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Simulation of RF Breakdown Effects on NLC Beam*

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Abstract

The linacs of the Next Linear Collider / Global Linear Collider will contain several thousand traveling wave X-band accelerator structures operating at an input power of about 60 MW. At this input power, prototypes of NLC/GLC structures have breakdown rates lower than one breakdown in ten hours. RF breakdowns disrupt flow of energy inside the structure and create arcs with electron and ion currents. Electromagnetic fields of these currents interact with the NLC beam. We simulated the deflection of the NLC beam caused by breakdown currents using the particle-in-cell code MAGIC. In this paper we present modeling considerations and simulation results.

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The linacs of the Next Linear Collider (NLC) / Global Linear Collider (GLC) will contain several thousand traveling wave X-band accelerator structures operating at an input power of about 60 MW. At this input power, prototypes of NLC/GLC structures have breakdown rates lower than one breakdown in ten hours. RF breakdowns disrupt flow of energy inside the structure and create arcs with electron and ion currents. Electromagnetic fields of these currents interact with the NLC beam. We simulated the deflection of the NLC beam caused by breakdown currents using the particle-in-cell code MAGIC. In this paper we present modeling considerations and simulation results.

INTRODUCTION

In the NLC/GLC, electron and positron multibunch beams traverse thousands of traveling wave accelerating structures. Each beam consists of 190 bunches spaced at 1.4 ns. Each 60 cm X-band accelerating structure is driven by about 60 MW of rf power and produces a 65 MV/m unloaded gradient. To fill the structure and accelerate the beam the effective rf pulse length is set to about 400 ns.

RF breakdown in a structure disrupts its operation. Because of that, the NLC has a stringent limit on the breakdown rate: it should be less than one breakdown per few million pulses. With this breakdown rate one breakdown will occur in the linac every few seconds. The structures operate below threshold for breakdown damage, so the rf power does not have to be switched off after the breakdown. Therefore only the beam that is in the linac during the breakdown get distorted. In this report we will discuss the effect of breakdown currents on the NLC beams.

RF Breakdown

RF breakdown is a phenomenon that abruptly and significantly changes transmission and reflection of rf power directed to the structure. Breakdown is accompanied by a burst of x-rays and by a bright flash of visible light. There is copious experimental data on rf breakdowns in the NLC/GLC structures obtained at the Next Linear Collider Test Accelerator (NLCTA) [1, 2]. Listed here are some properties of the rf breakdown phenomenon in the structures [3]:

1. During breakdown the transmitted power drops to unmeasurable levels in 20–200 ns. During the rf pulse the transmission never recovers.
2. Up to 80% of the incident rf power is absorbed by the arc.
3. At the NLCTA the beam current is measured using low-Q cavities located a few centimeters away from the output ends of the structure. These current monitors detect a short (order of 10 ns) burst of current concurrent with the first signs of breakdown in rf signals. Typically the sinal from the monitors corresponds to amps of current averaged over an rf pulse.

Breakdown Currents

Knowing that the instantaneous rf power absorbed by the arc reaches 80%, and assuming that this power is absorbed by the electrons, we can estimate the amplitude of the current. The average electron energy for current emitted from a spot on the cell iris tip is about 100 keV (as calculated by a particle tracking code), and the incident rf power is about 100 MW. To absorb this power, the amplitude of the electron current should be about 1 kA. This kA current will interact with the primary electron (or positron) bunches being accelerated in the structure, kick the bunch centroid (assuming that currents are not axially symmetric) and perhaps dilute the beam emittance.

Below, we report results of simulation of the breakdown kick on the centroid of the primary bunch in NLC/GLC structures. We used the commercially available Particle-In-Cell (PIC) code MAGIC3D [4] for the calculations.

PARTICLE-IN-CELL SIMULATIONS

To obtain the beam kick from rf breakdown we have built a 3D PIC model of a 3 cell travelling wave structure. It is a disk loaded waveguide with 120° phase advance per cell, cavity radius of 10.875 mm, period of 8.75 mm, iris radius 4.45 mm, and iris thickness 1.66 mm (the iris tip is rounded). This model was developed for 3D self-consistent simulations of breakdown currents [3]. The geometry is built in cylindrical coordinates with z = constant being the (x, y) plane. The model consists of one cell and two coupler cells that match the impedance of a coaxial waveguide to the impedance of the structure at a frequency of 11.424 GHz (with VSWR better than 1.2). Snapshots of the MAGIC3D screen with the geometry are shown in Fig.1.

To simulate the breakdown, the tip of an iris was divided into upstream and downstream parts. Then one half-tip sector was assigned to emit copper ions using EMISSION BEAM model with current 20 A. The same area is also assigned as a source of space-charge limited electron current. For that we used EMISSION EXPLOSIVE model. EMISSION BEAM and EMISSION EXPLOSIVE are keywords

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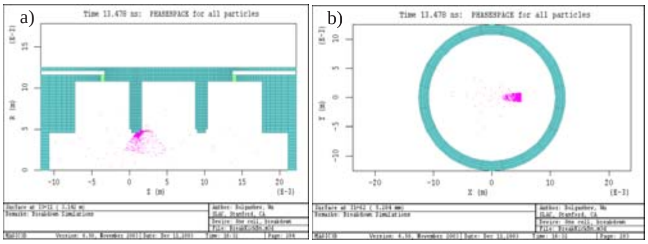

Figure 1: Snapshots of MAGIC3D screen with geometry of the travelling wave structure: electrons (red), and copper ions (magenta). a) (r, z) plane, b) (x, y) plane. Beam and rf energy move left to right in a); emission spot is at right in b), with $y = 0$. Emission spot is on downstream half of first iris.

in MAGIC3D. The amplitude of the ion current is set by requirements on drop-off of the transmitted power, since this drop-off is a feature observed in every breakdown. With ion currents equal to or higher than 20 A, the transmitted power drops from 70 MW to a fraction of a MW in about 25 ns after the start of emission. During this time, emitted electron current reaches 8 kA. Most of the electron current returns to the emission spot, and about 1 kA fills the cell and intensively interacts with the driving rf fields. For the breakdown kick simulations we set emission spot area to 2 mm^2. We note that the electron current, and reflected and transmitted rf power depend mostly on the amplitude of the ion current and weakly on the size of the emission spot.

The calculation of the breakdown kick was divided into two steps. First, we set up initial conditions: a model of a structure (without emission) is filled with 70 MW of rf power, and after one fill time (15 ns) all fields are dumped into a file. Then the simulation is restarted with one of the iris half-tips emitting copper ions and electrons. We stop the simulation after about 20 ns, when the transmitted power was significantly reduced. During the run with emission, all components of electric and magnetic fields along the trajectory of a primary beam are saved (with a 2.3 ps time step).

Then the transverse kick caused by the radial component of electric field and the azimuthal component of the magnetic field is integrated, assuming the bunch moves with the speed of light. Since the PIC code does not separate the rf and ion-electron fields, we verified that in absence of currents the transverse kick is zero, as it should be for a cylindrically symmetric structure.

RESULTS

The on-axis transverse kick for a cell breakdown (emission spot is located on the downstream tip of the first iris) is shown in Fig. 2, Fig. 3, and Fig. 4. The kick for coupler breakdown (emission from upstream tip of the first iris) is shown in Fig. 5, Fig. 6, and Fig. 7. Qualitatively, the results of the simulation are similar to results of a calculation of the transverse kick from dark currents [5]. The time dependence of the kick is almost periodic, with a period of one rf cycle. Within a period, the kick strongly depends on the rf phase, and this dependance slowly (in tens of nanosecond) changes with time.

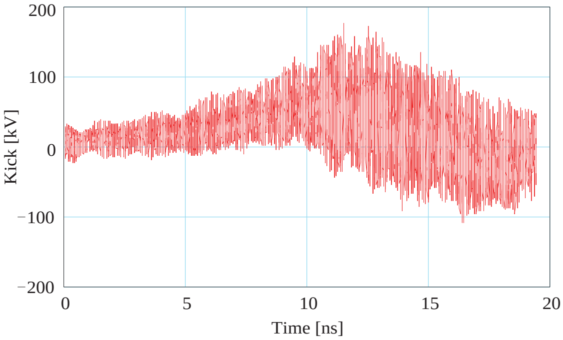

Figure 2: Transverse kick induced by arc current in a cell.

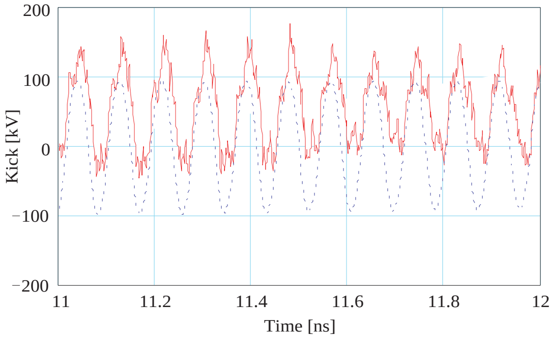

Figure 3: Transverse kick (solid) induced by arc current in a structure cell, after 11 ns. The dashed curve is one tenth of acceleration.

We find that the kick is largest when the primary beam "collides" with the emitted electrons near the emission site.

In the NLC/GLC linacs the bunch is accelerated at different rf phases to maintain BNS energy spread. At low energies, it is at +10°. Then it is almost on crest. At the end of the linac, the phase is close to -30°. Because of its dependence on the rf phase, the bunch kick will vary with

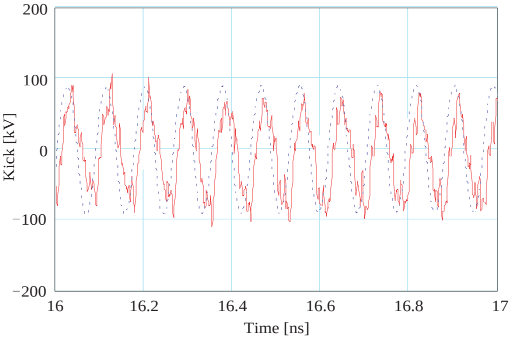

Figure 4: Transverse kick (solid) induced by arc current in a structure cell, after 16 ns. The dashed curve is one tenth of acceleration.

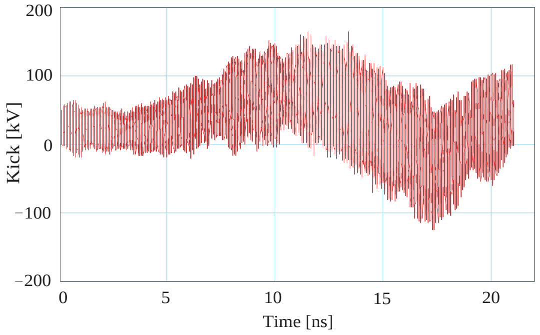

Figure 5: Transverse kick induced by arc current in a structure coupler.

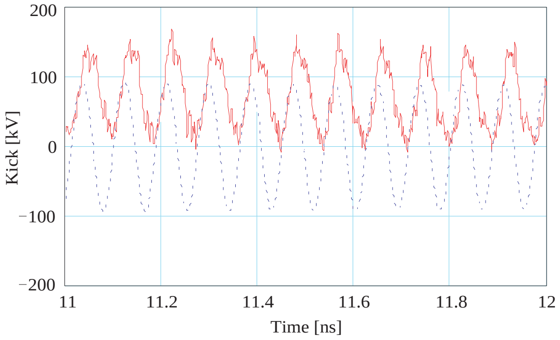

Figure 6: Transverse kick (solid) induced by arc current in a structure coupler after 11 ns. The dashed curve is one tenth of acceleration.

the beam position in the linac (assuming all breakdown parameters are the same). To show how the kick is distributed in reference to the rf phase, in figures 3, 4, 6, and 7 we plot the acceleration. The negative part of the sinusoidal acceleration curve corresponds to acceleration of electrons; the positive part to positrons. We note that, without a breakdown, maximum acceleration is 1.7 MV.

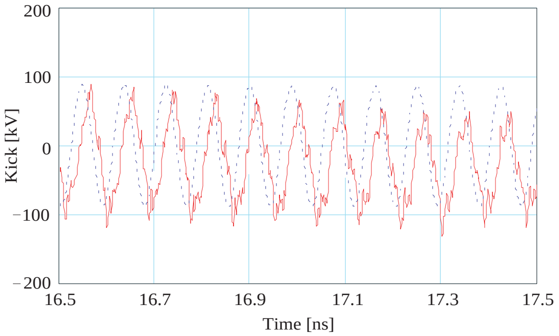

Figure 7: Transverse kick (solid) induced by arc current in a structure coupler, after 16.5 ns. The dashed curve is one tenth of acceleration.

SUMMARY AND DISCUSSION

We have calculated transverse kicks induced on the primary beam by a breakdown in an X-band travelling wave accelerating structure. The maximum on-axis kick is about 150 keV/c for positrons and about 100 keV/c for electrons, assuming a 20 A copper ion current. To hit the NLC collimators, the kick must be larger than 300 keV/c if the breakdown occurs in the beginning of the linac where its effect is strongest. During the first 20 ns of the breakdown, the kick reaches maximum at a negative acceleration rf phase. In the NLC this corresponds to the last part of the linac, where the effect of the kick on the beam is less significant.

We note that even though the PIC model explains the breakdown rf signals, it does not predict the behavior of the currents detected by the monitors in the beam pipes. The model shows that on the order of a 100 A current is launched into the beam pipes continually during the breakdown. In experiments, the monitors register a short burst of amps of current. The physics of this contradiction is not understood.

Recent measurements of the breakdown kick at NLCTA have shown that most of the kicks are within 30 keV/c [2, 6]. This number is well below the critical 300 keV/c needed to deflect the beam into the collimator, but since the measurements were done for a limited set of parameters (on-crest electrons), more experimental data is needed to verify the kick properties and to check the validity of the simulation results.

Other effects of breakdown current on the primary bunch, such as wakefields due to the breakdown plasma, *etc.*, are likely to be less critical for the NLC operation than the bunch centroid kick, and require further investigation.

REFERENCES

[1] C. Adolphsen, ROPC006, Proceedings of the PAC03, 2003, pp. 668 - 672.

[2] S. Döbert this conference.

[3] V.A. Dolgashev *et al.*, SLAC-PUB-8866, Proceedings of the PAC01, 2001, pp. 3807 - 3809.

[4] http://www.mrcwdc.com/Magic/

[5] V.A. Dolgashev *at al.*, “Effect of Dark Currents on the Acclerated beam in an X-band Linac,” WEPLT155, EPAC 2004, Lucerne, Switzerland, 2004.

[6] C. Adolphsen and S. Döbert of SLAC, private communication.