Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Comparison of electron cloud mitigating coatings using retarding field analyzers

Q1 J.R. Calvey, W. Hartung, Y. Li, J.A. Livezey [1], J. Makita [2], M.A. Palmer [3], D. Rubin

Q4 *Cornell Laboratory for Accelerator-based Sciences and Education, Cornell University, Ithaca, NY, USA*

ARTICLE INFO

Article history:
Received 14 March 2014
Received in revised form
24 April 2014
Accepted 11 May 2014

Q3 *Keywords:*
Q6 Storage ring
Electron cloud

ABSTRACT

In 2008, the Cornell Electron Storage Ring (CESR) was reconfigured to serve as a test accelerator (CesrTA) for next generation lepton colliders, in particular for the ILC damping ring. A significant part of this program has been the installation of diagnostic devices to measure and quantify the electron cloud effect, a potential limiting factor in these machines. One such device is the Retarding Field Analyzer (RFA), which provides information on the local electron cloud density and energy distribution. Several different styles of RFAs have been designed, tested, and deployed throughout the CESR ring. They have been used to study the growth of the cloud in different beam conditions, and to evaluate the efficacy of different mitigation techniques. This paper will provide an overview of RFA results obtained in a magnetic field free environment.

1. Introduction

The electron cloud effect is a well known phenomenon in particle accelerators (see, for example, [1]), in which a high density of low energy electrons builds up inside the vacuum chamber. These electrons can cause a wide variety of undesirable effects, including emittance growth and beam instabilities [2], particularly in positively charged (e.g. proton or positron) beams. In lepton machines, the cloud is usually seeded by photoelectrons generated by synchrotron radiation. The collision of these electrons with the beam pipe can then produce one or more secondary electrons, depending on the secondary electron yield (SEY) of the material. If the average SEY is greater than unity, the cloud density will grow exponentially, until a saturation is reached.

Electron cloud has been observed in many facilities (including, for example, PEP-II [3], CERN SPS [4], KEKB [5], ANL APS [6], FNAL Main Injector [7], LANL PSR [8], and the LHC [9]), and is expected to be a major limiting factor in next generation positron and proton storage rings. It is of particular concern in the damping rings of electron–positron colliders, which will produce a large amount of synchrotron radiation and require very small emittances [10].

In 2008, the Cornell Electron Storage Ring (CESR) was reconfigured to study issues related to the design of the International Linear Collider (ILC) damping ring, including electron cloud [11]. A significant component of this program, called CESR Test Accelerator (CesrTA), was the installation of several retarding field analyzers (RFAs) throughout the ring, in drift, dipole, quadrupole, and wiggler field regions. This paper will summarize results obtained from drift RFAs. More specifically, it will describe the design of the detectors and experimental program (Section 2), and present measurements (Section 3), with a focus on directly comparing different cloud mitigation techniques. More quantitative analysis of the RFA results will be presented in a separate paper [12].

1.1. *Retarding field analyzers*

A retarding field analyzer consists of three main components [13]: small holes drilled in the beam pipe to allow electrons to enter the device; a “retarding grid,” to which a voltage can be applied, rejecting electrons with less than a certain energy; and a positively biased collector, to capture any electrons which make it past the grid (Fig. 1). If space permits, additional (grounded) grids can be added to allow for a more ideal retarding field. In addition, the collectors of most RFAs used in CesrTA are segmented transversely to allow characterization of the spatial structure of the cloud build-up. Thus a single RFA measurement provides information on the local cloud density, energy, and transverse distribution. Most of the data presented here are one of two types: “voltage scans,” in which the retarding voltage is varied (typically from +100 to −250 V or −400 V) while beam conditions are held constant, or “current scans,” in which the retarding grid is set to a positive voltage (typically +50 V), and data are passively collected

[1] Present address: Department of Physics, University of California, Berkeley, CA, USA.
[2] Present address: Department of Physics, Old Dominion University, Norfolk, VA, USA.
[3] Present address: Fermi National Accelerator Laboratory, Batavia, IL, USA.

http://dx.doi.org/10.1016/j.nima.2014.05.051
0168-9002/© 2014 Published by Elsevier B.V.

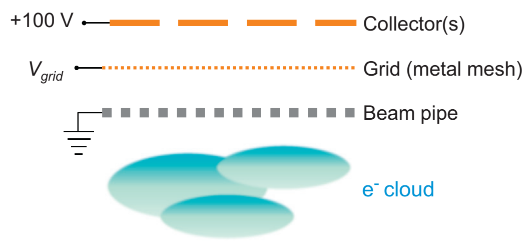

Fig. 1. Idealized diagram of a retarding field analyzer.

while the beam current is increased. When not actively in use, the RFAs were set to passively collect data, to measure the performance of the various chambers as a function of beam dose (see Section 3.2.3). The collector was set to +100 V for all our measurements, to capture any secondary electrons produced on it.

The use of RFAs for electron cloud studies was pioneered at APS [13]; additional studies have been performed at the FNAL Main Injector [14], PEP-II [15], and KEKB [16]. However, the CesrTA RFA program is unprecedented in terms of scale. We have used RFAs to probe the local behavior of the cloud at multiple locations in CESR, under many different beam conditions, and in the presence of several different mitigation schemes.

A few additional considerations were important in the design of the CESR RFAs:

- Some designs needed to fit into confined spaces (~2–3 mm), such as the aperture of the CESR dipole magnets.
- The detectors needed to be shielded from direct beam signal. A 3:1 depth to diameter ratio for the beam pipe holes was determined to be sufficient to effectively shield the RFAs.
- Production of secondary electrons inside the detector should be minimized. To accomplish this, most of the grids were coated with gold, which has a (relatively) low secondary electron yield [17].

1.2. Experimental sections

There are five main electron cloud experimental sections of CESR instrumented with drift RFAs. These include long sections at Q14E and Q14W (the names refer to their proximity to the 14E and 14W quadrupoles, respectively), shorter sections at Q15E and Q15W, and a long straight section at L3. The vacuum chambers at Q15E/W are approximately elliptical and made of aluminum (6063 alloy, as is most of CESR); the chambers at Q14E/W are approximately rectangular and made of copper; the pipe at L3 is circular and stainless steel. The specific needs of each experimental section necessitated the design of several different types of drift RFAs (Section 2.1). Fig. 2 shows the locations of these experimental sections in the CESR ring; more details on each location are given in Section 2.2.

1.3. CESR parameters

The primary advantage of CESR as a test accelerator is its flexibility. At CesrTA, we have been able to study the behavior of the electron cloud as a function of several different beam parameters, a small subset of which are presented here (additional measurements can be found in [18]). Table 1 gives some of the basic parameters of CESR, and lists some of the beam parameters used for electron cloud mitigation studies with RFAs.

1.4. Cloud mitigation

In addition to solenoid windings (which trap electrons near the vacuum chamber wall [3]), the primary method of reducing electron cloud density in a field free region is the use of beam pipe coatings, which reduce the primary and/or secondary emission yield of the chamber. Coatings tested at CesrTA include titanium nitride (TiN) [19], amorphous carbon (aC) [4], diamond-like carbon (DLC) [20], and Ti–Zr–V non-evaporable getter (NEG) [21]. More details on the various coated chambers have been published elsewhere [22].

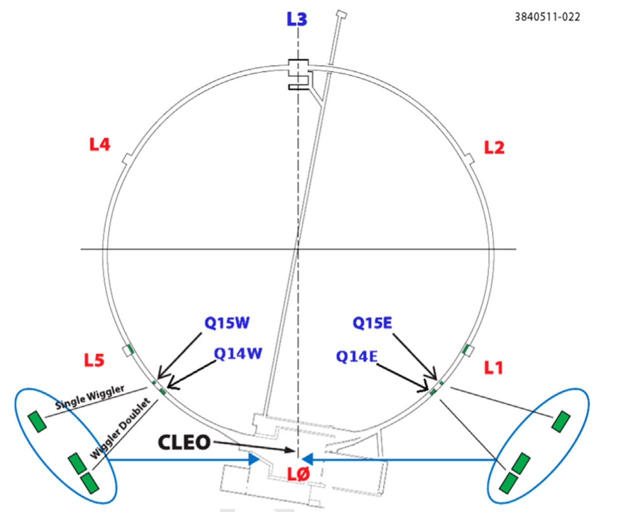

Fig. 2. The reconfiguration of the CESR vacuum system provided space for several electron cloud experimental sections. Drift RFAs are located at Q14E/W, Q15E/W, and L3.

Table 1
CESR parameters and typical beam conditions for electron cloud mitigation studies.

Parameter	Value (s)	Units
Circumference	768	m
Revolution period	2.56	μs
Harmonic number	1281	–
Number of bunches	9, 20, 45	–
Bunch spacing	4–280	ns
Beam energy	5.3	GeV
RMS horizontal emittance	144	nm
RMS vertical emittance	1.3	nm
RMS bunch length	20.1	mm
Bunch current	0–10	mA
Beam species	e^+, e^-	–

2. Instrumentation

The design of the RFAs has evolved over the course of the CesrTA program since it began in mid 2008. A thorough account of the design and construction of the RFAs can be found in Ref. [23]; here we provide an overview.

2.1. RFA styles

Several different styles of RFA have been deployed throughout drift sections in CESR. Table 2 summarizes the key parameters of each style, and Table 3 describes the different types of grids used. A more detailed description of each RFA style follows:

APS style: This design is based on a well understood style of RFA, originally used at APS [13]. It consists of a single collector, and two stainless steel (SST) meshes for grids. APS style RFAs were deployed at Q14E, as well as the L3 NEG test chamber (Section 2.2.3).

Please cite this article as: J.R. Calvey, et al., Nuclear Instruments & Methods in Physics Research A (2014), http://dx.doi.org/10.1016/j.nima.2014.05.051