TE WAVE MEASUREMENTS OF THE ELECTRON CLOUD IN A DIPOLE MAGNETIC FIELD *

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Abstract

The TE wave propagation method has become a widely used technique for measuring electron cloud density in an accelerator beampipe. In most instances the wave very low power is not capable of affecting the low-energy electrons distribution. During experiments in the CESR Damping Ring Test Accelerator (Cesr-TA), we have observed a particular situation where a resonance between the wave and a dipole magnetic field produces a large modification in the electron cloud distribution that can be measured by other detectors. We believe this resonance is strongly dependent on the geometry of standing waves pattern that discontinuities in the beampipe generate. We present measurements in Cesr-TA, which describe the effect and are in support of our hypothesis.

INTRODUCTION

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 [1]. 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 (Ref. [2]) 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, as discussed in [3].

In this paper we present the experimental results of our TE wave measurements in the Cesr-TA L3 region, which comprises a chicane and a straight section of the pipe, where other electron cloud diagnostic devices are also available.

Our measurements demonstrate an interesting resonance effect between the frequency of the propagating wave and the dipolar magnetic field in the chicane. This effect amplifies the modulation signal, due to the electron cloud presence, and therefore could in principle be used to detect the presence of the electron cloud at lower densities than the method would otherwise allow.

More interestingly, we found that in some circumstances this resonant effect is capable to drastically change the spatial distribution of the electron cloud.

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TE WAVE INDUCED CYCLOTRON RESONANCE

In the study of the electron cloud in particle accelerators, the appellation of "cyclotron resonance" is commonly used to designate a resonance of the electron cloud density with a dipolar magnetic field, which is driven by the circulating beam itself and depends on the bunch spacing [4].

When an electromagnetic wave is excited in the vacuum chamber, such as in the case of TE wave measurements, an other resonance is possible, which is independent on the beam conditions. This resonance, which we will indicate for brevity with the name "TE wave resonance", although it is not limited to TE modes, has long been studied in the plasma physics field [5]. Essentially, a linearly polarized wave that propagates in an electron plasma, in the presence of a uniform magnetic field and has both its propagation and electric vectors perpendicular to the magnetic field vector, is referred to as the "X wave" (for "extraordinary") and its dispersion relation contains a singularity at $\omega^2 = \omega_p^2 + \omega_c^2$, where

$$\omega_p \approx 56.4\sqrt{n_e} \quad (1)$$

is the plasma frequency and n_e the plasma density in electrons per cubic meter, while

$$\omega_c/2\pi \approx 2.80\cdot 10^{10} B_{dip} \quad (2)$$

is the cyclotron frequency and B_{dip} is the magnetic field intensity in Tesla.

It is worth noticing that in experimental situations typical of particle accelerators the plasma frequency value is of the order of a few MHz. At the same time cutoff frequencies of most vacuum chambers are of the orders of hundred of MHz, up to above 2 GHz. This means the wave frequency is always much larger than the plasma frequency and magnetic fields of hundreds of Gauss are required to satisfy the singularity condition, which can be rewritten as $\omega \approx \omega_c$ with good approximation.

In physical terms, the mathematical singularity corresponds to a resonance where the electron plasma absorbs energy from the electromagnetic wave. Consequently, at resonance the electron cloud induces an amplitude modulation on the TE wave. This is different from the standard measurement technique, where the electron cloud induces a phase shift in the propagating wave and a phase modulation is measured.

EXPERIMENTAL SETUP

The L3 region used in our measurements (Fig.1) is instrumented with a shielded pickup [6] and a retarding field analyzer [7] in each one of the four chicane dipoles. Four BPM's are available for TE wave measurements.

direction of propagation and power. Furthermore, the RFA measurements showed that only in correspondence of these stronger resonances the electron cloud distribution was strongly affected (Fig.3).

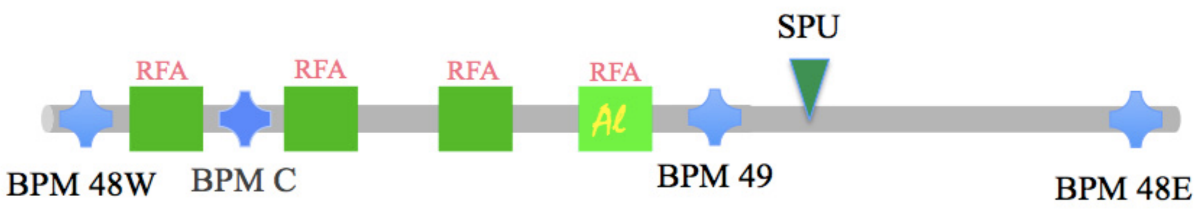

Figure 1: Cesr-TA L3 region. Four BPM's are accessible for TE wave measurements. Each one of the four chicane dipoles is instrumented with a RFA and there is a SPU in the straight section. The dipole closer to BPM 49 has an aluminium vacuum chamber, while the other three are equipped with different e-cloud mitigating techniques.

Each BPM can be used for excitation or detection of the wave and, by introducing a suitable phase delay between its four electrodes, it is possible to select a vertical or horizontal polarization for the electric field.

Two of these BPM's (48W and 48E) are at the extremities of the L3 region, while BPM 49 is at its center, near the chicane dipole with an aluminium chamber on one side and the SPU on the other.

EXPERIMENTAL RESULTS

When studying the chicane region with the TE wave technique, we encountered an effect with some characteristics, which initially puzzled us.

As expected, when the magnetic field was set to such a value that the cyclotron frequency coincided with the TE wave frequency, according to Eq.(2), the modulation sidebands amplitude underwent a large increase in the span of a few Gauss. This took place only when the wave was horizontally polarized, perpendicular to the B field, while the measurement was unaffected when using a vertical polarization.

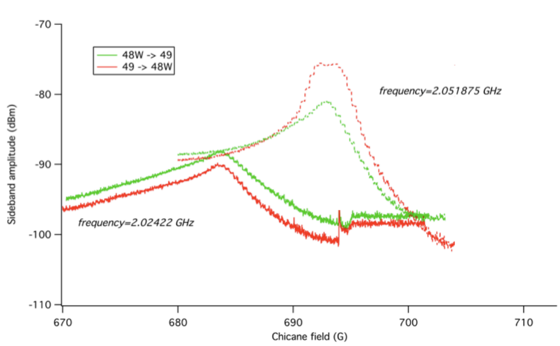

Figure 2: Modulation sideband amplitude near the TE wave resonance at two different frequencies. Red and green traces correspond to opposite direction of propagation of the wave.

Surprising, at certain frequencies this effect was highly enhanced (Fig.2), had a substantial dependence on the

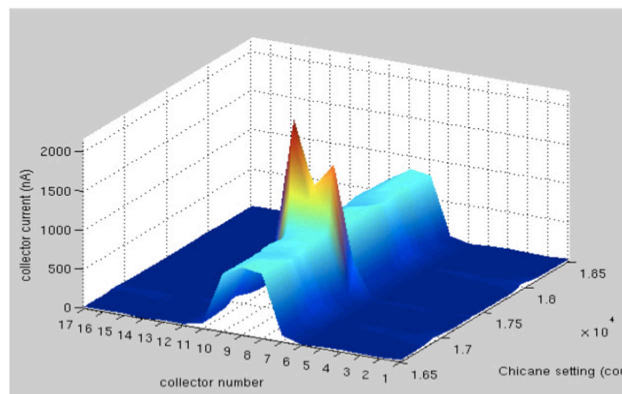

Figure 3: RFA data showing e-cloud distribution displacement in correspondence of the "strong" TE wave resonance in the aluminium-chambered dipole.

Eventually, a study of the effect of standing waves in the vacuum chamber [7] allowed us to understand that the stronger resonance corresponds to coupling with a standing wave having a maximum in the aluminium-chambered dipole, where the highest electron cloud density is to be expected. This was confirmed with experimental measurements: Propagating the wave from BPM 49 to 48E, also showed a dependence on the chicane setting, while the SPU did not. This confirmed that a TE measurement of nominal portion of pipe can be affected by nearby regions due to coupling to standing waves in the structure.

CONCLUSIONS

We have shown experimental evidence of the interaction between the TE wave and magnetic field at the cyclotron frequency. This effect enhances the modulation sidebands in the electron cloud measurements, thus offering higher sensitivity to the e-cloud density.

We also showed that the TE wave can drastically alter the e-cloud distribution, in certain situations.

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