A PERFECT ELECTRODE TO SUPPRESS SECONDARY ELECTRONS INSIDE THE MAGNETS

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Abstract

An electron cloud due to multipacting in the positron ring of B-factories and the damping ring of the International Linear Collider (ILC) is one of the main concerns. The electron cloud in the drift region can be suppressed by a solenoid. However, the solenoid doesn't work inside a magnet. Numerical studies show that there is strong multipacting in a dipole magnet of a B-factory positron ring. Electrons also can be trapped inside quadrupole and sextupole magnets. The electron cloud from dipole magnets and wigglers in the positron damping ring of the ILC gives a critical limitation on the choice of a circumference of the damping ring, which directly results in a choice of two 6km rings as the baseline for the positron damping ring. Various electrodes have been studied using the program CLOUDLAND. Our studies show that a wire type of the electrode with a few hundred voltages works perfectly to kill the secondary electrons inside various magnets.

INTRODUCTION

In a positron or proton ring, photoelectrons are emitted when the photons by synchrotron radiation hit the vacuum chamber wall. The photoelectrons are accelerated by the beam's space charge force. Therefore, the electrons can accumulate around the chamber center with large density. We call it an electron cloud. The electron cloud interacts with the circulating beam and can cause the two-stream instability. The electrons can also be produced by ionization and other sources. In positron machines, such as KEKB, PEP II and the ILC damping ring, the photoelectrons are the main source.

Various phenomena related to the electron cloud have been observed in recent high intensity positron and proton rings, such as CERN ISR, CERN PS (CPS), SPS with LHC beams, SPS with fixed target beams, LANL-PSR, RHIC in proton operations, APS, KEKB and PEPII [1]. The electron cloud may cause coupled bunch instabilities and beam size enlargement. The coupled bunch instabilities can be damped by a feedback system. However, there is no effective remedy to cure the beam size blow-up actively, which can limit the luminosity improvement of the colliders.

Many methods have been studied to reduce the electron density inside beam chambers in KEKB. A weak solenoid is a good remedy to clear the photoelectrons in the drift region [2, 3]. This has been proven in KEKB LER, PEP II and other accelerators. However, the solenoid does not work inside magnets. Strong multipacting inside dipole magnets has been observed in CERN SPS by an experimental study [4] and in KEKB LER by a numerical simulation [5]. The electron cloud in the dipole and wiggler magnets is dominant in the ILC positron damping ring. An ion clearing electrode has been tested as an electron clearing device in PSR and PF. But it has not shown promise as being effective. The suppression of electrons by clearing fields had a weak effect (~20%) on bunched beam and no effect on coasting beam thresholds [6]. Other ways are tried to reduce the secondary electron emission yield by the chamber surface preparation, such as vacuum chamber coatings, ribbed structures and beam scrubbing. Electrode effect in drift regions has been studied [7]. Here, one remedy to clear the electron cloud in the whole ring is studied. The clearing mechanism in various magnetic fields is described. A fully satisfactory electron clearing can be achieved with this clearing system. The clearing electrodes have a simple mechanical design of the vacuum chamber and may give a tolerable contribution to the machine impedance. A detail description of this system can be found in [8].

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PRINCIPLE

In accelerators and storage rings, ions created by the circulating negatively-charged particles from neutral molecules of the residual gas can be deeply trapped in the beam space-charge potential at the chamber center. A minimum condition for capture of the passing ion is that the transverse field provided by the electrodes equals the maximum beam space charge field so that the trapped ions can get enough energy to escape the beam potential. Therefore, a capturing electric field at the chamber center is necessary, which is strong enough to overcome the field of the beam. As a result, the ions are finally captured to the electrodes supplied with negative voltage.

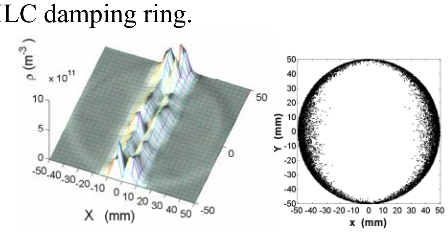
Unlike the ion, secondary electrons are emitted with low energy from the chamber wall, where the beam space charge field is weak. The center of the primary electron energy distribution is close to be 5 eV with an rms (root mean square) energy spread of 5 eV. More than 99% electrons have emission energy less than 25 eV. The secondary electrons have lower emission energy. Note that the electrons could receive energy from the positron or proton beam. The beam kick to the electron near the chamber wall depends on the beam size, beam current and the geometry of the chamber. It is less than 10 eV per bunch for normal parameters of KEKB LER with an average betatron function of 10 m. Therefore, a low potential barrier near the chamber can capture the electrons in the drift region. This necessary potential is about 35V for KEKB LER with the assumption that one electron only receives one beam kick.

This kind of potential can be generated by clearing electrodes consisting of negatively charged striplines paralleling the vacuum chamber so that the electric field provided by the electrodes can repel the electrons and reflect them back to the chamber wall. Because the energy of the secondary electrons from the beam near the pipe surface is low (35eV for KEKB LER), a weak clearing field can sufficiently suppress their emission.

CLEARING SYSTEM IN DIPOLE MAGNET

Inside strong dipole magnets, crossed-field and gradient drifts could not eliminate the electrons because the effects are inversely proportional to the magnetic field strength. Therefore, the clearing electric field must be along the magnetic field line in order to effectively repel the electron. This conclusion holds for other strong magnetic fields.

Fig. 1 (a) shows the photoelectron cloud distribution inside a dipole magnet of KEKB LER [5]. Two multipacting strips near the horizontal center are clearly visible in the figure. The CERN SPS experiments [4] exhibited two similar multipacting strips in a dipole magnet. There is little multipacting in the central region, because the photoelectrons with horizontal coordinate close to zero receive more energy than the energy at which the secondary emission yield is bigger than 1. In order to excite an effective clearing field in vertical direction in a dipole magnet, 2 stripline electrodes are located on the top and bottom of the chamber as shown in Fig. 2. Such electrodes provide a strong trapping field around the surface. The clearing field is perfect with a very weak field at the chamber center and a strong vertical capturing field around both the top and bottom of the chamber, where multipacting could happen as shown in Fig. 1 (a). Therefore, the clearing field has no effect on the positron beam. Fig. 1 shows its clearing effect with different clearing voltage simulated using the code CLOUDLAND. This system requires –300~ –400V clearing voltage to clear the electrons in the dipole magnet. Fig. 3 shows an orbit of an electron motion in a dipole magnet with clearing field. The crossed-field effect is clearly shown in the figure, although this effect is weak. Fig. 4 shows the clearing effect in a dipole magnet of the ILC damping ring.



(a) (b)

Figure 1: Electron distribution in a dipole magnet of KEKB LER with 0 (a) and -400 V (b) clearing field. Magnetic field is 0.25Tesla, bunch intensity is 3.3×10^{10} and bunch spacing is 8ns.

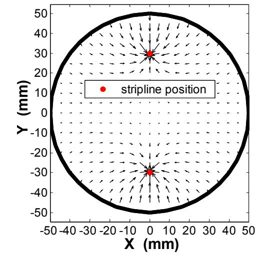


Figure 2: Configuration of electrodes and a clearing field in a dipole magnet.

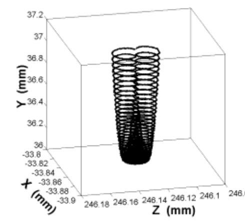
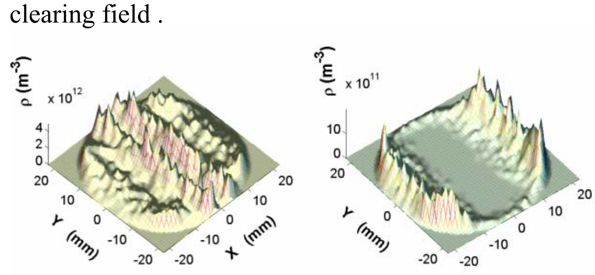


Figure 3: Electron's orbit in a dipole magnet with a clearing field .



(a) (b)

Figure 4: Clearing effect in a dipole magnet of ILC positron damping ring with (a) 0V and (b) -100V. Bunch intensity is 2×10^{10} and bunch spacing is 6 ns.

CLEARING SYSTEM IN MULTIPOLE MAGNETS

In a general multipole magnet, the magnetic field can be expressed as

$$B_r^n = (-1)^{n-1} C r^{n-1} \sin n\theta \,, \qquad (1)$$

$$B_\theta^n = C r^{n-1} \cos n\theta \,, \qquad (2)$$

where *2n* is the number of poles in order to excite the n-th multipole, *n*=1 for a dipole, 2 for a quadrupole and so on. *C* is a constant value for each type of magnets. In a strong magnet, electrons can drift to the chamber center only along the magnetic field lines with the stronger radial field component. These field lines are close to position which satisfies

$$\sin n\theta \sim \pm 1 \,. \qquad (3)$$

These points are the middle position of magnet poles. Therefore, clearing electrodes should be placed at these positions to excite the maximum effective clearing field. A dipole magnet, as discussed in the above section, is the simplest case. Fig. 5 shows a clearing field in a quadrupole magnet. Fig. 6 shows the electron distribution in a quadrupole magnet with 0 and -100V clearing fields.

Without the clearing field, the electron density at the chamber center is very low in both quadrupole and sextupole magnets. But electrons can be deeply trapped around the mirror points of the outer region of these two types of magnets due to a mirror field trapping [9]. Such clearing system gets perfect clearing effects with only –100V voltage inside a quadrupole magnet with a field gradient of 10.3T/m.

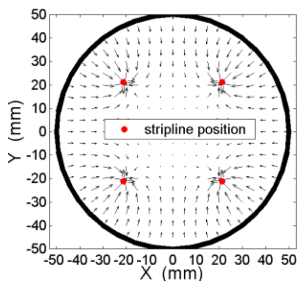
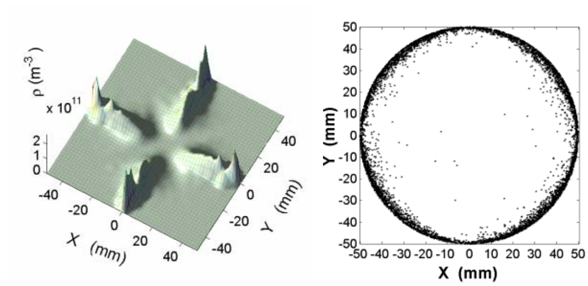


Figure 5: Configuration of electrodes and clearing field in a quadrupole magnet.



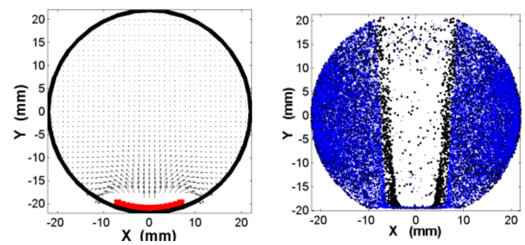
(a) (b)

Figure 6: Effects of a 4 electrodes clearing system in a quadrupole magnet with clearing potential 0V (a) and –100V (b).

COMPARISON WITH OTHER CLEARING SYSTEM

A weak solenoid is a good remedy to clear the photoelectron in the drift region. The mechanism is that the electron makes a gyration motion in the longitudinal magnetic field and finally hits the beam chamber wall. A beam position monitor (BPM) with buttons has small impedance, but it can not excite the effective clearing field around the beam chamber wall due to its small size and position configuration. Hence, it could not serve as a clearing system. A BPM with striplines can work as a good electron clearing system in a dipole magnet with similar mechanism as the stripline system applied here.

Fig. 7(a) shows the configuration of a traditional electrode for ILC. There is only one electrode located at the bottom of the chamber. The electrode is curved with the same shape as the chamber (round one here). A similar electrode was proposed for SPS [10], while the bottom of the chamber surface is flat. The clearing mechanism is to capture all the electrons to the electrode, where the electrode is positively polarized. Therefore, electrons emitted on the top of the surface will cross the chamber to the bottom. The electrode is electrically and thermally isolated to operate at a few hundreds voltage with respect to the beam pipe. Fig. 7(b) shows the clearing effect in the ILC dipole magnet with two different sizes of the electrodes. Electron mutiplacting is suppressed by the electric field. Therefore, there is a low electron density near the beam, which varies with the beam (bunch‘s intensity, spacing, length, etc.). The width of low electron density region increases with the size of the electrode. On the other hand, there are more electrons accumulated out of the electrode region due to the effect of the clearing field. The width of mutipacting region in the ILC dipole is about 15mm, thus a similar width of the electrode is required. A curved stripline electrode is planed to be tested in PEPII in 2007.



(a) (b)

Figure 7: Clearing field (a) and effect (b) of a traditional stripline electrode. The red color in (a) shows the electrode. The blue and black dots in Fig. 7(b) show the electrons with different size of the electrode.

SUMMARY

Various clearing systems based on the multi-striplines are studied using a numerical method. The clearing system works well in various magnetic fields, especially in dipole and quadrupole magnets where multipacting could happen and the solenoid does not work. Such kind of clearing system may contribute to low impedance due to its small size.

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