MEASUREMENT OF THE ELECTRON CLOUD DENSITY AROUND THE BEAM

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Abstract

In KEKB low energy positron ring (LER), the density of the electron cloud near the beam is estimated by separating a high energy component of the electron current monitored at a pump port of a vacuum chamber. The estimated density is consistent with simulations. Further investigation is necessary to understand the obtained data.

INTRODUCTION

It is now well known that the electron cloud in high-intensity storage rings exerts detrimental effects on the stability and the quality of the stored beam [1].

In observational studies of the electron cloud, one of the main concerns is the measurement of the density of the cloud. In this paper, a very simple idea to measure the density near the beam is explained. The obtained density is consistent with simulation results. This idea can be applied to most positron storage rings.

BASIC CONSIDERATIONS

In KEKB LER, a number of retarding field analyser (RFA) type detectors are installed at the pump port of vacuum chambers (see Fig.1).

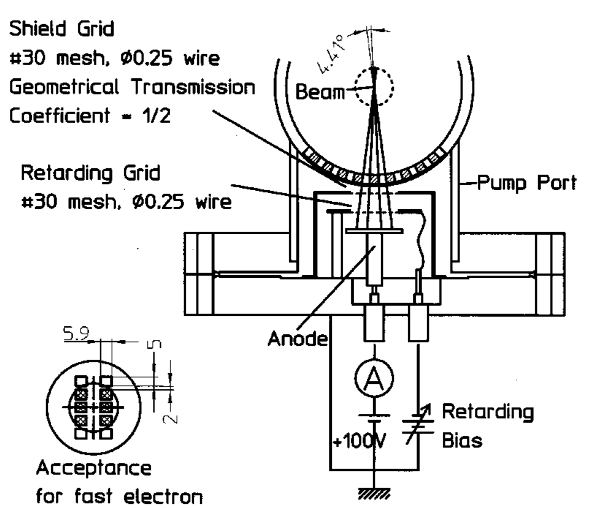

Figure 1: Schematic drawing of an RFA at a pump port of a KEKB LER duct.

One detector is equipped with a micro channel plate (MCP) instead of a standard planar collector. An output of the MCP is shown in Fig.2.

Though the in-coming electron current is too high for the MCP to operate in the normal condition, the MCP reveals suggestive features for a different retarding bias.

By selecting high energy electrons, sharp peaks that coincide with the bunch pattern emerge. Since energetic electrons are produced near the circulating bunch, the peak can be attributed to those electrons located near the beam and accelerated by the passing bunch. Each peak is, then, proportional to the local density just before the arrival of the bunch. On the other hand, from the retarding bias one can estimate the volume around the beam from which observed electrons come. Therefore, from the electron current per bunch and the retarding voltage, the cloud density near the beam can be estimated.

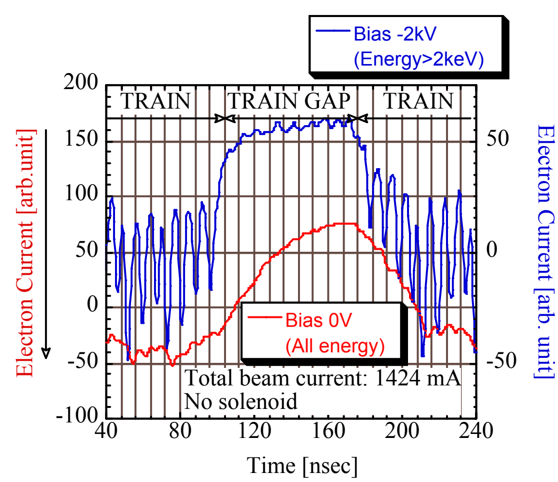

Figure 2: Time variation of the number of electrons impinging on the chamber wall by MCP.

FORMULATION

Above idea will be formulated for the data of an RFA with a planar electrode. KEKB LER has a circular beam duct. The beam is assumed to be at the center and to have no size. In the following, the axial symmetry around the beam is assumed.

An electron with a lateral distance r from a passing bunch receives a radial momentum change,

$$\Delta p = \frac{2r_e}{r} N_b m_e c, \tag{1}$$

where r_e is the classical electron radius, N_b is the number of positron in the bunch, m_e is the mass of an electron, and c is the velocity of light (= the velocity of the bunch). Since most electrons have a low energy [2], if r is sufficiently small, above Δp is approximately the final

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momentum of the electron. (Space charge of the cloud is negligible near the beam.)

By applying a retarding bias of V_b, observed electrons are limited to those that come from the cylindrical region within the distance r that is related to V_b as

$$eV_b = \frac{1}{2m_e}(\Delta p)^2 = 2\frac{r_e^2}{r^2}N_b^2 m_e c^2, \quad (2)$$

where e is the charge of an electron.

An RFA sees the part of the cylindrical region. The volume from which electrons enter the RFA can be written as

$$V_{obs}(V_b) = A\pi r^2 = 2\pi A r_e^2 N_b^2 \frac{m_e c^2}{eV_b}, \quad (3)$$

where A is a kind of the acceptance. A can be determined mainly by the geometry of detection, assuming that all electrons in this region move towards the center of a duct.

The number of high energy electrons per bunch is given as

$$\mu(V_b) = \frac{I_{obs}(V_b)}{e n_b f_{rev}}, \quad (4)$$

where $I_{obs}(V_b)$ is the monitored (DC) electron current, n_b is the number of bunch, and f_{rev} is the revolution frequency of the stored beam.

Finally, the average density of the cloud within the distance r from the beam is given by

$$D = \frac{\mu(V_b)}{V_{obs}(V_b)}. \quad (5)$$

Note that this density is a time average of the density at a special timing, i.e. just before the arrival of a bunch. It is important to keep this point in mind in comparing the measurement with simulations because, as Zimmermann [3] shows, the density of the cloud near the beam varies rapidly.

MEASUREMENT

RFA's in KEKB LER are not calibrated before installation. πA is estimated based on the drawing as 0.0003 m. However, an ambiguity remains due to the use of two meshes. Each mesh has the geometrical transmission coefficient of 1/2. However, the combined coefficient can vary from 1/2 to 1/6 according to their overlapping pattern. In the above estimation, the combined coefficient is assumed to be 1/4 (see Fig.1).

A high retarding bias is preferable to make the approximation of neglecting initial energies of electrons appropriate. However, if the corresponding r (see Eq.2) is comparable to the beam size, above formulation cannot be applied.

There is another requirement for a retarding bias given by the condition that observed electrons must enter the detector much earlier than the arrival of the next bunch. This makes the association of the observed current with a single kick by the bunch more unambiguous. This condition can be written as

$$\frac{r_c}{v_{min}} < \frac{s_b}{c} \rightarrow v_{min} > \frac{r_c}{s_b}c, \quad (6)$$

where r_c is the radius of a beam duct, s_b is the bunch space, v_{min} is the lowest velocity of electron that is determined by the retarding bias V_b.

The condition for V_b is, then,

$$eV_b = \frac{1}{2}m_e(v_{min})^2 > \frac{1}{2}m_e c^2 (r_c/s_b)^2. \quad (7)$$

For the case of KEKB LER, where r_c = 0.047 m and typically s_b = 1.2 ~ 2.4 m (2 ~ 4 rf buckets), this condition gives, V_b > 400V ~ 100V.

In the following data, V_b is 500 V. This is practically limited by the use of BNC type connectors. The corresponding radius of the observed region which is given from Eq. 2 as

$$r = r_e N_b \left(2mc^2/eV_b\right)^{1/2}, \quad (8)$$

is shown in Fig. 3 as a function of the bunch current. For a low bunch current, r is close to the beam size. The estimated density below 0.2 mA is not reliable.

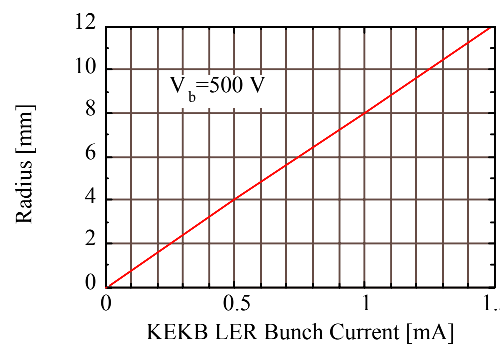

Figure 3: Radius of the observed volume. f_{rev} of KEKB LER is 9.94 kHz.

Fig.4 shows an example of the estimated cloud density. The location of the measurement is in the arc section of LER. Only few data are available for the NEG coated chamber, because it was replaced with the TiN coated chamber before this idea is developed. The cloud density is lower in the TiN coated chamber.

The density of the order of 10^{12} m^{-3} is also obtained with the simulation with CLOUDLAND[4], assuming realistic parameters. This supports the correctness of the idea explained in this paper. The bump of the density around the bunch current of 0.9 mA in the TiN coated chamber is not predicted by simulations. Further comparison taking into account the special timing of the measured average density is necessary.

High densities at a low bunch current are not reliable as stated before. Apparently, this divergence comes from a linear component of $I_{obs}(V_b)$ with respect to the bunch current. This seems to correspond to the not clearly separated foot of the peak in Fig.2.

In Fig.5, electron cloud densities are plotted against the linear current density that is an important parameter in discussing the growth of the electron cloud. At the location of the antechamber type duct, the intensity of synchrotron radiation is much higher than the TiN coated chamber is exposed. However, by removing the

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contribution of photoelectrons, the density of the cloud is much lower.

Bumps that are clear in TiN coated chamber are not so clear in the antechamber type duct. This suggests the bump is related to photoelectrons. In this figure, one must be careful that for the same linear current density, each cloud density is an average in a different volume size.

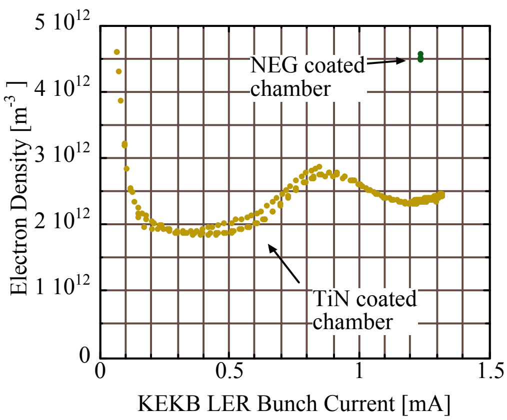

Figure 4: Electron (cloud) density in a NEG coated chamber and a TiN coated chamber. NEG coating was performed by BINP with the permission by SAES Getters and CERN. TiN coating was performed by BNL.

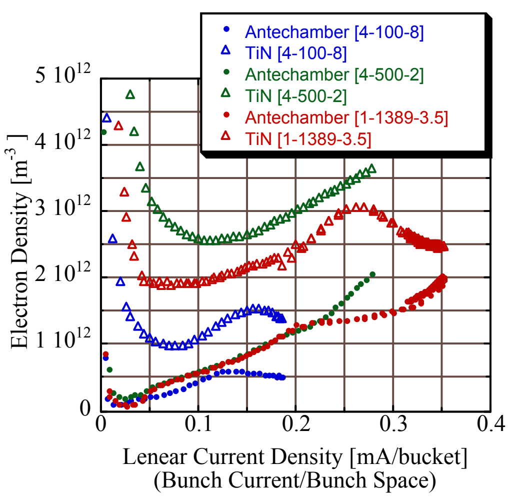

Figure 5: Electron (cloud) density in an antechamber type duct and the TiN coated chamber under various bunch patterns. The location is different. The notation of bunch pattern in the legend means [Number of train - Bunch per train - Bunch space (rf bucket as a unit)].

SUMMARY AND DISCUSSION

An idea to observe the central density of the electron cloud with an RFA is explained. The obtained numbers are of the same order as those given by simulations. This method is very simple and can be applied to most positron storage rings. For a non circular beam duct, the volume corresponding to a retarding bias can be numerically estimated. For proton rings with long bunches, a different approach is necessary. Of course, the proposed method is possible only in a field free region.

There are two domains where this formulation contains a large error:

- The radius of the observed volume, r, is comparable to the beam size (too high retarding bias or a small bunch current).
- The retarding bias is comparable to the average energy of electrons or does not satisfy Eq.7.

As to the obtained density, it is important to keep in mind the following points ;

- The obtained density is a time average of the local density just before the arrival of a bunch.
- The observed volume depends on two parameters, retarding bias and bunch current (Eq. 3). If the retarding bias is kept constant, the volume differs for a different bunch current. If the retarding bias is changed with bunch current so that the volume may become constant, data at a low bunch current becomes less reliable as a trade off.

Though the proposed idea is considered to be essentially correct, such a feature as bumps in Figures 14 and 15 is not known by simulations. More detailed comparison with simulations is under way.

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