



**DR Deliverable 2: Report on Impact of e-Cloud and Fast Ion Instabilities on DR Performance, Including Recommendations for Controlling the Effects**

F. Zimmermann <sup>1</sup>

December, 2008

**Abstract**

This paper describes the accomplishment of the 2<sup>nd</sup> deliverable of the Damping Ring (DR) Work Package.

1) CERN – Geneva, Switzerland

## **WP3 Deliverable 2: Report on the impact of electron-cloud and fast-ion instabilities on DR performance, including recommendations for controlling the effects**

### **Electron cloud impact on positron damping ring**

An electron cloud in the positron damping rings of ILC and CLIC could drive multi-bunch, single-bunch, and incoherent single-particle instabilities [1,2], as well as degrade the vacuum [3] contributing to a pressure instability [4]. Each of these phenomena can lead to unacceptable emittance growth and beam loss.

The various effects all impose limiting values for the maximum number of electrons inside the vacuum chamber that can be tolerated. Analytical estimates and simulation studies have shown that the suppression of the single-bunch instability requires an electron density in the damping-ring wigglers of less than  $2 \times 10^{11} \text{ e}^-/\text{m}^3$  for the ILC [5] and of less than  $5 \times 10^{12} \text{ e}^-/\text{m}^3$  for CLIC [6]. It is interesting to note that the electrons' impact on the vacuum becomes noticeable for an electron flux at the chamber wall of order  $10^{16} \text{ e}^-/(\text{s}\cdot\text{m})$ , which, assuming a typical electron impact energy of 200 eV, corresponds to a heat load of about 0.3 W/m [3].

The electron cloud is generated by a combination of photo-emission from synchrotron radiation, secondary emission via a beam-induced multipacting process and ionization of the residual gas. In order to achieve the desired low electron-cloud level, both the effective photo-electron emission and the effective secondary electron emission yield must be suppressed. Simulations with the code Faktor2 (WP3 deliverable no. 1) show that for both ILC and CLIC an effective photo-electron yield below  $10^{-4} \text{ e}^-/(\text{e}^+ \text{ m})$  is needed [3,6]. For ILC the maximum secondary emission yield must stay below 1.1 [3], while for CLIC the required secondary emission yield is higher, about 1.3 [6]. At vacuum pressures below 10 ntorr the contribution from gas ionization to the electron cloud is negligible, for both CLIC and ILC [3], as long as field ionization can be neglected.

### **Ion impact on electron damping ring**

In the electron damping rings of CLIC and ILC, ions created during the beam passage by residual-gas ionization can be trapped along the length of a bunch train. These transient ions can give rise to substantial linear and nonlinear transverse tune shifts, which increase along the length of the train, as well as to the "fast beam-ion instability".

For the CLIC damping ring, the ion oscillation frequency inside the bunch train in final equilibrium during the store ranges from 300 MHz (horizontal plane) to about 1 GHz (vertical plane), to be divided by the square root of the mass number of the ion. However, only the ion types with mass numbers above 13 will be trapped inside the bunch train. Assuming a residual gas pressure of 1 ntorr for a species that can be trapped ( $\text{H}_2\text{O}$  or  $\text{CO}$ , for instance), the tune shift caused by the ion accumulation at the end of a bunch train can be as high as 0.05, and the ions can render the beam unstable within one turn [15]. This means that the vacuum level in the CLIC damping ring should be lower than 1 ntorr and/or that a very fast feedback system should be developed to fight this effect [7].

For the ILC damping ring, the ion oscillation frequency inside the bunch train in final equilibrium ranges between 100 MHz (horizontal plane) and about 1 GHz (vertical plane),

again to be divided by the square root of the mass number of the ion [8]. Only ion types with mass numbers above 7 or 27, respectively, depending on the filling mode, will be trapped inside the bunch train for the equilibrium beam [8]. At a residual gas pressure of 1 ntorr for a species that can be trapped, the tune shift caused by the ion accumulation at the end of a single long bunch train can be as high as 0.3 [8]. The ion density is reduced toward a more tolerable level by dividing the long bunch train into many short trains of 22-45 bunches each, with intermediate gaps [9]. This “mini-train” scheme significantly reduces the maximum ion density and the resulting tune shift. Even with mini-trains, the simulations show that the fast ion instability cannot be damped for a partial CO vacuum pressure larger than 1 ntorr [9]. Employing the currently foreseen ILC fast feedback system with 50 turns damping time, in the simulation the growth of the fast ion instability slows down. The growth is completely stopped for a feedback damping time around 20 turns [9].

### **Recommendations for controlling electron-cloud and ion effects**

The design dynamic vacuum pressure in the electron damping ring of ILC and CLIC should be around 0.1 ntorr, to keep ion-induced tune shift and ion-driven instabilities under control. This pressure may be accomplished with antechambers or dedicated photon-absorber sections, and TiZrV NEG coating of the chamber surface, plus complementary discrete UHV pumping (e.g. near photon absorbers).

To keep ions at a benign density level and to suppress the fast beam-ion instability, even for a vacuum pressure as low as 0.1 ntorr the ILC electron damping ring must operate with mini-trains and with a bunch-by-bunch feedback of 20 turn damping time. Without mini-trains and at 0.1 ntorr partial pressure, the CLIC electron damping ring requires a bunch-by-bunch feedback that damps in about 10 turns.

The pressure tolerance for the positron damping rings of ILC and CLIC is much relaxed, about 10 ntorr, but the distributed pumping speed per unit length must be high enough to avoid pressure instability, i.e. the pumping speed should be much larger than the product of beam current, ionization cross section, and desorption yield. This calls for a NEG-coated beam pipe, for pumping through an antechamber, for strong local pumping near the photon absorbers, or a combination thereof.

To suppress the electron-cloud build up, both the photoelectron yield and the “effective” secondary emission yield must be, and must stay, below certain tight threshold values. The technical mitigation options include low SEY coatings, mechanically or magnetically rough surfaces, grooves, and clearing electrodes [10,11]. Novel types of coatings based on amorphous carbon, ideally on a black-metal substrate, which have been developed at CERN in 2007-08, combine a low maximum secondary emission yield around 1, with UHV compatibility, and low resistivity. Most importantly, their secondary emission yield shows little sign of degradation after days or even weeks of air exposure. Therefore, they are a promising candidate for “solving” the electron-cloud problem. Beam tests at the SPS indeed demonstrated the complete suppression of electron-cloud formation in regions with these coatings, as had been expected from their surface properties previously determined in the laboratory. Carbon-coated samples were also tested for photon-induced desorption in a dedicated beam line at the ESRF, showing a desorption yield lower than that for stainless steel, and exhibiting similar conditioning behavior as steel after long-time exposure to synchrotron radiation. One remaining uncertainty for applications in ILC or

CLIC is the yet unknown photo-emission yield. To qualify the effectiveness of the carbon coatings for a positron beam it is planned to install a carbon-coated test chamber in the CESR-TA facility at Cornell University during 2009.

In addition to the tailoring of the secondary emission yield, the generation rate of photo-electrons must be brought down to the extremely low level of  $10^{-4}$   $e^-/(e^+ m)$  [3,6]. Optimistically assuming a true photo-emission yield of the chamber wall of about 1%, for example, this condition requires that 99.9% of the photons emitted in the CLIC wiggler sections be absorbed by antechambers or dedicated photon absorbers [6].

Single-bunch electron-cloud instabilities of positron beams due to the residual electron cloud could be suppressed by an ultra-wide-band feedback system. Damping only the bunch-centroid motion would not suffice to suppress the emittance growth from head-tail type instabilities. However, a feedback bandwidth of about  $\sim c/(2\sigma_z)$  together with 5-turn damping time could stabilize the beam [12].

Electron-driven multi-bunch instabilities in the positron damping rings can be combated with a strong bunch-by-bunch feedback. In 2008 it was shown at DAFNE that by adding a new horizontal feedback in the positron ring the effective total feedback power was doubled, i.e. that the damping rates of several independent feedbacks add up linearly, pointing to a practical way for lowering the damping times. Specifically, for a bunch distance of 3 ns (the same as foreseen for the ILC damping ring) DAFNE has demonstrated a damping in 30 revolution periods ( $\sim 10$   $\mu s$ ) for 1 feedback and in half that time ( $\sim 5$   $\mu s$ ) with 2 feedbacks [13,14].

At several accelerator facilities, microwave transmission measurements have proven effective for monitoring global electron-cloud densities over tens or hundreds of m, e.g. across an arc or wiggler section. It is recommended that the ILC and CLIC positron damping rings be equipped with such type of diagnostics, in addition to local instrumentation.

Table 1 provides a summary in tabular form.

Table 1: ILC and CLIC damping-ring requirements in regard to electron-cloud and ion impact, plus recommendations for meeting the requirements and controlling the effects

	ILC		CLIC	
	requirement	recommendation	requirement	recommendation
<b>positron damping ring</b>	threshold e-density $\sim 2 \times 10^{11} \text{ e}^-/\text{m}^3$	target values for secondary & photo-emission emission yields	threshold e-density: $\sim 5 \times 10^{12} \text{ e}^-/\text{m}^3$	target values for secondary & photo-emission emission yields
	maximum secondary emission yield < 1.1	NEG coating or TiN coating; carbon coating as alternative	maximum secondary emission yield < 1.3	novel carbon coating; NEG coating as backup
	maximum acceptable photo-electron generation rate $\sim 10^{-4} \text{ e}^-/(\text{e}^+ \text{ m})$	low photo-emission yield of coating combined with 99.9% absorption efficiency of antechamber and photon stops; fast feedback as backup	maximum acceptable photo-electron generation rate $\sim 10^{-4} \text{ e}^-/(\text{e}^+ \text{ m})$	low photo-emission yield of coating combined with 99.9% absorption efficiency of antechamber and photon stops; fast feedback as backup
	vacuum pressure < 10 ntorr & distributed pumping	pumping by activated NEG coating	vacuum pressure < 10 ntorr	UHV pumping on antechamber and at photon stops
		microwave diagnostics		microwave diagnostics
<b>electron damping ring</b>	suppress fast ion instability	mini-trains, bunch-by-bunch feedback with 20 turn damping time, meet pressure target	suppress fast ion instability	bunch-by-bunch feedback with 10 turn damping time, meet pressure target
	partial vacuum pressure < 0.1 ntorr	pumping by activated NEG coating	partial vacuum pressure < 0.1 ntorr	pumping by activated NEG coating

## Acknowledgement

This work is supported by the Commission of the European Communities under the 6th Framework Programme “Structuring the European Research Area”, contract number RIDS-011899.

### References:

- [1] E. Benedetto, “Emittance growth induced by electron cloud in proton storage rings,” CERN-THESIS-2008-096, CARE-THESIS-06-007
- [2] F. Zimmermann et al, “Modeling Incoherent Electron Cloud Effects,” Proc. PAC’07 Albuquerque, p. 3393
- [3] O.B. Malyshev and W. Bruns, “ILC Vacuum Design and E-Cloud,” EPAC’08 Genoa, EUROTeV-Report-2008-057
- [4] O.B. Malyshev, “Study of Ion Induced Pressure Instability in the ILC Positron Damping Ring,” EUROTeV-Report-2008-058
- [5] M.T.F. Pivi, T.O. Raubenheimer, L. Wang, K. Ohmi, R. Wanzenberg, A. Wolski, F. Zimmermann, “Simulation of the Electron Cloud for Various Configurations of a Damping Ring for the ILC,” Proc. EPAC’06 Edinburgh, p. 2958
- [6] G. Rumolo, W. Bruns, Y. Papaphilippou, “Electron Cloud Build up and Instability in the CLIC Damping Rings,” EUROTeV-Report-2008-037
- [7] G. Rumolo, J.-B. Jeanneret, Y. Papaphilippou, D. Quattraro, “Collective Effects in the CLIC Damping Rings,” EUROTeV-Report-2008-038
- [8] G. Xia, E. Elsen, “Ion Effects Estimation in the ILC Damping Ring,” EUROTeV-Report-2007-013
- [9] G. Xia, E. Elsen, “Simulation Study of Fast Ion Instability in the ILC Damping Ring,” EUROTeV-Report-2008-004
- [10] Joint CARE-HHH-APD, CARE-ELAN and EUROTEV-WP3 mini-Workshop on “Electron Cloud Clearing - Electron Cloud Effects and Technological Consequences,” CERN, Geneva, 1-2 March 2007; Proceedings published as EUROTeV-Report-2007-060, CARE/ELAN document-2007-004 ; workshop web site <http://care-hhh.web.cern.ch/CARE-HHH/ECL2/default.html>
- [11] CARE-HHH-APD Mini-Workshop on Electron-Cloud Mitigation (ECM’08) , CERN, 20-21 November 2008 ; Summary published as CARE-Conf-08-031-HHH ; workshop web site <http://indico.cern.ch/conferenceDisplay.py?confId=42645>
- [12] J. Thompson, J.M. Byrd, W. Höfle, G. Rumolo, “HEADTAIL Feedback Module: Implementation and Results,” CERN-AB-2008-070
- [13] A. Drago, “Fast feedbacks for diagnostics and mitigation of e-cloud instability,” presentation at LCWS08 - ILC Linear Collider Workshop, Chicago, 15-20 Nov. 2008; <http://ilcagenda.linearcollider.org/conferenceOtherViews.py?confId=2628&view=static&showDate=17-November-2008&showSession=all&detailLevel=contribution>
- [14] A. Drago, “Electron cloud and feedback in DAFNE,” talk at ECM’08 [11]