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Emittance Evolution of the Drive Electron Beam in Helical Undulator for ILC Positron Source

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Abstract: The effect of ILC positron source helical undulator to electron beam is of great interest. People have been looking into the effect of wakefield, quad misalignment and also the effect of radiation. In this note we'll report an emittance damping effect of the ILC positron source undulator to the drive electron beam.

There are many aspects in the ILC positron source undulator which will affect the emittance evolution of the drive electron beam passing through the undulator. Many people have reported some studies on this issue. Duncan Scott and James Jones has studied the effect of transverse resistive wall wakefields of undulator beam tube and the optics also [1]. They found that the kick from wakefields is very small and the emittance growth is due to the optics. Their study shows that 10um resolution in BPM-Quad will result in ~8% emittance growth in vertical plane. Kiyoshi Kubo from KEK has reported a study on the effect of BPM-Quad misalignment and the synchrotron radiation from undulator [2]. He reported that the effect of undulator radiation and QUAD-BPM misalignment on the emittance growth can be tolerated.

We did some simulation on the effect of radiation from helical undulator using elegant and found that there is a damping to the normalized emittance of drive electron beam caused by the radiation from helical undulator.

Undulators and beam parameters

The parameters of undulators we studied are given in the following table 1.

Table 1. Parameters of undulators

	K	λu(cm)
UK1	0.92	1.15
UK2	0.79	1.1
UK3	0.64	1.05
Cornell 1	0.42	1.0
Cornell 2	0.72	1.2
Cornell 3	0.3	0.7

The energy of drive electron beam is 150GeV as in RDR. The normalized emittance of drive electron beam is 10 mm-mrad in x (horizontal) and 0.04 mm-mrad in y (vertical)[3]. With the assumption of 12.5m quad spacing and 72.6 degree food array, the β_{max} for undulator input will be 41 m and then beam spot size and divergence can be estimated as: σx=3.7e-5 m, σy=2.4e-6 m, $\sigma x'$=0.9e-6 rad and $\sigma y'$=0.06e-6 rad.

Simulation results.

Our first set of simulations was done for 100m undulator with no other optical and energy spread in drive beam. The elegant simulation results are given in table 2.
Table 2. Elegant simulation result for 100m undulator.

	Δεnx/εnx (%)	Δεny/εny (%)	ΔE/E (%)	σ_{x_out}	σ_{xp_out}	σ_{y_out}	σ_{yp_out}
UK1	-1.37464	-1.06	-1.3756	9.4259e-5	8.8774e-7	6.4835e-6	6.0111e-8
UK2	-1.10608	-0.912	-1.112	9.4316e-6	8.8907e-7	6.4871e-6	6.0190e-8
UK3	-0.79802	-0.679	-0.804	9.4381e-6	8.9059e-7	6.4908e-6	6.0274e-8
CO1	-0.38277	-0.395	-0.383	9.4464e-6	8.9258e-7	6.4973e-6	6.0398e-8
CO2	-0.77138	-0.652	-0.789	9.4385e-6	8.9070e-7	6.4928e-6	6.0298e-8
CO3	-0.39768	-0.382	-0.399	9.4462e-6	8.9251e-7	6.4972e-6	6.0394e-8

As showing in table 2, the normalized emittance of drive electron beam is damped as a result of radiations in undulators. The rate of damping is roughly proportional to the rate of energy lost.

Our second set of simulations was done for 100m RDR baseline undulator to study the effect of when beam is passing through off axis. The results are presented in table 3.
Table 3. Elegant simulation result for 100m RDR baseline undulator with off axis injection

Offset	Δεnx/εnx (%)	Δεny/εny (%)	σ_{x_out}	σ_{y_out}	σ_{xp_out}	σ_{yp_out}
0,10μm,50μm	-1.37	-1.06	9.42e-5	6.48e-6	8.93e-7	6.01e-8
1mm in x	-1.59	-1.13	9.40e-5	6.48e-6	8.83e-7	6.01e-8
1mm in y	-1.59	-1.14	9.42e-5	6.46e-6	8.88e-7	5.98e-8

As showing in table 3, for offset smaller than 50 micron, there is no noticeable effect on the emittance evolution. When the offset is 1mm, the damping in both x and y direction increased because the beam is now seeing a stronger magnetic field and thus losing more energy due to radiation.

Table 4. Elegant simulation results for RDR baseline undulator at different undulator length.

configuration	Δεnx/εnx (%)	Δεny/εny (%)
~100m	-1.36	-1.18
~200m	-2.69	-1.27
~300m	-3.93	0.84

Showing in table 4 are the emittance evolution of drive e- beam after passing through RDR undulator. In this set of simulations, the input drive e- beam has a energy spread of 25MeV. As showing in the table, transverse emittance is keep damping down when increasing the undulator length from 100m up to 300m. But for the vertical plane, the emittance damped down about by 1.18% after 100m, after 200m it only damped by about 1.27% and eventually grown by 0.84% after 300m of undulator. Based on this result, the length of undulator has to be shorter than 300m to avoid significant emittance growth due to radiation in undulator.

An analytical estimate on the damping and excitation for 100m RDR baseline undulator shows that the damping/excitation ratio is 3 in vertical and 600 in horizontal. If the undulator length increases, this ratio will get smaller and smaller and eventually be smaller than 1. The emittance will start growing after this ratio is smaller than 1.

We also did simulations with Quad FODO arrays. Simulation result shows that 300μm with cause a large emittance growth. This result does not agree with Kiyoshi Kubo's result but agrees with Duncan Scott's result to some extend.

Summary

For RDR undulator, the emittance of drive electron beam will be damped down by about 1% instead of growing as the damping is stronger than quantum excitation for undulator length smaller than 200m.
The emittance growth due to quad misalignment is still unconfirmed and more works are needed to be done.

[1] Duncan Scott and James Jones, Transverse Resistive Wall Wakefields of the ILC Positron Undulator Beam Tube and their Effects on an Orbit Dependant Emittance Growth, EUROTeV-Report-2007-007
[2] Kiyoshi Kubo, Simulation of electron beam in undulatorsof e+ source of ILC -Emittance and orbit angle with quad misalignment and corrections-No wakefiled, ILC-LET meeting, Daresbury, 2007.01
[3] ILC RDR