RESISTIVE WALL WAKES AND CLEARING ELECTRODES*

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Abstract

One electron and one positron damping ring are foreseen for the International Linear Collider (ILC). Damping rings are necessary to reduce the emittances delivered by the particle sources to the small values required for luminosity production. In this paper the effect of resistive wall wakes on the clearing electrodes, which are one option to mitigate or suppress the effects due to electron clouds, are investigated. Furthermore the resistive wall effects of NEG coating and the implications on transverse mode coupling instabilities are presented.

INTRODUCTION

Damping rings are necessary to reduce the emittances obtained from the particle sources to the design values of the linear collider. In the recent reference design of the International Linear Collider (ILC) [1] one electron and one positron damping ring, each about 6.7 km long, are foreseen. The main parameters of the damping rings are listed in Table 1.

Table 1: ILC DR Parameters

Parameter	ILC DR
Energy / GeV	5
Circumference /m	6695
RF Frequency / MHz	650
RF harmonic number	14516
RF Voltage / MV	24
Momentum compaction	1.22 10-3
Synchrotron tune	0.067
Total current / mA	376
Number of bunches	2625
Bunch population / 10^{10}	2.0
Bunch separation / ns	7.69
Emittance (horz.) /nm	0.51
Bunch length / mm	9
Damping time H/V/L / ms	25.7 / 25.7 / 12.9

In positron storage rings electrons produced by photoemission, ionization and secondary emission accumulate in the vacuum chamber forming an “electron cloud”. The interaction of the electron cloud with the positron beam can cause transverse single bunch instabilities [2] leading finally to an emittance blow up. These effects have been studied in [3, 4] using computer simulations and analytical estimates.

Simulations indicate that the use of clearing electrodes is an effective method to suppress the electron effects [5, 6, 1]. Furthermore it has been proposed to use TiVrZr films as an effective getter material (NEG pump) with a low secondary emission coefficient inside the vacuum system of the damping rings [7].

CLEARING ELECTRODES

There exist different designs for the clearing electrodes to minimize the effect of the geometric impedance. A schematic layout of a clearing electrode is shown in Fig. 1. A metallic electrode is mounted in the vacuum pipe using feed-throughs.

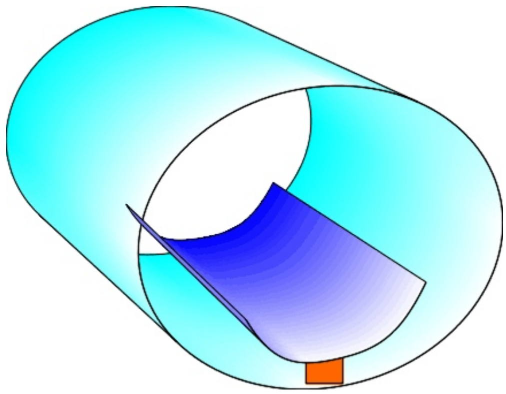

Figure 1: Schematic layout of a clearing electrode.

In addition, other designs with continuous clearing electrodes based on double layers of enamel coating have been proposed [8,9,10]. The calculation of the resistive wall wakefields, which are presented in this paper, are based on metallic surfaces in a round beam pipe. It is assumed that enamel layers are not visible for the beam, which is a rather crude approximation.

RESISTIVE WALL WAKEFIELD

The wake field due to the resistivity of the metallic wall has been calculated for various geometries [11, 12, 13, 14, 15]. To estimate the resistive wall wake fields for the damping ring the results for a round vacuum chamber have been used [12]. The normalized longitudinal and transverse wake potential for a Gaussian bunch are shown in Fig. 2.

From the wake potential the total loss parameter and the kick parameter are calculated:

$$k_{loss} = \int ds\ \lambda(s)\ W_{\|}(s) \qquad (1)$$

$$k_{\perp} = \int ds\ \lambda(s)\, W_{\perp}(s) \qquad (2)$$

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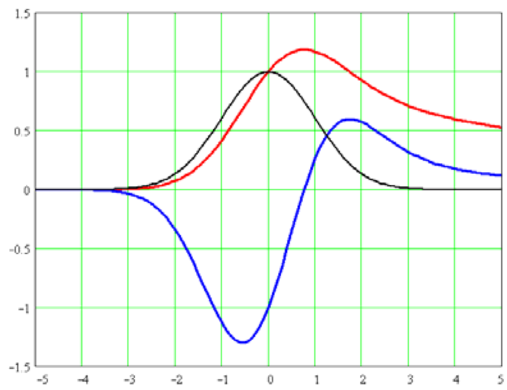

Figure 2: Normalized longitudinal (blue line) and transverse (red line) resistive wall wake potential of an Gaussian bunch (black line).

For a round beam pipe with radius r and conductivity σ_{cond} the loss and kick parameter are [13, 15]:

$$k_{loss} = \frac{1}{4\pi^2\sqrt{2}}\Gamma(\tfrac{3}{4})\ \frac{c}{r\ (\sigma_z)^{3/2}}\sqrt{\frac{Z_0}{\sigma_{cond.}}}, \quad (3)$$

$$k_{\perp} = \frac{1}{2\pi^2\sqrt{2}}\Gamma(\tfrac{1}{4})\frac{c}{r^3\sqrt{\sigma_z}}\sqrt{\frac{Z_0}{\sigma_{cond}}}, \quad (4)$$

where Z_0 is the impedance of free space (378 Ω), σ_z is the bunch length and Γ is the gamma function. The conductivity of copper, stainless steel and NEG material are summarized in Table 2.

Table 2: Conductivity of materials

Material	Conductivity /(Ωm)$^{-1}$
copper	58.0 x 10^6
steel	1.5 x 10^6
NEG	0.31 x 10^6
Enamel	~ 0

The loss parameter can be used to calculate the transient power loss, according to the formula:

$$P_{loss} = N_{bunches}\ f_0\ q_b^{\ 2}\ k_{loss}, \quad (5)$$

where $N_{bunches}$ is the total number of bunches, f_0 the revolution frequency (see table 1) and q_b the single bunch charge.

The threshold for the transverse mode coupling instability can be calculated from the betatron tune shift [16]:

$$\Delta Q_\beta = \frac{I_B\langle\beta\rangle T_0}{4\pi E/e} k_{\perp}, \quad (6)$$

which depends on the kick parameter. In formula (6) I_B is the single bunch current, <β> is the average beta function, T_0 is revolution time and E is the energy of the beam.

MODE COUPLING INSTABILITIES

Using the parameters from table 1 for the ILC damping ring design and assuming a vacuum pipe radius of 20 mm the kick parameter has been calculated for copper and NEG material. The results are show in Table 3:

Table 3: tune shift and kick parameters for the ILC DR

Material	$\Delta Q/Q_s$	$k_\perp$ (V/pC/m/m)
copper	0.017	0.13
NEG	0.23	1.79

An average beta function of 25 m and a single bunch current of 0.143 mA have been used to calculate the tune shift due to the wall resistivity. The tune shift has been normalized with respect to the synchrotron tune Q_s. The tune shift for copper is very small. But even the larger tune shift for NEG material is still acceptable. It should be mentioned that the calculated kick parameter for NEG material is based on a rather pessimistic model assuming that all wall losses occur in the NEG material. But the NEG layer is usually much thinner than the skin depth, which can be calculated from the following formula:

$$\delta(\sigma_{cond.},\omega) = \sqrt{\frac{2}{\mu_0\ \sigma_{cond.}|\omega|}} \quad (7)$$

For the rms frequency of the bunch spectrum, $\omega = c/\sigma_z = 2\pi\cdot 5.3\ \mathrm{GHz}$, one obtains a skin depth of 12.64 µm for NEG material and 0.9 µm for copper. The typical thickness of a NEG layer is only 1 µm.

A smaller pipe radius will give a significantly larger tune shift since the kick parameter scales with the third power of the inverse radius.

HEATING OF CLEARING ELECTRODES

The total power loss in the clearing electrode can be calculated from the total loss parameter, formula (3) and (5), or from the longitudinal resistive wall impedance:

$$P_{loss} = \Gamma(\tfrac{3}{4})\frac{\sigma_z}{c}\frac{N_{bunches}}{T_0}\ \hat{I}^2\ \mathrm{Re}(Z_{\parallel}(\omega = \tfrac{c}{\sigma_z})) \quad (8)$$

where $\mathrm{Re}(Z_{\parallel}(\omega))$ is the real part of the resistive wall impedance and $\hat{I}$ the peak beam current. The resistive wall impedance of a clearing electrode with length L and an angular extension ϕ (see Fig.3) is

$$Z_{\parallel}(\omega) = (1\mp i)\frac{\phi}{2\pi}L\sqrt{\frac{|\omega|\mu_0}{2\sigma_{cond.}}} = (1\mp i)\frac{\phi}{2\pi}\frac{L}{\delta(\sigma_{cond.},\omega)}\frac{1}{\sigma_{cond.}}. \quad (9)$$

The total power loss and the loss parameter per meter for a pipe radius of 20 mm and $\phi = 2\pi$ is summarized in Table 4.

Table 4: power loss and loss parameter per meter

Material	P_{loss}(W/m)	$k_{\|}$ (V/nC/m)
copper	1.18	0.98
NEG	16.2	13.4

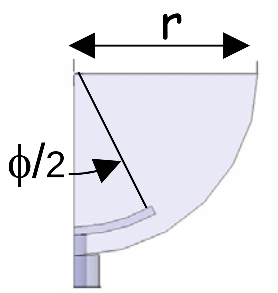

Figure 3: Cross section of a clearing electrode (schematic)

The temperature T of the clearing electrode can be estimated from the Stefan-Boltzmann Law:

$$T = \sqrt[4]{\frac{P_{loss}}{\varepsilon_{th}\,\phi\, r\, L\;\; c_{StB}} + T_E{}^4}\,, \tag{10}$$

$$c_{StB} = 5.67 \cdot 10^{-8} \frac{\mathrm{W}}{\mathrm{m}^2\,\mathrm{K}^4}\,,$$

where T_E is the environment temperature (beam pipe), ϕ r L is the radiating area of the electrode and ε_{th} is the thermal emission constant of the electrode, which is equal to one for black body radiation. It is assumed that the clearing electrode is in poor thermal contact with the environment via the feed-throughs. The temperature increase:

$$\Delta T = T - T_E \tag{11}$$

has been calculated for copper and NEG material:

Table 5: Temperature increase of the clearing electrode

Material	ΔT / K $\varepsilon_{th} = 1$	ΔT / K $\varepsilon_{th} = 0.5$
copper	1.4	2.7
NEG	17.5	32.6

These results do not depend on the angular extension of the electrode since:

$$\hat{I}^2 \sim \phi^2,\;\; Z_{\|} \sim \phi,\;\; P_{loss} \sim \phi. \tag{12}$$

CONCLUSION

The loss and kick parameters for a resitive wall have been calculated for the ILC damping ring for different materials. The betatron tune shifts seems to be tolerable even if the whole vacuum system is coated with NEG material. Therefore no transverse mode coupling instability due to the resistive wall is expected. The dissipated power in the chamber wall is about 1 W/m for a copper chamber and 16 W/m for chamber made from NEG material. The heating of an isolated clearing electrode is small if the electrode is made from copper.

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