WAKE POTENTIALS IN THE ILC INTERACTION REGION*

A. Novokhatski#, SLAC National Accelerator Laboratory, Menlo Park , CA 94025, U.S.A.

Abstract

The vacuum chamber of the ILC Interaction Region (IR) is optimized for best detector performance. It has special shaping to minimize additional backgrounds due to the metal part of the chamber. Also, for the same reason this thin vacuum chamber does not have water cooling. Therefore, small amounts of power, which may be deposited in the chamber, can be enough to raise the chamber to a high temperature. One of the sources of "heating" power is the electromagnetic field of the beam. This field diffracts by non-regularities of the beam pipe and excites free-propagating fields, which are then absorbed by the pipe wall. In addition we have a heating power of the image currents due to finite conductivity of the metallic wall. We will discuss these effects as updating the previous results [1]-[2].

BEAM PARAMETERS AND BEAM SPECTRUM

We will consider three ways in which power can be transferred from the beam. They are: losses due to propagating wake fields, which stay for a short time in the IR; losses from the absorbed trapped modes and image current losses (resistive-wall wake fields). To calculate these effects we use wake field code NOVO [3] and Eigen mode calculations with MAFIA [4]. We present the results of these calculations for the parameters of the ILC beam [5].

Table 1: Beam Parameters

Parameter	Value
Bunch charge	3.2 nC
Bunch length	0.2-0.3 mm
Bunch spacing	480 RF buckets
Beam current in a pulse	9 mA
Duty ration	200
RF frequency	1.3 GHz

We assume a bunch has a Gaussian shape with the bunch length σ, so the bunch spectrum is $A(\omega) \sim e^{-\left(\frac{\omega}{c}\sigma\right)^2}$. The maximum frequency of the exciting modes is

$$f_{\max} = \frac{c}{2\pi\sigma} = 160 - 240 \text{ GHz}$$

Bunch spacing resonances are

$$f_n = \frac{n}{\tau_b} \qquad n = 1, 2, 3, ... \qquad \frac{1}{\tau_b} = \frac{f_{RF}}{480} = 2.7 \text{ MHz}$$

Bunch spacing τ_b is the time between bunches. It is a very dense spectrum.

IR GEOMETRY AND HOM HEATING

The layout of the IR is shown in Fig. 1. This is a 3-D STL model.

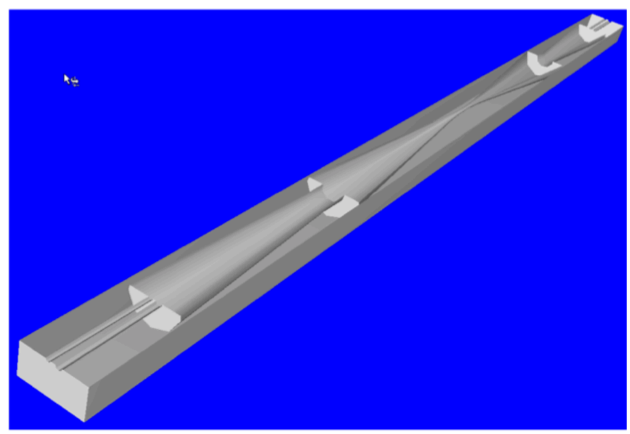

Figure 1: STL 3-D model of IR.

An electron or a positron bunch passing interaction region produces wake fields. Snapshots of these fields are shown in Fig. 2. The left red arrow at the left plot points the wake field, when the right red arrow at the same plot shows the bunch field (field attached to the bunch). Middle plot shows wake fields after the second geometry step and the right plot shows concentrated fields near a corner after the third geometry step.

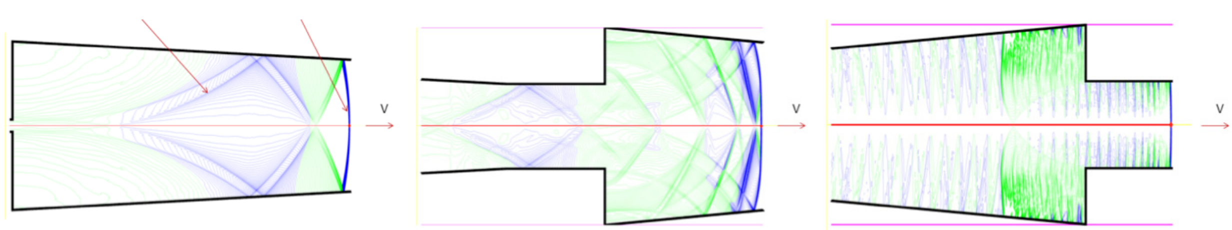

Figure 2: Snapshots of electric force lines of the wake field, excited by a short bunch at IR.

*Work supported by U.S. DOE under contract DE-AC02-76SF00515.
#novo@slac.stanford.edu

For the analysis of electromagnetic heating of the vacuum chamber of the ILC Interaction Region (IR) we consider this region as a radio frequency cavity of very complicated shape. As the cavity it has many resonant modes, the so called higher order modes (HOMs). However, in our case, the modes may have frequencies lower than or comparable to the main accelerating frequency. Cavity modes are excited by the colliding beams. Over time, they are absorbed by the cavity walls. As our cavity is connected to the incoming and outgoing beam pipes, the higher frequency modes can leave the cavity before they were absorbed. Naturally, this type of modes can be excited in a different place, propagate to the cavity and then absorbed within the cavity.

WAKE FIELD POTENTIALS

Wake potential describes the integrated effect of the wake fields on a particle inside a bunch

$$W(\tau) = \int_{-\infty}^{\infty} E_z(t,z)_{z=c(t-\tau)}\,dt$$

$s = c\tau$ is a particle longitudinal position inside a bunch. Wake potentials can be calculated in the time domain by solving Maxwell's equations. Wake potential of IR of a 0.2 mm bunch is shown in Fig. 3. This short range wake potential is calculated using the code NOVO.

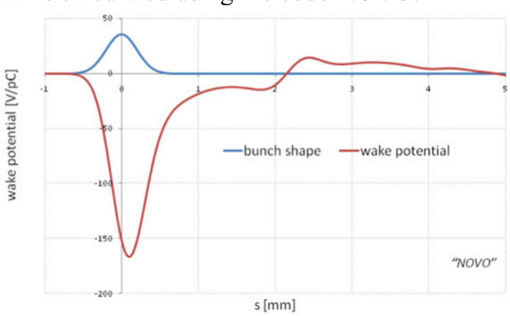

Figure 3: Short range wake potential.

Convolution of a wake potential with a bunch shape gives a total energy, which a bunch loses for the wake field production. This is the so called loss factor.

$$k = \frac{1}{Q}\int_{-\infty}^{\infty} W(\tau)\rho(\tau)d\tau \qquad Q = \int_{-\infty}^{\infty}\rho(\tau)d\tau$$

IR loss factor as a function of the bunch length is shown in Fig. 4.

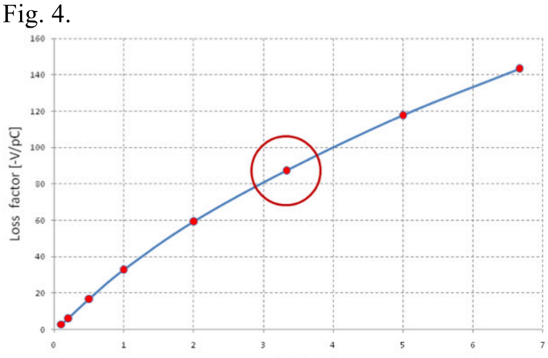

Figure 4: IR loss factor.

To know the correspondent frequency range of the loss factor of a given bunch length we calculate the loss frequency integral

$$K_s(\omega) = \mathrm{Re}\{\frac{1}{\pi}\int_0^{\omega} W_s(\omega)\rho(-\omega)d\omega\}$$

Figure 5 shows the IR loss frequency integral. We can compare it with the loss frequency integral of an accelerating cry-module (Fig. 6).

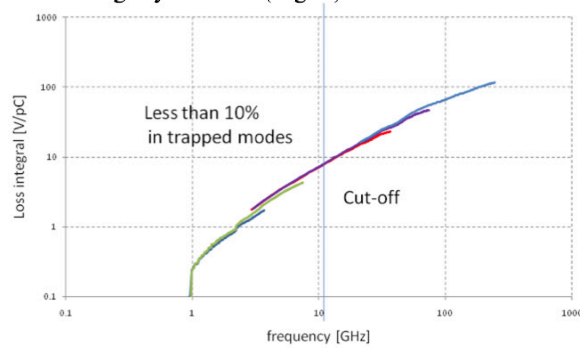

Figure 5: Loss frequency integral and the cut-off frequency.

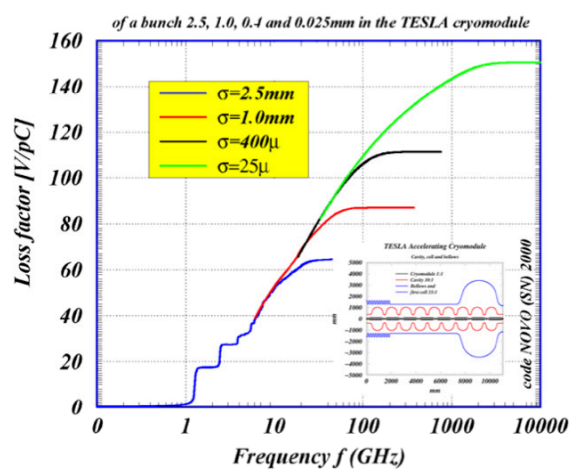

Figure 6: Loss frequency integral of an accelerating ILC (TESLA) cryomodule.

One can see that we have approximately same values for the loss factor. This means that interaction region is equivalent to an accelerating module for the wake field energy loss.

LONG RANGE WAKE POTENTIALS AND CUT-OFF FREQUENCY

To analyze the HOMs in IR we have calculated a long range wake field potential, which is shown in Fig. 7. This potential describes fields traveling up to 20 m after a bunch. A Fourier transform gives all longitudinal modes trapped in IR (Fig.7). Trapped modes have frequencies, which are lower than the so called cut-off frequency

$$f_{[GHz]}^{cut-off} = \frac{c}{a}\times\frac{\nu_{01}}{2\pi} = \frac{0.11474}{a_{[m]}}$$

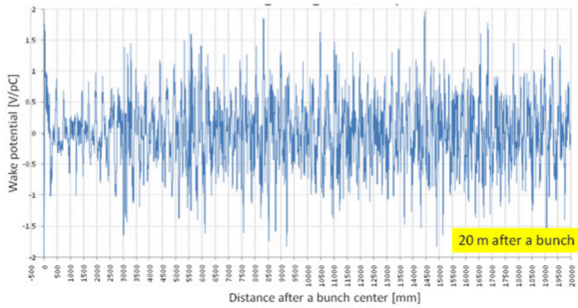

Figure 7: Long range wake field potential.

The incoming and outgoing IR beam pipes have radius a=10 mm. Correspondent cut-off-frequency is 11.47 GHz. This cut-off frequency is shown in Fig. 5 and Fig. 8.

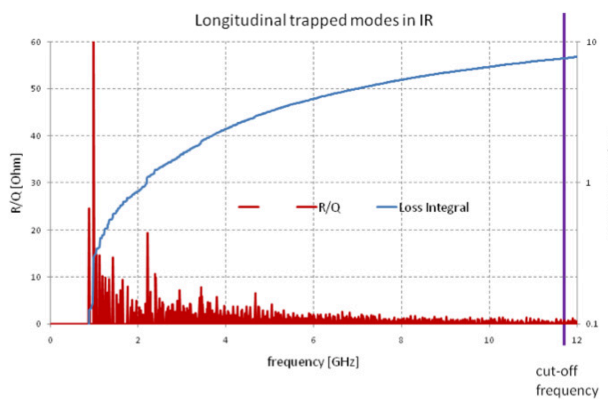

Figure 8: Trapped modes in IR.

The second mode in Fig. 8 corresponds to concentration of the wake fields in the corner, shown at the right plot of Fig. 2. Simulations with a MAFIA code gives same result (Fig. 9).

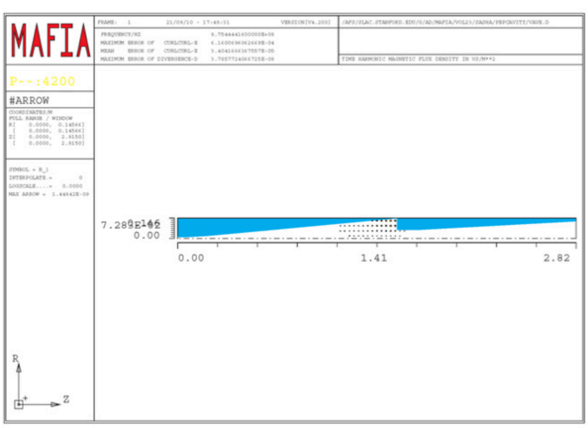

Figure 9: Second trapped modes in IR.

TRAPPED MODE EXCITATION

Resonant excitation of a trapped mode can occur under condition that the loaded Q-value of this mode is large enough $Q_l >> \pi f_n \tau_b$. For the trapped mode frequency range 0.85-11.5 GHz and ILC beam parameters, the loaded Q-values must by higher than 990-13300. As it is planned to use only materials like stainless steel and beryllium, we may only achieve these Q-values. That means trapped modes can be coherently excited only by two bunches $P_{coh.} = 2I^2 \sum_n k_n \tau_{l,n}$

The pulse power in this modes will be of order of 1000 W and correspondent average power will be only 5 W.

RESISTIVE-WALL WAKE FIELDS

The shape of the wake field due to resistive–wall is shown in Fig. 10. These losses are distributed in IR differently. However, the total losses are not so high, approximately 200 W in a pulse (1W average). Using the NEG coating the loss can go up, but even in the worst case they will not be more than 1000 W in a pulse (5W in average).

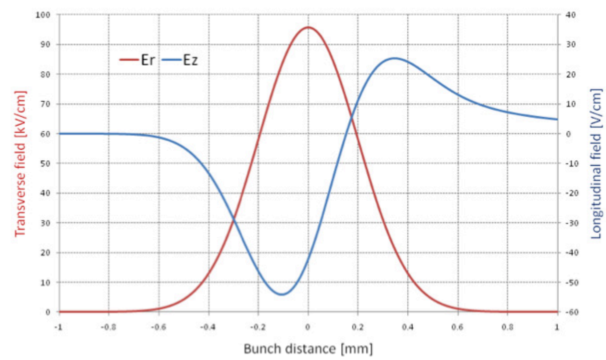

Figure 10: Resistive-wall wake field.

CONCLUSIONS

- The amount of the beam energy loss in IR is almost equal to the energy loss in one ILC (TESLA) accelerating cryo-module.
- Addition energy spread at IR is very small.
- Spectrum of the wake fields is limited 300 GHz
- Average power of the wake fields excited in IR is 30 W for nominal ILC parameters.
- Pulse power in this case is 6 kilowatts.

ACKNOWLEDGEMENTS

The author would like to thank Mike Sullivan for help and valuable comments, Marco Oriunno for the STL IP model, Martin Breidenbach and Thomas Markiewicz for fruitful discussions.

REFERENCES

[1] Novokhatski, ILC Interaction Region Engineering Design Workshop (IRENG'07), SLAC, Sept. 2007
[2] S. Pei at al., EPAC 2008, Genoa, Italy.
[3] A. Novokhatski. SLAC-PUB-11556, Dec. 2005.
[4] MAFIA Collaboration
[5] ILC RDR, ILC GDE, August, 2007