to assess the minimum gap length necessary for a complete decay of the cloud. When it is possible to inject patterns with a relative freedom, one can also experiment using two bunch trains with different separations. Assuming that both trains are long enough to reach an equilibrium value in the cloud density, eventually reducing their separation will cause a decrease in the modulation sidebands amplitude offering a guideline on the necessary gap length.

Variable beampipe attenuation

Large errors can be committed due to the fact that the beampipe attenuation can be several dB different between the carrier and the sidebands frequencies. A 3dB difference would lead to a factor of 2 error in the phase shift calculation. To make things more difficult differences in the attenuation function can depend on beam conditions and present relatively large excursions.

To avoid such an error we use a phase modulated carrier, at a frequency of 410 kHz, which originates sidebands nearby the electron cloud sidebands at our 390 kHz revolution frequency. The expected amplitude of these reference sidebands can then be used as a correction factor, which is continuously updated. Figure 2 shows those reference sidebands generated by a 1 mrad phase modulation. The theoretical sidebands amplitude being -66 dBc we can determine a 9.1 dB attenuation for the lower sideband (LSB) and of 16.6 dB for the upper sideband (USB).

Fig.3 shows a measurement of the phase shift in the Cesr-TA wigglers straight as a function of the wiggler field.

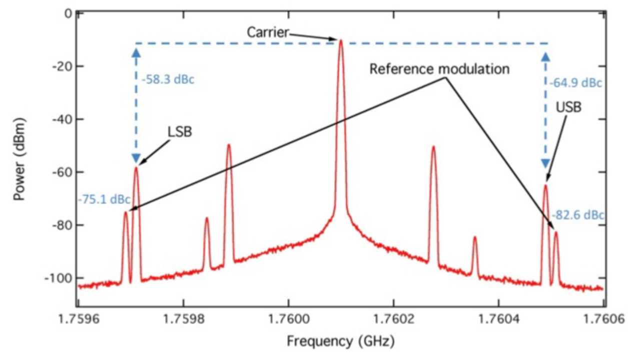

Figure 2: Reference modulation sidebands for beampipe attenuation calibration.

One can notice how at 30 kG field the synchrotron radiation pattern must hit a vacuum chamber element and start producing photoelectrons. At the same time heating of the pipe causes large changes in the attenuation at the sideband frequencies evidenced by the uncorrected data.

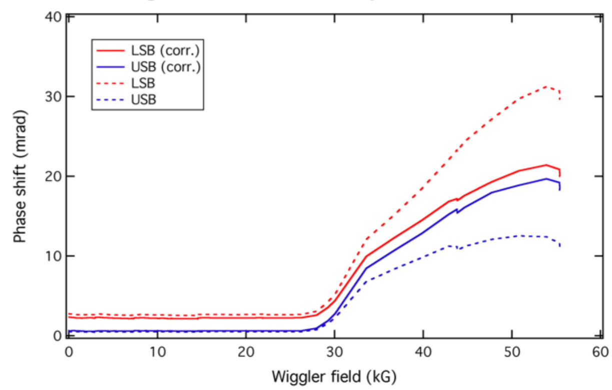

Figure 3: Phase shift as a function of the wiggler field. 45-bunch positron train 60 mA beam current.

Effects of the cloud time evolution

Another common effect that needs to be taken into account to correctly calculate the phase shift from the modulation sideband amplitudes originates from the fact that those sidebands do not depend only on the electron cloud density value, but also on its time dependence. The multiple sidebands usually observed contain the information about this time dependence. If the exact time evolution were known a priori, one could measure its amplitude by measuring a single sideband. The original formulation [3] of the technique implied exactly that: In the hypothesis of sinusoidal modulation, the first sideband amplitude relative to the carrier is equal to one half the modulation depth. The modulation caused by fill pattern usually encountered in practice deviates substantially from a sinusoidal one, and a rectangular modulation is a more accurate model [4].

Fig.4 shows how trains of different length, but equal bunch charge, can produce rather different sidebands. We know from other measurements that those trains are long enough to generate the same equilibrium value in the cloud density, and therefore the phase shift is expected to be the same.

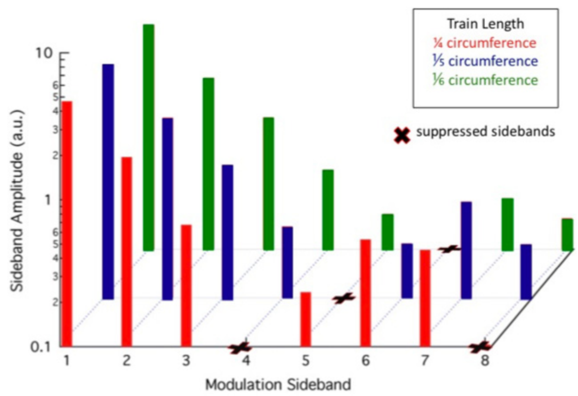

Figure 4: Modulation sidebands for different bunch train lengths.

In such cases (trains longer than the cloud rise/fall time) we can define a correction factor based on the hypothesis of rectangular modulation. From the Fourier transform theory, it is arguable that the suppressed sidebands shown in the figure confirm a strong rectangular component in the modulation.

$$\Delta\varphi = 2 \cdot SB_c \left[\frac{\sin(\pi t_{tr} / t_{rev})}{\pi t_{tr} / t_{rev}} \right] \tag{1}$$

Eq.(1) shows such a correction factor for the first sideband in square brackets: t_{tr} is the train length and SB_c the sideband amplitude. Analogous expressions can be derived for other sidebands. It can be noted that, since it is always $t_{tr}<t_{rev}$ the correction term is always less than unity.

CONCLUSIONS

In this paper we have discussed a number of effects that can affect the measurement of the electron cloud density using the TE wave method. These effects depend on the method itself, rather than on the particular experimental situation, and are therefore of general interest, although it is conceivable that in some situations their influence on the measurement could be more or less relevant.

In particular, we have discussed how particular attention must be paid in calculation the phase shift from the modulation sidebands measurement and listed the principal causes of error.

For our Cesr-TA measurements we have developed ways to eliminate, or reduce, these effects presented in this paper, which can be easily implemented on other machines as well.

REFERENCES

[1] M. Palmer, et al. "The Conversion and Operations of the Cornell Electron Storage Ring As a Test Accelerator (CESRTA) For Damping Rings Research and Development", in Proc. of PAC 2009, Vancouver (2009).
[2] S. De Santis, J. M. Byrd, et al. Phys. Rev. Lett. 100, 094801 (2008).
[3] F. Caspers, T. Kroyer, et al. in Proc. of the 31st ICFA Beam Dynamics Workshop. Napa (2004).
[4] N. Eddy, S. De Santis, et al. "Measurements of the Electron Cloud Development in the Fermilab Main Injector Using Microwave Transmission" in Proc. of PAC 2009, Vancouver (2009).