RECOMMENDATION FOR MITIGATIONS OF THE ELECTRON CLOUD INSTABILITY IN THE ILC*

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Abstract

Electron cloud has been identified as one of the highest priority issues for the international Linear Collider (ILC) Damping Rings (DR). An electron cloud Working Group (WG) has evaluated the electron cloud effect and instability, and mitigation solutions for the electron cloud formation. Working group deliverables include recommendations for the baseline and alternate solutions to the electron cloud formation in various regions of the ILC Positron DR, which is presently assumed to be the 3.2 km design. Detailed studies of a range of mitigation options including coatings, clearing electrodes, grooves and novel concepts, were carried out over the previous several years by nearly 50 researchers, and the results of the studies form the basis for the recommendation. The recommendations are the result of the working group discussions held at numerous meetings and during a dedicated workshop. In addition, a number of items requiring further investigation were identified during the discussions at the Cornell meeting and studies will be carried out at CesrTA, a test accelerator dedicated to electron cloud studies, and other institutions.

INTRODUCTION

The electron cloud effect has been identified as high priority issue for the ILC positron Damping Ring (DR). During the last two years, a working group has been set up to evaluate the electron cloud effect and beam instability and evaluate viable mitigation solutions for the electron cloud formation.

The mitigation recommendations for the ILC DR presented in this paper are the result of the working group discussions held during numerous workshops and regular online meetings. Finally, the working group met at Cornell University, during a satellite meeting of the ECLOUD10 Workshop. The workshop itself was devoted to hearing the results of detailed studies of a range of mitigation options and the satellite meeting was devoted to the selection of the most suitable suppression techniques for the various DR regions. The recommendation will be summarized in this report and presented in a more detailed report later in 2012. Input from the workshop participants was included in the evaluation. The assessments of the significance of the different issues associated with each mitigation item, and the benefits or risks associated with the various options for each item, were based on a systematic ranking scheme. We should emphasize that although our systematic approach allows a "score table" for the various options for each item to be drawn up, our recommendations were reached through structured discussion, and not by simply adding up the benefit and risk scores for the different options.

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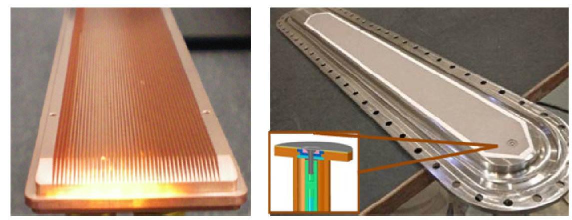

Figure 1. Grooves (left) on copper and clearing electrodes (right) on stainless steel substrates [1, 2, 3].

RECOMMENDATION PROCESS

To make decisions on the mitigation techniques, we have utilized an analytic process [4] that decomposes the problem into a hierarchy of criteria and mitigation alternatives. A numerical weight is derived for each element of the hierarchy, thus allowing diverse elements to be compared to one another in a rational and consistent way. The essence of the method is that expert's judgments, and not just the underlying information, can be used in performing the evaluations. In the final step of the process, numerical priorities are calculated for each of the decision alternatives.

The first step was to identify the criteria for the evaluation. Four criteria (each one based on a set of sub-criteria) were identified, that include:

- Efficacy of mitigations, including:
  1) Material photoelectric yield (PEY)
  2) Surface secondary electron yield (SEY)
  3) Ability to keep vertical emittance growth <10%
- Costs, including:
  1) Design and manufacturing of mitigation
  2) Maintenance of mitigation
  3) Operational costs
- Risks, including:
  1) Mitigation manufacturing challenges
  2) Technical uncertainty
  3) Incomplete evidence of efficacy
  4) Incomplete experimental studies
  5) Reliability
  6) Durability of mitigation
- Impact on Machine Performances, including:
  1) Impact on vacuum performance
  2) Impact on machine impedance
  3) Impact on optics
  4) Operational

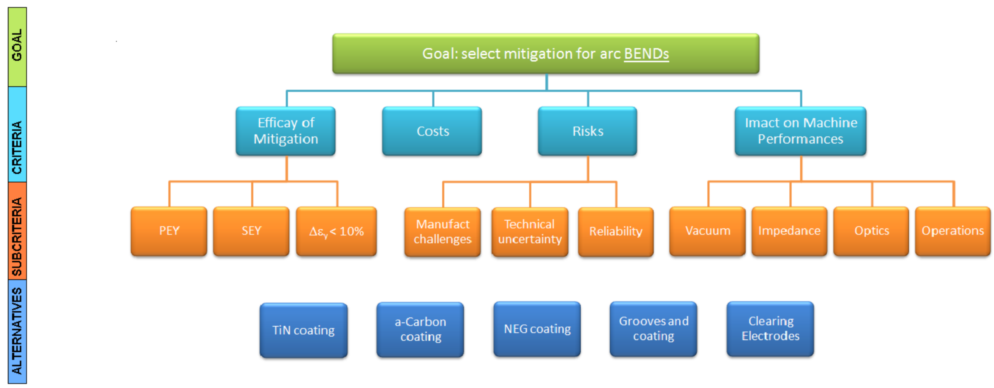

Figure 2. Decision making decomposition into a hierarchy [6] of criteria, sub-criteria and mitigation alternatives.

Table 1. Rating of the evaluation criteria.

Criteria for the evaluation of mitigations: Working Group rating				
	Efficacy of Mitigation	Costs	Risks	Impact on Machine
Rating	10	1	4	4
Normalized Weighting	0.53	0.05	0.21	0.21

Table 2. Rating of technical mitigations against each evaluation criteria, on a scale -4 to +4 with Aluminum as reference.

Evaluation of mitigations in BEND magnets: Working Group rating				
	Efficacy (0.53)	Costs (0.05)	Risks (0.21)	Impact on machine (0.21)
Al (reference)	-4	1	1	0
TiN coating	1	0	1	0
C coating	1	0	-1	0
NEG coating	1	-1	0	1
Grooves & coating	3	-1	-1	-1
Clearing Electrodes	4	-3	-2	-2

Here we provide examples of a few issues taken into consideration during the analysis. The "Costs" analysis included: replacement of clearing electrode power supplies; and time incurred for replacement of damaged clearing electrode power supplies. The analysis of "Risks" included: the impact of grooves of height ~ 1mm in a small aperture vacuum chamber; installation of clearing electrodes in regions of limited space or near BPM buttons; and the absence of a long-term durability study for amorphous-Carbon in the synchrotron radiation environment of electron/positron machines; potential damage of clearing electrode feed-throughs; and the potential failure of clearing electrode power supplies. Examples of "Impact on Machine Performances" of mitigations included: the potential positive vacuum impact of NEG coating; the added surface area of grooves for pumping, and vacuum outgassing; the impedance of grooves and clearing electrodes; x-y coupling due to solenoids; NEG re-activation cycles after saturation; and replacement times for damaged components. The criteria have been rated by the WG as shown in Table 1.

RECOMMENDATION FOR ELECTRON CLOUD TECHNICAL MITIGATIONS

Considering a wealth of experimental data [1, 2, 3, 5, 6], we then rated the mitigation options by comparing them against each of the criteria on a scale of -4 to +4, where negative values indicate detrimental impact, 0 values - no impact, and positive values - helpful impact. As an example, the WG rating for the mitigations in the bend magnets is shown in Table 2. An overall ranking is obtained by normalizing the mitigation ratings and factoring in the weight of each criteria. These rankings guided the selection of baseline mitigations I and II and alternate mitigations for each specified region of the ILC positron DR. The complete set of Working Group mitigation recommendations is shown in Table 3.

Our most recent simulations indicate that antechambers are required in the arc and wiggler regions to minimize the number of photoelectrons that can initiate cloud formation in these regions. This is particularly serious issue for the high current option in the 3.2 km ring design. Thus antechambers are included in the recommendation for the baseline mitigation design in these regions. Furthermore, solenoids, which have been demonstrated to be an excellent mitigation in the drift regions of the B-factories, have been chosen for the baseline mitigation II for the ILC DR drift regions.

In the next sections, we summarize the region-by-region recommendations, as extracted from the executive summary of the dedicated WG recommendation meeting.

Drift Region Mitigation Recommendation

TiN is the recommended baseline mitigation for the drift regions. TiN has good efficacy and the risks for its implementation are the lowest. Furthermore it has no significant impact on other aspects of the machine performance. NEG coating is recommended as an alternative. Although NEG has somewhat lower mitigation efficacy, it has the advantage of providing vacuum pumping in the long straight sections, which may decrease the costs of distributed pumping. In addition, solenoids are recommended for inclusion in the baseline design as additional mitigation, particularly for the high beam current option ultimately desired for the 3.2 km DR.

Dipole Region Mitigation Recommendation

Grooves with TiN coating [1,2,3] are the recommended baseline mitigation in the dipoles. In this region, we desire the greatest possible protection against the electron

Table 3. Recommendation for technical mitigations of the electron cloud (EC) effect in the ILC Damping

EC Working Group Baseline Mitigation Recommendation				
	Drift*	Dipole	Wiggler	Quadrupole*
Baseline Mitigation I	**TiN Coating**	**Grooves with TiN coating**	**Clearing Electrodes**	**TiN Coating**
Baseline Mitigation II	Solenoid Windings	Antechamber	Antechamber	
Alternate Mitigation	NEG Coating	TiN Coating	Grooves with TiN Coating	Clearing Electrodes or Grooves

*Antechambers will be included into Drift and Quadrupole chamber designs in the arc and wiggler regions.

cloud and grooves have very good efficacy. Although clearing electrodes offer the best effectiveness, see Table 2, the use of clearing electrodes in the large number of bend magnet vacuum chambers has potentially significant impact on the machine impedance as well as an inherent operational risk from the large number of power supplies and vacuum feed-throughs required. At present, these drawbacks make clearing electrodes less attractive for the design. Further R&D may change this assessment.

Wiggler Region Mitigation Recommendation

Clearing electrodes deposited *via* thermal spray on copper chambers [1, 3] is the recommended mitigation in the wiggler region. Clearing electrodes offer the best protection in the region of greatest concern for electron cloud formation. The impedance and risk issues are less critical than in bends due to the smaller number of chambers involved. These are acceptable impacts in order to obtain the best efficacy in this region. Grooves with TiN coating are recommended as the alternative mitigation. In particular there are concerns about the transverse impedance issues with the trajectory of the beam in this region as well as manufacturing challenges of very small grooves. In this case, the alternative option will need considerable additional investigation before it could be implemented.

Quadrupole Mitigation Recommendation

TiN coating is the recommended mitigation in quadrupoles since it offers good efficacy against electron cloud with low risks and low impact on the machine performance. There are concerns about long-term build-up of electrons in the quadrupole field that would require extremely effective mitigation. This could be provided by clearing electrodes or grooves but more R&D will be required to validate either option.

Acceptable Electron Densities to Achieve the Design Emittance

A particular concern for meeting the emittance specifications of the damping ring is the possibility of emittance growth occurring at electron cloud densities below the threshold for the single-bunch instability. Recent simulations and measurements in CesrTA suggest that this effect may be significant and are leading to a re-evaluation of the acceptable electron densities near the beam. While work remains to precisely quantify this issue, initial results suggest that the acceptable cloud densities may need to be lowered by a factor of several. This further emphasizes the need to employ the most effective mitigation techniques, consistent with risk and cost constraints, in each region of the ring.

Further Comments

It is important to point out that several mitigation methods are under active study at present. For this recommendation, it was felt that coatings such as amorphous and diamond-like carbon [5, 6], which do show significant promise, have not yet been tested sufficiently in the high synchrotron radiation environment of an electron or positron machine to be included in the baseline or alternate recommendations. Furthermore, high efficacy techniques such as grooves and electrodes could be used more extensively depending on the results of further investigation into their manufacture and potential impacts on machine operation.

SUMMARY

The DR electron cloud Working Group has made recommendations for technical mitigations to adopt in the ILC Damping Ring.

Preliminary machine results and simulations suggest the possible presence of a *linear emittance growth* occurring at electron cloud densities below the threshold for single-bunch instability, which is of particular concern and it requires further investigation. It may require reduction in the acceptable cloud density and an increase in the safety margins. Furthermore, an aggressive mitigation plan is required to obtain optimum performance from the 3.2 km positron DR and to pursue the high current option.

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