DARK CURRENT STUDIES IN ILC MAIN LINAC

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Abstract

Studies and optimization of design of the International Linear Collider (ILC) based on the TESLA-type 9-cell 1.3 GHz superconducting RF (SRF) cavities are currently underway. Dark current (DC) electron generated by field emission in SRF cavities can be captured and accelerated in the main ILC linac up to very high energy before they are removed by focusing and steering magnets. DC electrons, interacting with the materials surrounding SRF cavities, produce electromagnetic showers and contribute to the radiation in the main ILC tunnel. In this paper present preliminary results of the simulation study of dark current in the ILC linac.

INTRODUCTION

Design of SRF linacs requires extensive investigation of dark current radiation in order to protect accelerator components from radiation damage and optimize thickness and cost of the radiation shields.

In paper [1] we describe a model of dark current in SRF linac. Our model combine tracking of electrons in RF field of cavities and magnetic field of focusing magnets with MARS simulation of interactions of lost particles with the materials of the accelerator components. In the current paper we apply this model to a study of DC in ILC main linac. Our assumption is that all cavities of the linac contribute equally 50 nA into DC. We perform tracking of DC electrons in sections of linac consisting of up to 40 basic RF units[1]. We consider a "normal" mode of operation of the linac, when both RF power to the cavities and focusing magnets turned on. We also study few "commissioning" modes of operation when only cavities RF power is ON, but focusing magnets are turned OFF.

RESULTS

Normal Mode of Operation

In the normal mode of linac operation, when focusing magnets are turned on, most of the DC electrons are lost in the magnets or in the cavity down stream of the magnet. The maximum energy of the lost DC electrons may reach up to 800 MeV. In this case the equilibrium state, when losses of DC particles along the linac are compensated by newly generated DC electrons, is reached already at the 2^{nd} RF unit. Table 1 summarizes losses in the equilibrium (steady) state at the varius point along the linac. As one can see, the largest losses in normal operation are at the end of the linac and concentrated at the locations of focusing magnets.

Table 1: Equilibrium Losses

Beam Energy, GeV	5	10	15	125	250
Quad, W	0.07	0.15	0.22	1.35	1.7
Cavity, W	0.36	0.36	0.45	0.45	0.2
RF Unit, W	4.1	3.5	3.2	2.7	2.6

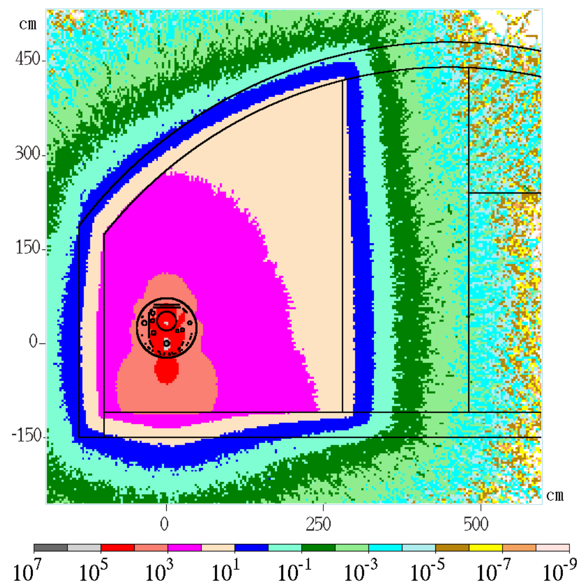

Figure 1: Total prompt dose (mSv/hr, color scale) at the tunnel cross section at the end of ILC linac during normal operation. Focusing magnet strength corresponds to 250 GeV beam.

Figure 1 shows distribution of the total propt dose in the tunnel cross section at the focusing magnet location at the end of the linac. Total dose is about 100 mSv/hr at the tunnel wall. It drops to the safe level of 25 uSv/hr 1.2 m into the wall. In the current design of the ILC main linac 3.5 m concrete wall between main and service tunnels provides very large safety margin for radiation protection.

Operation of Linac with Focusing Magnets Off

Turning off focusing magnets while still having RF power in cavities may potentially present worse conditions for DC radiation than the normal operation of the linac. We consider four distinct scenarios: 1) straight section of the linac (bunch compressor) with steering/correcting magnets turned off ; 2) curved section of linac, which follows Earth curvature, with steering/correcting magnets turned off; 3) curved section with steering magnets on, but no correction for mis-

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[1] In ILC such unit contains 3 cryo-modules, 26 cavities and a focusing magnet.

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alignment; and 4) curved linac with steering magnets on and correction on for misalignment.

When focusing quads are turned off, DC electrons can traverse many RF units of linac before they lost. Consequently, equilibrium state of losses may be reached only after multiple RF units. In our study we track DC particles through 40 RF units (1.5 km) of the linac.

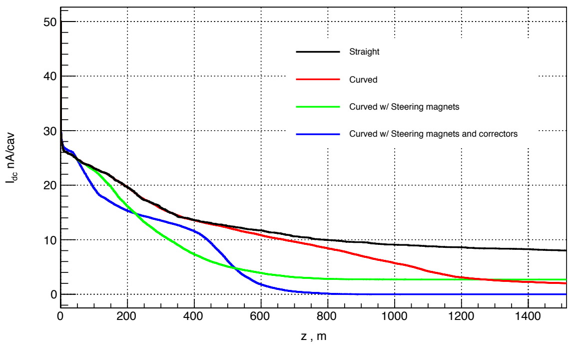

Figure 2: 50 nA DC from a single cavity at the beginning of 1.5 km linac section of 40 RF units with focusing magnets turned off. Different colors show distributions for 4 different scenarios: straight section (black), curved section (red), curved section with steering magnets (green), and curved section with correctors and steering magnets (blue).

Figure 2 shows DC from a singe cavity at the beginning of 1.5 km section of the linac, corresponding to 40 RF units. Different colors in the plot correspond to four scenarios described above. One can see, that losses, which are the rate of decreasing of DC, are higher in the curved section of the linac with the steering magnets turned on. In these cases (3 and 4) most of the DC is lost after approximately 600 m from the emitting cavity. Correctors settings are varied along the linac according to the needed corrections for the linac misalignment and change local losses. We use one specific set of random linac misalignment parameters and respective correctors settings. Different set of random linac misalignments and correctors settings will change local distribution of losses along the linac, but we expect average equilibrium losses to be similar.

Energy spectra of the lost DC particles, when all cavities of the linac contribute 50 nA, are shown in Figure 3 for the case 4). Different colors show distributions of losses in RF units 1, 10, 20, 30, and 40. Since equilibrium losses are achieved around 24th RF unit, energy distributions are similar from that unit and up. Maximum energy of the lost electrons can reach up to 20 GeV.

Figure 4 shows power loss of DC electrons per single cryo-module along the linac curved section with steering magnets turned on. Here red and blue graphs correspond to the perfectly align linac with corrector magnets turned off and a randomly misaligned linac with correctors turned on. Steady state equilibrium DC losses are reached at 900 m (24th RF unit) and approximately 8 W per cryo-module for the aligned linac. Random misalignments of the linac elements and the corresponding corrections can change equilibrium losses

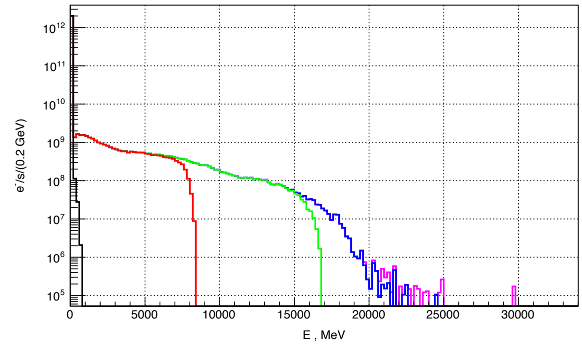

Figure 3: Energy distribution of lost particles in a single unit in a curved section of linac of 40 RF units with correctors and steering magnets turned on. All cavities contribute 50 nA DC. Different colors show distributions for unit 1 (black), unit 10 (red), unit 20 (green), unit 30 (blue), and unit 40 (magenta).

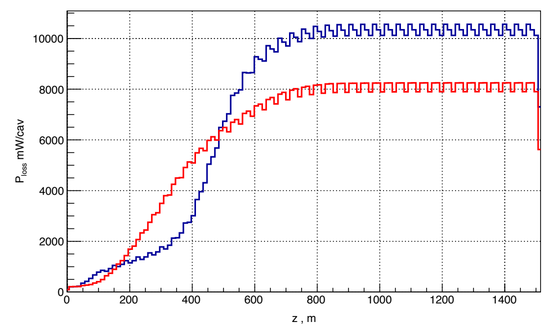

Figure 4: Power loss of DC electrons per cryo-module in the curved section of linac with steering magnets turned on and correctors off (red) or on (blue). All cavities contribute 50 nA.

to a higher or lower value. In the specific set of random misalignment parameters used in our simulation we observe losses of 10 W per cryo-module with correctors turned on.

Distribution of the total prompt dose in the tunnel cross section due to equilibrium DC losses in the curved section of the linac with steering and correcting magnets turned on is shown in Figure 5. Total dose at the tunnel wall is approximately 2000 mSv/hr, 20 times larger compared to normal linac operation. Analysis of secondary particles show that main contribution into the radiation behind the tunnel wall is due to neutrons.

Figure 6 show dependence of the total prompt dose as a function of depth into the tunnel wall. The set of data point on the lower curve of this plot corresponds to the normal mode of linac operation. The upper set of points represents total prompt dose due to DC losses in the operational mode with focusing magnets turned off and steering and correcting magnets turned on. One can see that in this last case, radiation can be attenuated to the safe lavel of 25 uSv/hr after approximately 2.2 m of the concrete and current design of the wall of 3.5 m provide large safety margin.

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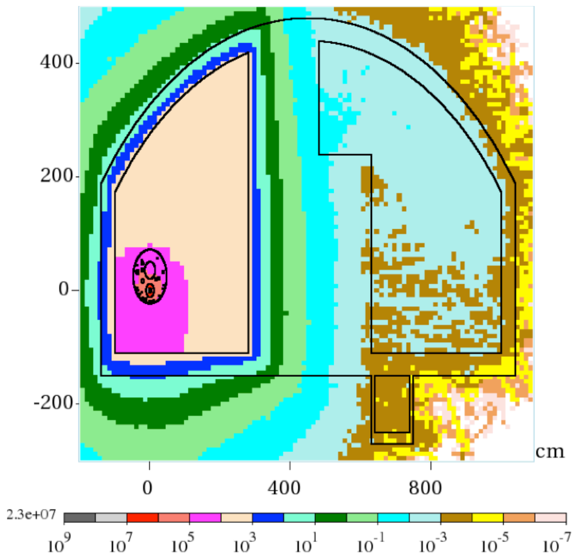

Figure 5: Total prompt dose (mSv/hr, color scale) at the tunnel cross section for the equilibrium DC losses in a curved section of randomly misaligned linac with steering and corrector magnets turned on.

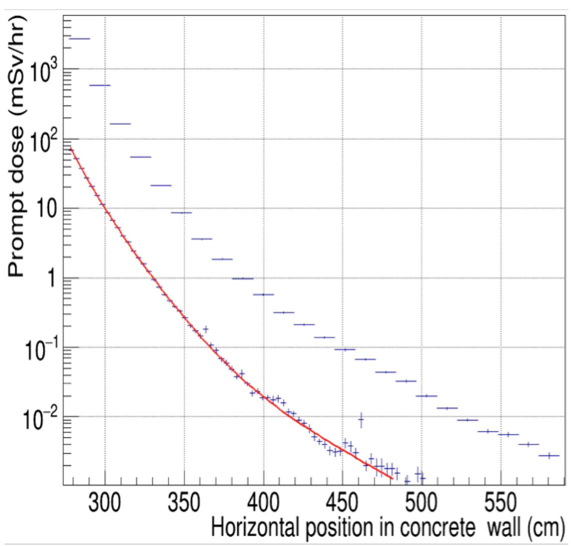

Figure 6: Distribution of prompt dose in the tunnel wall. Set of data points at the lower curve corresponds to normal operation of linac. Upper set of points corresponds to operation with focusing magnets turned off and steering and correcting magnets turned on.

CONCLUSION

We apply previously developed model [1] of dark current in SRF linac to study DC radiation in the ILC main tunnel. We consider normal mode of operation of the linac with focusing magnets turned on as well as commissioning mode, when focusing magnets turned off. We assume that each cavity contribute 50 nA of DC. We track DC in sections of linac up to 1.5 km (40 basic RF periods) long and use MARS simulation in order to calculate radiation levels in the linac tunnel.

Our results show, that during normal operation, most of the DC is lost in the focusing magnet following the RF unit, where DC is emitted. Maximum energy of the lost DC particles is up to 800 MeV. Largest DC losses occur at the end of the linac, with the power loss of 1.7 per magnet or 2.6 W per RF unit. Total prompt dose in this mode is approximately 25 mSv/hr at the tunnel wall. Safe level or radiation (25 uSv/hr) is achieved just after 1.2 m of concrete wall.

In the worst case scenario of the commissioning mode, when both steering and correcting magnets turned on, losses reach steady state equilibrium regime after approximately 800 m (24 RF units). After that losses and radiation are practically independent of the longitudinal location. At the tunnel wall radiation is approximately 2000 mSv/hr. It drops to the safe lavel of 25 uSv/hr after 2.2 m into the wall.

We conclude that the current design of the ILC main linac tunnel with the concrete wall of 3.5 m, provide large safety margin in radiation protection of the personnel in the service tunnel.

REFERENCES

[1] A. Sukhanov *et al.*, "Model of Dark Current in SRF Linac", in *Proc. IPAC'15*, paper TUPJE081.

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