SUPPRESSION OF THE BEAM INSTABILITY RELATED TO ELECTRON CLOUD AT PEP-II B-FACTORY*

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Abstract

PEP-II B-factory operates at a record high circulating current - currently ~2.5 A in the positron ring. Electron cloud effects became apparent [1] when the positron ring current reached ~ 0.7 A with a bunch current ~1.5 mA. Initially, electron cloud induced beam instabilities significantly limited collider luminosity [2]. However, suppression of the electron cloud related beam instabilities have been achieved with ~30 Gauss solenoids covering the drift sections of LER vacuum chamber.

LER PARAMETERS

The Low Energy Ring (LER) stores 3.1 GeV positrons. The ring circumference is 2199.3 m and the RF harmonic number is 3492. The minimal distance between bunches is two RF buckets or 4.2 ns, which limits the number of bunches in the ring to 1746. Beam emittance (x/y) is 50/2 nm-rad and the bunch length is about 10 mm. The present (27 May 2004) bunch pattern is 1582 bunches in 24 trains and the width of the abort gap is 48 RF buckets. A typical stored beam current is about 2450 mA. The LER lattice has a phase advance of 90 degrees per cell and theaverage beta function in both planes is ~12 m.

LER VACUUM SYSTEM

Five of six LER straight sections have stainless steel cylindrical vacuum chambers with an internal diameter of 89 mm. The chambers were glow discharge cleaned before the installation. The pumping in these sections is done by means of the lump 400 l/s sputter-ion pumps placed every 5–7 meters along the beam line.

The interaction region straight section has extruded octagonal copper chambers with a cross section 50 mm high and 90 mm wide equipped with distributed non-evaporable getter pumps and sputter-ion lump pumps.

The six LER arcs have extruded aluminum vacuum chambers. The drift sections have an elliptical beam chamber with dimensions 59 mm by 95 mm and an antechamber where synchrotron radiation from the dipole magnet propagates to a photon stop placed near the end of the section. Approximately 65% of the synchrotron radiation power from the dipole magnet is absorbed by the first photon stop after the magnet and the other 35% by the second one. 35% of the synchrotron radiation power from the last bending magnet in the arc propagates into the straight. In the arcs the beam channels of the vacuum chamber are coated with TiN to reduce secondary electron emission. Each drift chamber has a sputter-ion pump placed in the antechamber at the beginning of the section and a titanium sublimation getter pump (TSP) placed underneath the photon stop. The dipole magnets are located in the arc every 7.4 m (32 magnets per arc) and the length of the drift section of the chamber is 5.4 m.

ELECTRON CLOUD INDUCED BEAM INSTABILITY

Early in LER commissioning, we observed a sharp nonlinear vacuum pressure increase with the beam current (Fig.1)

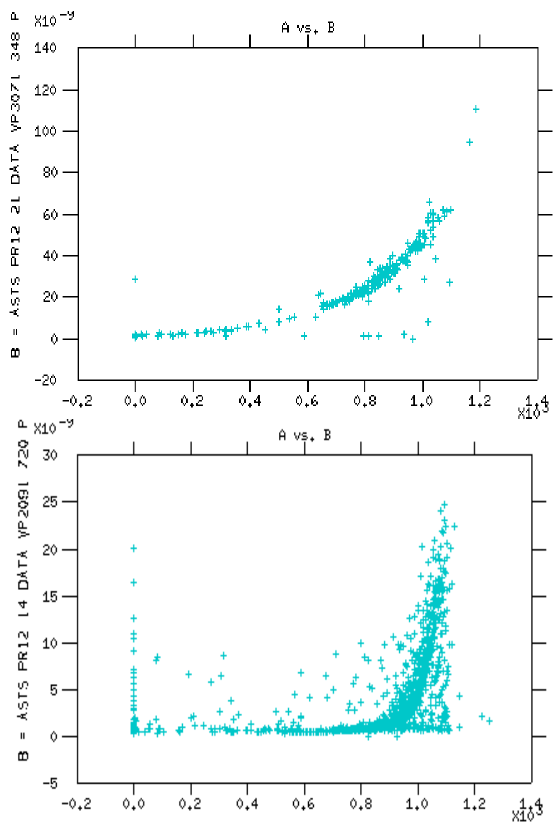

Figure 1: Nonlinear pressure rise with the beam current in the straight section of the ring. The top graph represents the region with a significantly higher level of the synchrotron radiation compared to the example at the bottom.

It has been shown that the cause of the effect is electron multipacting driven by the positron beam.

It has also been determined that in the LER straight sections vacuum pump current increase comes mostly from electrons entering the pump from the beam chamber and beeng collected at the pump anode. Removing the permanent magnets from the ion pump makes it a

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"dedicated electron cloud instrument" sensitive only to the electrons entering the pump from the beam chamber.

The LER arc ion pumps, mounted underneath of the pumping chamber, are not "coupled" to the electrons in the beam chamber. To gather the electron cloud information in the LER arc an electron collecting electrode has been installed in one LER arc vacuum chamber (Fig.2).

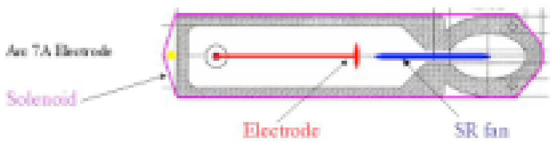

Figure 2: Arc 7A Electrode. Electrode installed in the arc pumping chamber close to the SR fan border to collect electrons propagated from the beam chamber. Electrode is biased ~ +100 Volts relative to the vacuum chamber.

The initial pressure increase due to electron multipacting is significant and consistent with the decrease of the stored beam lifetime. After some time, multipacting electrons remove gases from the vacuum chamber surface and the vacuum pressure improves with time. We did not observe that such processing helps to eliminate or decrease the electron multipacting.

The positron beam size measurements show an increase of the horizontal and vertical beam sizes with the development of electron multipacting. This enlargement has been explained as a result of a single bunch head-tail instability due to the presence of a large number of electrons (electron cloud) close to the positron beam orbit [3].

Electron multipacting has been detected in all drift sections of the LER straights, independent of the level of synchrotron radiation (number of photoelectrons) present in the particular region, this is also true in the LER arcs.

LER SOLENOIDS

The first solenoids have been installed in the straight section of LER with a diagnostic purpose – to understand the origin of the nonlinear pressure increase with the beam current.

It has been shown that an axial magnetic field of several Gauss is sufficient to suppress electron multipacting in the cylindrical SS vacuum chambers in these straights with the circulating beam current of about 1 A. The axial magnetic field keeps the low energy secondary electrons close to the vacuum chamber wall, which reduces the energy that an electron can obtain from the positron bunch. With the lower energy, the electron produces less secondaries, and, if the average secondary emission coefficient becomes less than one, the electron multipacting will be suppressed.

The LER Straight Section solenoids are wound at the surface of the cylindrical or octagonal vacuum chamber using AWG 10 wire (a single layer) with a linear density of about 200 turns per meter. Changes of the solenoid polarity (the direction of the field) take place at the magnetic elements with the size along the beam line of about 0.5 m or larger. Each straight has several (8 to 10) sections of solenoids and each section has a bipolar 12 A, 30 V power supply (~30 Gauss max. field).

The LER Arc solenoids wound at the surface of the drift sections of the vacuum chamber using a four conductor flat cable (AWG 10 conductors) with a linear density of 44 turns per meter. Each arc has two solenoid sections with 16 drift chambers in each section. Solenoids in the section are connected in series with alternating polarity. Individual cable conductors are connected in parallel at the ends of the 16 chambers assembly. The solenoid nominal current is 50 A which corresponds to 27.6 Gauss magnetic field. Each section, a half of an arc, has a single 200 V power supply.

All LER solenoids cover approximately 80% of the ring circumference.

SUPPRESSION OF THE ELECTON CLOUD INSTABILITY

The first solenoids installed in the LER straight sections significantly improved collider performance. Thirteen straight solenoid sections were energized May-02-2000 during routine beam delivery, which icreased the delivered luminosity by about 25% (Fig.3)

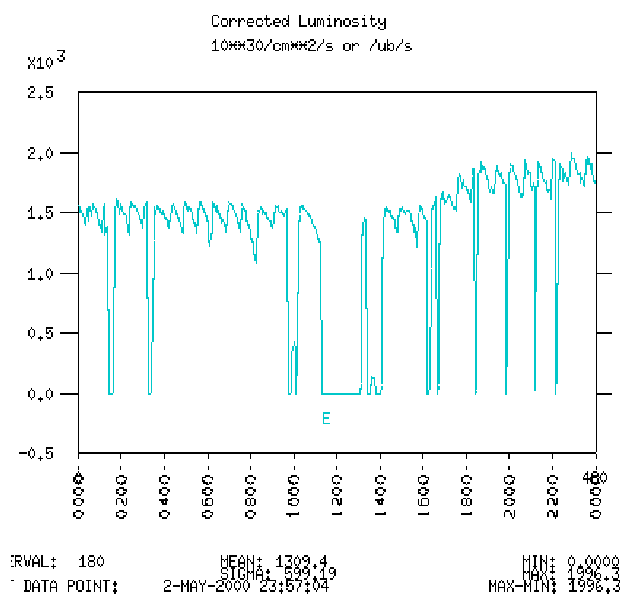

Figure 3: Luminosity improvement due to increase of the number of energized solenoid sections from 10 to 23. The average length of a section is about 9 meters.

It has been shown in a single ring experiment that suppression of electron multipacting in part of the ring decreases the transverse size of the positron beam (fig. 4).

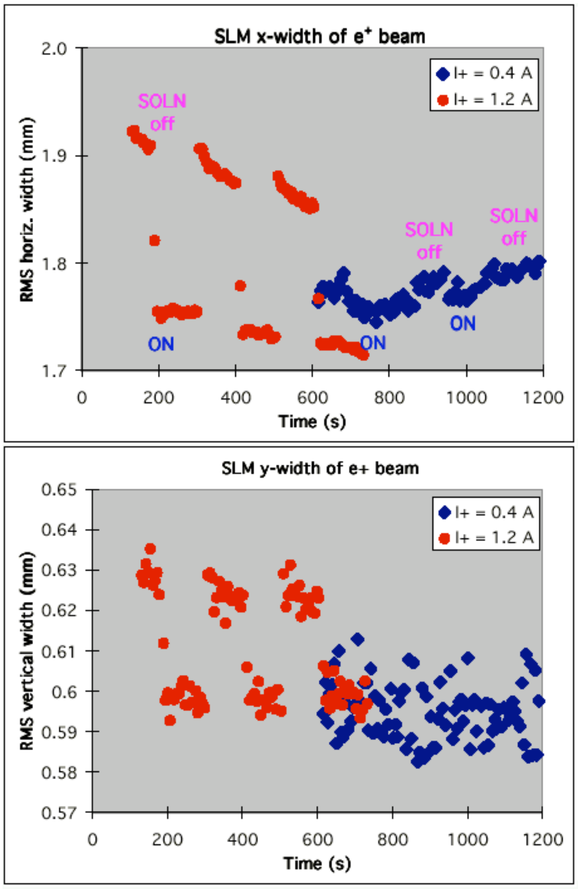

Figure 4: Positron beam sizes driven by the electron cloud with solenoids “on” and “off”. Red points - beam current 1.2 A. Blue points- beam current 0.4 A (below the multipacting threshold).

Switching solenoids “on” and “off” changes the beam sizes only with the high (above the multipacting threshold) beam current. At the time of this experiment (July-31-2000) solenoids had been installed in the three ring straights located 1/3 of the ring circumference apart. The data show that the transfer beam size with a 1.2 A beam current and with the solenoids “on” does not exceed the beam size with a 0.4 A beam current, i.e. the transfer beam instability was suppressed with ~ 300 meters of solenoids in the three LER straights. Although, it is possible that the result will be different with different parameters of the ring such as beam current, fill pattern, etc.

Since July 2000 the LER current has increased by more than a factor of two. The number of populated bunches in the ring has increased ~3 times. LER solenoids cover to-date all available space – about 80% of the ring circumference.

In order to check if 20% of the ring circumference with multipacting electrons is affecting collider performance all solenoids in half of the arc 7 (~5% of the ring circumference) were switched “off” while the beams were in collision. The response of the arc 7A electrode (Fig. 5) shows that without the solenoid field, electron multipacting takes place in the TiN coated arc vacuum chamber. Fig. 6 demonstrates that switching arc solenoids “off” and “on” does not affect the collider performance.

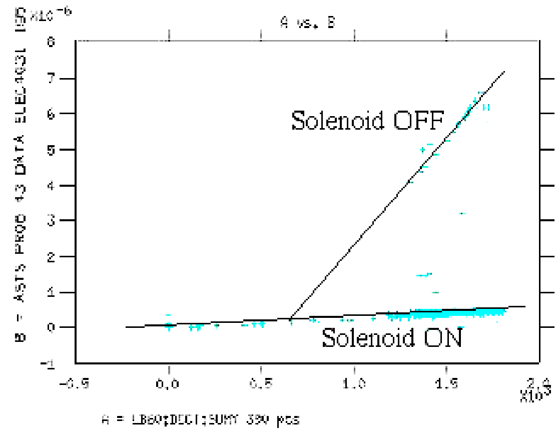

Figure 5: Arc 7A Electrode current as a function of the beam current with the solenoid “on” and “off”.

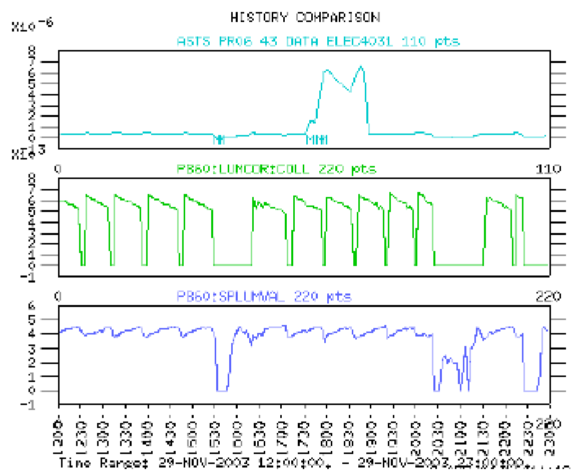

Figure 6: Electrode current (upper plot), luminosity (middle plot) and specific luminosity (lower plot). Solenoids are ON-OFF in arc 7A. The rise of the electrode current is clearly seen when the solenoids are switched off.

Measurements show that for the present LER beam parameters, a solenoid field of several gauss is sufficient to suppress electron multipacting. Figure 7 shows such data for the downstream section of the straight where the level of synchrotron radiation is low.

The numerical simulations of the electron cloud inside the straight section SS vacuum chamber show that with higher intensity positron beams (2 mA/bunch, bunch pattern by 2) a higher solenoid magnetic field (about 60 Gauss) is needed in orer to to suppress multipacting [5]. In the numerical model we used a secondary electron emission yield that was experimentally measured at SLAC [6]. To meet this challenge the LER straight solenoids have been upgraded and are capable of producing field of up to 90 Gauss.

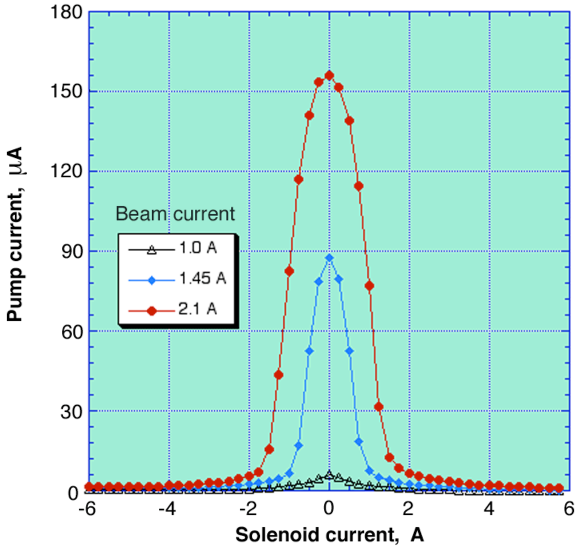

Figure 7: Pump 2021 PR04 with the magnet removed. The 6 A solenoid current corresponds to a magnetic field of 15 Gauss.

ELECTRON CLOUD AND THE HIGH ORDER MODES

The following is a study of the interaction between the electron cloud and High Order Mode (HOM) fields propagating in the LER straight vacuum chamber. HOM are generated at collimators in the upstream section of the straight [7]. A spectrum Analyzer pick-up is located at the end of the straight. Solenoids at the beam pipe between the collimators and the Analyzer pick-up (~20 meters of solenoids) can be switched “off” and “on” creating and removing the electron cloud in the beam pipe. The electron density in the beam pipe is monitored with the “no magnet” ion pump (VP2021 PR04). The goal of the experiment is to detect HOM modulation synchronous with the electron density in the beam pipe.

A typical HOM spectrum is shown at Fig.8. Figure 9 shows several HOM amplitudes, LER beam current and the signal of the ion pump proportional to the electron density in the beam pipe.

LER beam parameters are: max, beam current – 1300 mA; number of bunches – 1126 (average bunch current ~1.2 mA).

We did not find any noticeable modulation of the HOM amplitudes with the density of the electron cloud (Fig.9).

ACKNOWLEDGEMENTS

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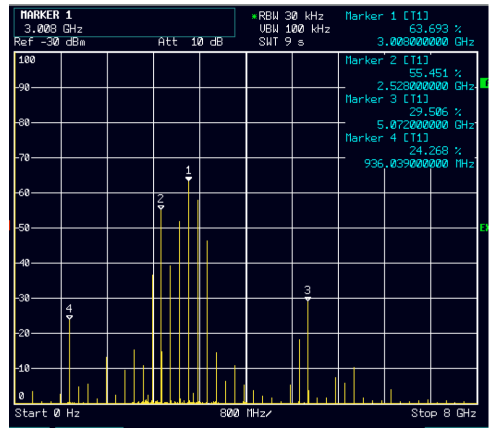

Figure 8: Spectrum of HOM propagating through the straight section.

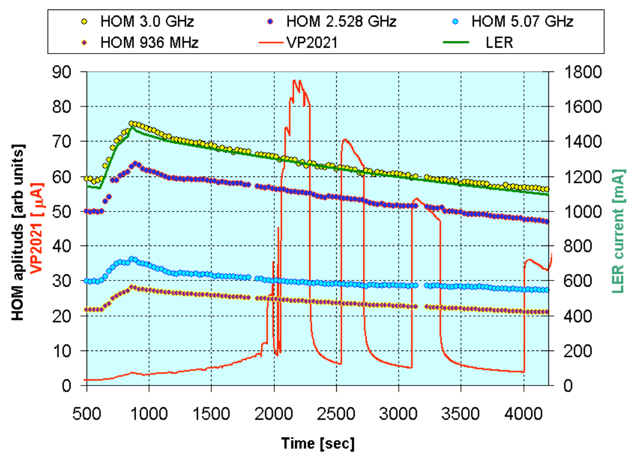

Figure 9: HOM amplitudes (yellow, pink, blue and brown circles), pump current (red solid line) and LER current (green solid line).

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