MASTER

ELECTRON CLEARING AND DIMENSIONAL TOLERANCE FOR THE ISA CHAMBER

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I. Introduction

In the straight sections of the ISA ring the clearing of the low energy electrons produced by the beam-gas collisions will take place by longitudinal motion. Thus, an electron of low energy, which is prevented from escaping transversely by the attractive field of the beam, will receive successive kicks by the circulating protons and thereby acquire sufficient energy to travel longitudinally toward the clearing electrodes. However, a discontinuity or step in the chamber diameter, which occurs within an axial distance equal to a few diameters, gives rise to a potential difference along the chamber axis. In the case of a section of chambers which has a larger diameter, that is, a small cavity, the two steps result in a longitudinal potential well, or attractive region. It is then necessary that the electrons be given additional energy in order to overcome this longitudinal trapping potential. Though the ISA design¹ envisions the placement of clearing electrodes at the location of significant chamber discontinuities, particularly in the experimental insertions, it is desirable to have some estimate of the magnitude of the diameter discontinuity that can be tolerated without a clearing electrode.

II. Longitudinal Potential

We assume a cylindrical geometry with a circular beam of diameter (2a) centrally located in a circular chamber of diameter D. The transverse potential V between the beam of current I and the wall is then

$$V = \frac{I}{2\pi\epsilon_0 c} \ln \left(\frac{D}{2a} \right) . \quad (1)$$

Corresponding to a small increment in diameter ΔD of the chamber, there is a change in the beam to wall potential ΔV given by

$$\frac{\Delta V}{V} = \frac{1}{\ln (D/2a)} \frac{\Delta D}{D} . \quad (2)$$

1. J.C. Herrera, Proc. 1975 ISABELLE Summer Study, Brookhaven, BNL 20550 p. 658.

Since, under the stationary electrical conditions that exist, the difference of potential between two locations on the chamber wall must be zero, it follows that ΔV in Eq. (2) is also equal to the longitudinal potential due to the diameter discontinuity. The ISA has a chamber diameter of 8 cm and a typical value of beam diameter (2a) is 0.28 cm. Equation (2) now takes on the form:

$$\frac{\Delta V}{V} = 0.3 \frac{\Delta D}{D} \quad (3)$$

One can then see that a 10% change in diameter (8 mm) is associated with a longitudinal potential equal to 3% of the potential to the chamber wall. For a current of 10 A the latter voltage is, per Eq. (1), 2000 V and the longitudinal potential is therefore 60 V.

III. Clearing Rate Due to Beam Heating

In a previous report,² the various mechanisms that contribute to the clearing of the proton beam have been discussed. It is there shown that in order to achieve the desired neutralization (N_e/N_p) of 10^{-4} in the ISA, a clearing rate, R_c , equal to 100/sec is necessary. Thus, in the presence of a chamber discontinuity, it is required that the clearing rate due to beam heating, R_c^{BH} , be at least equal to 100/sec. In this way the electrons will be pushed along by the protons and given the requisite energy, ΔV , at a rate sufficient to yield a net neutralization of 10^{-4} . Referring to Ref. 2, we see that R_c^{BH} is given by the expression

$$R_c^{BH} = \frac{1}{\Delta V} \frac{d\bar{E}}{dt} = \frac{2I}{ea^2} \frac{mc^2}{\Delta V} \ln \left[\frac{(\Delta V)}{2mc^2} \left(\frac{b}{r_e} \right)^2 \right] \quad (4)$$

where:

- e = electronic charge (Coulomb)
- mc^2 = rest mass energy of electron (0.511×10^6 eV)
- r_e = classical electron radius (2.818×10^{-13} cm)
- b = maximum impact parameter (cm) .

Assuming a longitudinal potential equivalent to $\Delta V = 100$ eV, and using the typical values: $I = 10$ A, $a = 0.14$ cm, and $b = 0.28$ cm, we find that $R_c^{BH} = 119/\text{sec}$, a value greater than $100/\text{sec}$.

IV. Dimensional Tolerance

The discontinuity associated with a longitudinal potential of 100 V is now readily derived from Eq. (3). For $V = 2000$ V and $D = 8$ cm, we calculate a value of $\Delta D = 1.33$ cm. We may therefore conclude: If longitudinal beam heating alone is to provide adequate electron clearing in the ISA straight section chambers, radial discontinuities should be less than about 7 mm in a chamber of 8 cm diameter.

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