Low Loss Parameter for New CESR Electrostatic Separators *

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Abstract

The electrostatic separators in the e^+e^- storage ring CESR have been large contributors to the overall impedance. In addition, the RF fields generated by the beam passing through the separators have seriously degraded the high voltage performance. These problems are becoming more acute as the beam current and bunch current are increased to meet our luminosity goals. A new separator has been designed for which bench measurements on a full scale mockup indicate we can expect a loss parameter of only 0.123 V/pC – about one quarter the value for the existing separators. A factor of two reduction came from tapering the ends. The other factor of two came from the unique ground electrode structure, which serves to keep electromagnetic energy close to the beam. At the ends of the separator, the taper and ground electrode are blended together in an unusual surface.

Separators and High Beam Currents

Electrostatic separators in e^+e^- storage rings are used to deflect electrons and positrons with opposite angles thereby providing different closed orbits. By carefully choosing the separator locations as well as controlling the betatron phase advance throughout the ring, closed orbits can be obtained with good separation between the beams at all unwanted collision points. This scheme allows multiple bunches of electrons and positrons to be stored, thereby increasing the luminosity.

When a bunch passes through a separator it leaves energy behind in the form of broad-band RF electromagnetic fields. This field energy is dissipated in the separator vacuum chamber, electrodes and especially any series resistors in the high voltage circuit. As the beam current is increased, the power absorbed from the beam by the separators also increases and several technical problems arise. The original CESR separators experienced increased breakdown (high voltage arcing) rates with beam current, burning of energy absorbing resistors, vapor lock due to boiling Freon coolant, and excessive Freon pressure due to Freon heating. These problems occurred at total stored beam currents below 150 mA where the estimated total power absorbed is about 3 kW per separator. Soon CESR will have the RF capacity to support 600 mA of average beam current. For a 14 bunch configuration, at this current the original separators would each dissipate about 17 kW.

Absorbing many kilowatts of broad band RF power in a separator is made quite difficult by the fact that the electrodes, feedthroughs, cables and power supplies must simultaneously operate around ±100 kV with a very low breakdown rate[1]. To obtain optimum performance at high beam current every effort must be made to reduce the overall amount of power absorbed by the separator.

New separators are being constructed whose design addresses the problems of higher beam currents without compromizing a reliable DC high voltage design. In particular, electrode gaps and surface profiles were chosen so that the ratio of peak electric field on the electrodes to deflecting electric field is substantially lower than in the existing separators. Having more or less fixed the high voltage electrode design, it was somewhat surprising to find that there was still enough design freedom left to effectively reduce the loss parameter. Nevertheless, by concentrating on reducing the loss from the ends of the separator vacuum chamber, we were able to obtain a loss parameter of about one quarter that of the original CESR separators. At 600 mA of total stored beam current, the new separators are expected to dissipated only about 4 kW – almost the same power as the existing separators in CESR with only 150 mA of total beam current.

Design for Low Loss Parameter

There are two important ideas implemented in the design of the new separators which reduce the loss parameter:

- close proximity ground electrodes
- tapered ends

The ground electrode idea is to fill with metal some of the region which is effectively at ground potential midway between the plus and minus electrodes. (See Figure 1.) This

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[1] The RF fields themselves can add a voltage 'spike' of tens of kV to the DC voltage through the peak beam current and the characteristic transmission line impedance of the separator components.

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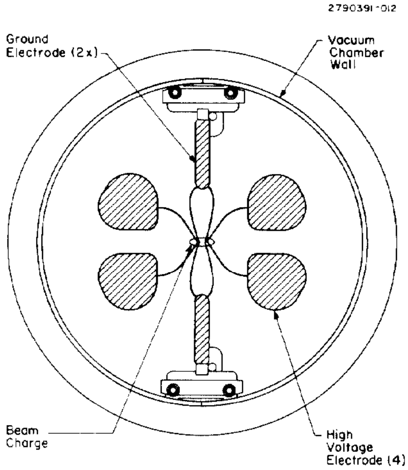

Figure 1: Electric field lines emanating from the charge in a bunch passing through the separator electrodes are shown schematically in this section taken through the middle of the separator. Very few field lines make it past the electrode structure where their energy would be lost, so most of the field energy is kept relatively close to the bunch.

metal helps to confine the electromagnetic fields that travel along with the bunch, keeping them from spreading into the larger part of the vacuum chamber where their energy would be lost. [1] Electromagnetic energy becomes 'lost' to the bunch if it is allowed to propagate far enough from the beam axis that it cannot reflect off the metal surfaces and catch up with the back of the bunch before the bunch leaves the separator structure. Additional electrodes at intermediate potentials would be even more effective at reducing the loss, but would also require additional feedthroughs thus reducing the high voltage reliability and raising the cost.

The other important idea, tapering the ends helps to reduce the amount of energy lost by effectively producing less perturbation of the bunch electromagnetic fields. (See Figure 2 on next page.) The surface profile of the vacuum chamber is chosen so that radii of curvature are large compared with the bunch length. Short radii would cause intensification of field lines and increase the amount of electromagnetic field energy at the surface.

These two ideas are merged in one unusual surface which smoothly guides the field energy from a normal almost elliptical vacuum chamber geometry to the multiple electrode geometry and then back to the normal vacuum chamber. (See Figure 2.)

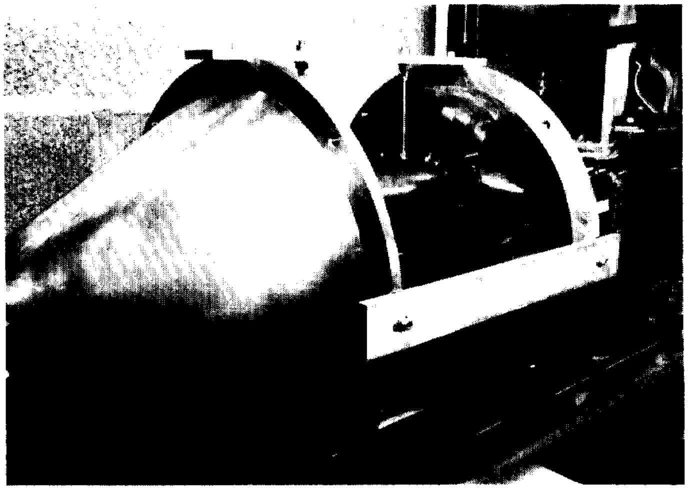

Figure 3: This photo of the separator mockup shows the 30° taper, high voltage and ground electrodes, and the open wall configuration used in the measurements.

No.	Description	k [V/pC]
(1)	Empty Chamber, 30° tapers, no electrodes	0.206
(2)	Ground electrodes, no high voltage electrodes, straight ends	0.0917
(3)	Ground electrodes, no high voltage electrodes, blended ends	0.0730
(4)	All electrodes present, blended ends	0.123
(5)	High voltage electrodes, no ground electrodes	0.226

Table 1: The measured energy loss parameter k, is shown here for different configurations of the separator mockup. The effective bunch length was 2.1 *cm*.

Measurements

The bench measurement of the beam energy loss parameter k for the new CESR horizontal separators was performed on the Cornell University G machine [2]. A detailed description of this machine may be found in reference [2]. The method is based on the technique first described by Sands and Rees. [3]

The following is a physical description of the mockup designed for the G parameter measurement studies. A photo of the actual mockup is given in Figure 3. Considering the maximum measurement arm space available on the G machine is only 4 feet, a relatively short model was chosen. The tapers at both ends of mockup have the same size, both in longitudinal and transverse dimensions, as the actual separator to be built. We kept the gaps between the electrodes and chamber wall, the cross section of the ground electrode, and the transverse dimensions, close to the actual separator values. To smooth irregularities at the intersection of the ground electrode and taper surface, the ends of the ground electrode were spread using metal tape to form a concave surface.

Because the ground electrodes and the high voltage electrodes are so close to the central conductor they dominate

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[2] 'G' is a currently less conventional symbol for the energy loss parameter. k [V/pC] $= G[m^{-1}] * 0.009$

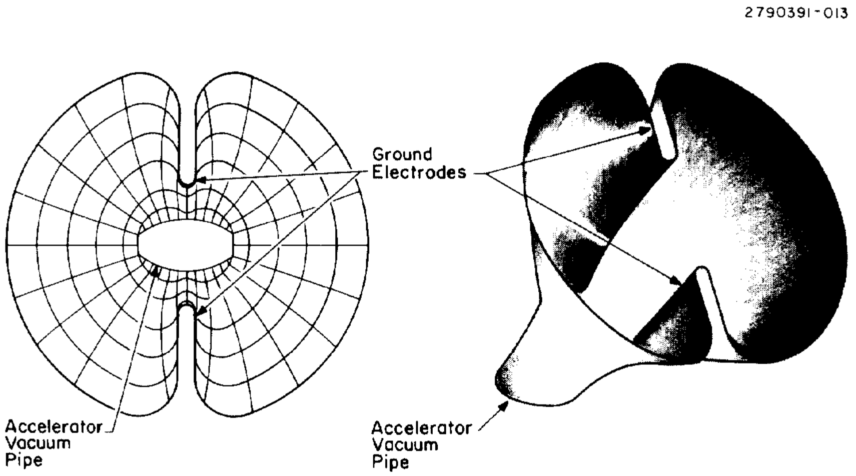

Figure 2: The surface connecting the beam tube to the main part of the separator vacuum chamber is shown in two views.

the pattern of the wake field. We chose to leave out the exterior wall (corresponding to the vacuum chamber wall) on the straight section; only four aluminum bars were used to fix the tapers together. A measurement of k with and without the outside wall in the straight section was made, and no significant difference was found.

Several measurements were made with various parts of the separator structure installed. The results presented in Table 1, show:

- Comparing (4) with (5), we can see that the addition of ground electrodes approximately halves the k value.
- A measurement was made for a mockup of existing CESR horizontal separators with the results [2]:

  $$k\ [V/pC] = 1.05 \left(\frac{1}{\sigma[cm]}\right)^{1.176}$$

  With $\sigma = 2.1\ cm$, we have: $k = 0.440\ V/pC$. Compared with (4), $k = 0.123\ V/pC$, we find the new design has about one quarter the loss parameter of the existing separator.
- Blending the ends of the ground electrodes into the taper reduces k by about 20% compared with the straight ends' model.

The k values in Table 1 are the average of four measurements performed at different times. Typically, the variation of the measurements was 0.004 V/pC. The uncertainty depended on many variables including the timing, the relative amounts of inductive to the resistive impedance of the mockup, the signal to noise ratio, the temperature drift, and uncertainty of baseline signal level, etc. A considerable source of variation came from bolting and unbolting the nulling piece and the mockup. Exchange of components can cause a change in the position of the axis of the central wire and an error in the length of the transmission arms.

A systematic correction has been added to the calculation of k which takes into account the variation of the current pulse due to the secondary fields produced by the current pulse and the perturbations in the chamber geometry [3]. The correction is explained as follows: In the storage ring, the longitudinal electric fields due to the bunch will change the energy of the particles in the bunch, but will not have any significant effect on the charge and current distribution on the bunch. One other hand, in the G machine the fields induced by the simulated bunch interact with the chamber walls and return to the central conductor. The current pulse changes to match the boundary conditions of the conducting wire. The magnitude of the change is related with the dimension of central wire. In our case, about 10% correction was made to the calculation for G value.

References

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