MODELLING OF E-CLOUD BUILD-UP IN GROOVED VACUUM CHAMBERS USING POSINST*

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Abstract

Use of grooved vacuum chambers have been suggested as a way to limit electron cloud accumulation in the ILC-DR. We report on simulations carried out using an augmented version of POSINST, accounting for e-cloud dynamics in the presence of grooves, and make contact with previous estimates of an effective secondary electron yield for grooved surfaces.

INTRODUCTION

Electron cloud accumulation and related instabilities are of serious concern for the International Linear Collider (ILC) positron damping ring (DR). Surface coating, scrubbing, and conditioning are known methods to mitigate electron build-up but may be insufficient. It is believed that to achieve the baseline specifications for the machine performance [1] effective techniques to suppress electron cloud build-up beyond levels currently demonstrated will have to be developed. As a consequence 'non-traditional' techniques, including clearing electrodes and grooved vacuum chambers, are being actively investigated.

Analytical and numerical modelling of the interaction of electrons with grooved surfaces have indicated the effectiveness of this technique and accelerator-based experiments to confirm these results are planned or already underway. Previous simulations [2, 3, 4] so far have generally aimed at determining an effective secondary electron yield (SEY) by considering a beam of monochromatic electrons (primary particles) impinging on the grooved surface and keeping track of the electrons (secondary particles) emerging from the groove regions – a setting typical of laboratory bench measurements where an effective SEY can easily be determined as a function of the energy of the primary electron beam. In the work described here we are interested in a direct characterization of the electron cloud build-up in the vacuum chamber of an operating accelerator in the presence of both the driving beam and space-charge from the electrons. This will be useful for a closer comparison between current e-cloud modelling and accelerator-based measurements.

IMPLEMENTATION AND SIMULATIONS

We carried out our work by augmenting the current version of the code POSINST to include the option to follow

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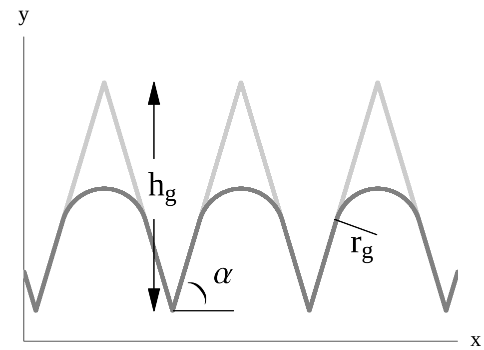

Figure 1: Triangular grooves with sharp tips are characterized by the steepness angle α and height h_g. Grooves with rounded tips have the additional parameter r_g, the radius of the groove tip. The interior of the chamber is on the top side.

the electron dynamics in the presence of grooves. Electron-surface collisions and secondary electron production following those collisions are modelled using the modules already built in POSINST [5, 6]. At present we have a provision to simulate rectangular cross-section vacuum chambers with triangular grooves located on the top and bottom sides – closely reproducing the configuration of a proposed e-cloud experiment at PEP-II. The steepness angle α of the triangular grooves as well their height (see Fig. 1) are input parameters controlled by the user. An option to include rounding of the groove tips has also been implemented. Space charge from the electrons is included in the model. However, at present the electric field lines are terminated on a hypothetical smooth surface immediately behind the grooves thus neglecting possible field enhancement by the groove tips.

Grooves reduce the effective SEY by increasing the probability that immediately after production secondary electrons may be rapidly reabsorbed through wall collisions and therefore prevented from contributing to multipacting. The effectiveness of the grooves strongly depends on the geometry. For triangular grooves the existence of a critical angle for effective suppression of the electron cloud can be clearly extracted from Fig. 2 and 3. Fig. 3 shows the maximum linear electron density accumulated during the single passage of a 111-positron bunch train through one of the ILC DR dipoles as a function of the triangular grooves steepness angle α. All the calculations reported in this paper are for the ILC-DR dipoles. The bunch train is 0.68 μs long, for a 6.1 ns separation between bunches. The bunches

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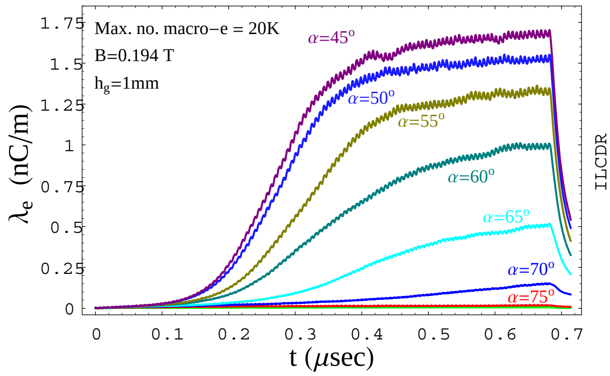

Figure 2: E-cloud accumulation during passage of a 0.68 μsec bunch train for various steepness angles of triangular (sharp edge) grooves.

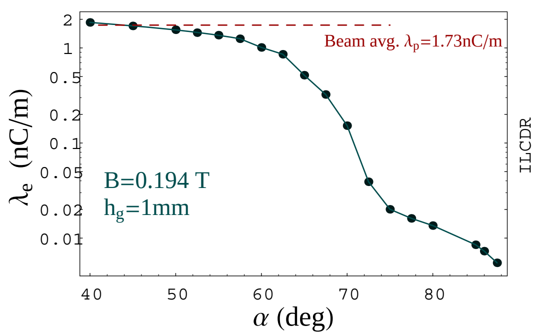

Figure 3: Maximum linear density of electrons accumulated during a passage of a train of positron bunches in a ILC damping ring dipole *vs.* steepness angle α of triangular grooves (with sharp edges). Al chamber with $\delta_{\max} = 1.75$.

have a population of 2×10^{10} and sizes $\sigma_x = 0.62$ mm, $\sigma_y = 8$ μm, $\sigma_z = 6$ mm (this is smaller than the current baseline value $\sigma_z = 9$ mm). The magnetic field in the dipoles is about 0.2 T. The calculation is for grooves height $h_g = 1$ mm and the model of SEY adopted was that of Al, with maximum SEY set to $\delta_{\max} = 1.75$.

A drop in electron density by about two orders of magnitude compared to the smooth-chamber case is seen to occur for steepness angle α larger than 75°. For shallower angles the electron accumulation is increasingly larger, approaching and in fact slightly overtaking the electron cloud density for a smooth surface when $\alpha < 45°$. This latter behavior is not implausible. It is a basic property of the model employed in the calculation that the SEY is minimum for electrons hitting the surface at a normal incidence. At a smaller α the grooves become ineffective at capturing the secondaries and the effective SEY may become larger if on average the primary electrons hit the surface off the local normal.

To make contact with previous studies we extracted an effective max SEY from our data by making comparison

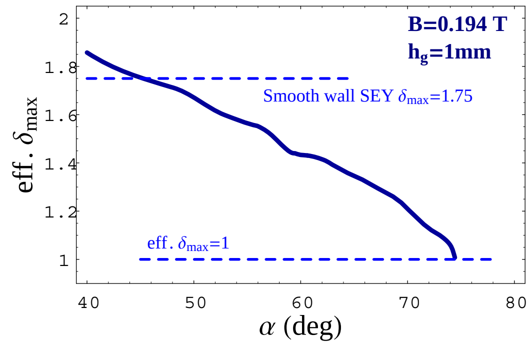

Figure 4: Effective SEY as a function of the steepness angle α as derived from the simulation of e-cloud build-up.

with the electron density we would obtain in a smooth chamber as we vary the value of $\delta_{\max}$ for the smooth surface. An effective yield corresponding to a given α is then defined as that $\delta_{\max}$ producing the same maximum e-cloud accumulation in a smooth chamber during the passage of the same train of positron bunches. The result is shown in Fig. 4 where the effective max. SEY is plotted as a function of the steepness angle α. The curve is reasonably smooth and again indicates $\alpha \simeq 75°$ as the critical angle where the effective secondary yield crosses into values smaller than unity corresponding to effective electron cloud suppression.

Our results are substantially consistent with calculations reported in [2], where for the same groove geometry (and same maximum SEY for the smooth surfaces) an effective secondary yield as a function of energy is found to remain <1 for angles just above $\alpha \simeq 70°$. Both the present and Wang *et al.*'s findings are somewhat less pessimistic than those obtained by W. Bruns [4], which indicate that an angle $\alpha = 75°$ would still yield an effective SEY larger than unity; $\alpha = 75°$ was the largest steepness angle reported in [4] but a rough extrapolation from the data shown would appear to predict a noticeably larger critical angle for a SEY<1.

There have been speculations that these discrepancies in the results could perhaps be ascribed to differences in the SEY model at low electron energies. While in the model used by W. Bruns $\delta(E)$ is unity at zero energy [7, 8] (and displays a local minimum at low energy) in the POSINST model (and possibly in L. Wang's calculations [2]), the same limit is $\delta(0) \simeq 0.5$ [6]. It is not unlikely that the capturing properties of the grooves may be sensitive to the details of the yield curve at small energy but we have yet to run simulations to test this supposition.

A systematic study of the dependence of the electron cloud build- up for a given geometry of the grooved surface on the strength of the magnetic field is shown in Fig. 5, where the magnetic field values for the ILC DRs dipoles and wigglers have been highlighted (but in both cases the calculation is done for a dipole with uniform B-field). In general a larger magnetic field makes the triangular grooving less effective. The various levels of e-cloud accumu-

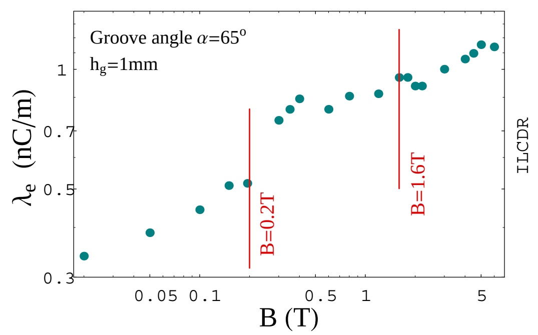

Figure 5: Max. accumulated e-cloud as a function of the magnetic field for a given grooved surface geometry.

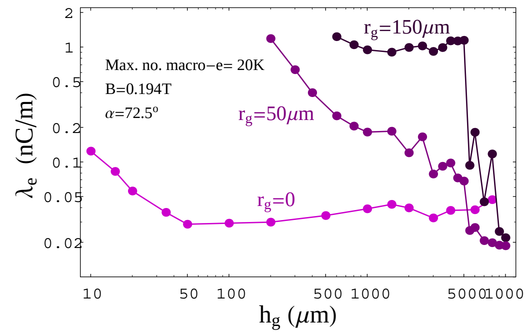

Figure 7: Max. accumulated e-cloud, for fixed α, as a function of the groove hight h_g for three choices of the grove tip radius r_g.

lation shown in the picture also reflect a larger number of primary photo-electrons produced at a larger B-field.

A drawback of grooving the inner surface of a vacuum chamber is an enhancement of the resistive wall impedance [2]. A possible remedy is to introduce some rounding at the edges of the triangular grooves hence reducing the field enhancement caused by sharp boundaries. Rounding the tips, however, can be expected to degrade the e-cloud suppression property of the grooves (electrons impinging on the rounded surface on the groove tips are less likely to be recaptured) and its modelling should be included in the simulations. Moreover, studying the effect of the tip rounding would be important in setting acceptable tolerances on the machining of the grooves. The present implementation in POSINST only allows for the rounding of the triangular groove edges facing the inner side of the chamber (see Fig. 1).

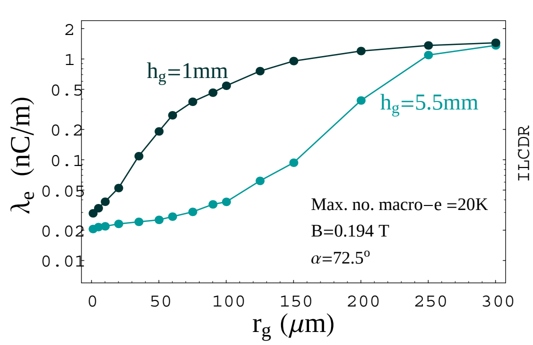

Figure 6: Max. accumulated e-cloud for fixed α, as a function of the groove tip radius r_g for two choices of groove height.

Our simulations confirm the expected degradation of e-cloud suppression by the rounding of the tips. In Fig. 6 the maximum e-cloud density accumulated during the passage of a bunch train is reported as a function of the tip radius r_g for a given steepness angle α and two choices of the groove height h_g. For $h_g = 1$ mm we observe a substantial increase of the e-cloud density for $r_g \simeq 50$ μm or larger. The simulations suggest that one way to recover the suppression of electrons is to deepen the grooves. For a fixed steepness angle this results into a smaller number of grooves per unit-length and a smaller ratio between rounded tip surface and groove aperture. The same picture shows that a 5.5 mm groove height could withstand a rounding radius up to 100 μm without a substantial degradation of the grooves effectiveness.

Finally, a study of the dependence of electron accumulation as a function of the groove height for three choices of the rounding tip radius r_g is reported in Fig. 7 confirming that sufficiently deep grooves can suppress the electron cloud build-up significantly regardless of the tip radius.

In conclusion, we have enhanced the current version of POSINST to allow for modelling of the electron cloud dynamics in grooved vacuum chambers. We expect this to be a useful feature in particular for simulation of accelerator-based experimental measurements presently under consideration.

Interesting conversations with W. Bruns and R. Cimino, are gratefully acknowledged.

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