

ILC DR VACUUM DESIGN AND E-CLOUD *

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Abstract

Electron cloud parameters and vacuum design are tightly bounded to each other. Input parameters for the e-cloud depend on the shape of the vacuum chamber and surface properties. Beam induced electron multipacting in the vacuum chamber causes the electron stimulated gas desorption and may require modification of the vacuum system to deal with it. This paper describes the e-cloud modelling performed in a way to optimise ILC positron DR vacuum design and to have a clear understanding of what modifications in the vacuum chamber are required. Three parameters of e-cloud were varied in turn: photo-electron emission, secondary electron yield and gas pressure. It was found that all three parameters should not exceed a certain value to keep the e-cloud density down to an acceptable level. The energy and intensity of electron bombardment of the vacuum chamber walls and electron stimulated gas desorption were also calculated. It was found that electron stimulated gas desorption is comparable or larger than the photon stimulated desorption and should be considered in vacuum design.

INTRODUCTION

The damping rings (DR) of the International Linear Collider (ILC) will provide high quality electron and positron beams for achieving the required luminosity at the interaction point. The vacuum system, one of the key components in the ILC DR, was studied for baseline configuration OCS-6 [1] in consideration of thermal and synchrotron radiation induced gas desorption only [2]. Based on these results the ideal ILC vacuum chamber in presence of SR was specified as:

- Round or elliptical tube: it is the cheapest from the technological point of view and requires smaller size of bellows, in-line valves.
- No antechamber if SR power can be absorbed with vacuum chamber wall cooling (air convection or water cooled): beam conditioning is most efficient as it has a minimum inner wall area to condition with no shadow; it is an easy geometry for TiZrV coating.
- TiZrV NEG coated: it requires less number of pumps with less pumping speed comparing conventional technology (20-l/s pump every 30 m instead of 200-l/s pump every 5 m); it requires lower bakeout temperature: 180°C for NEG activation temperature instead of 250-300°C used for bakeout of stainless steel vacuum chamber; it provides better flexibility in choice of material for a vacuum chamber (stainless

steel, copper and aluminium) because it does not affect vacuum in this case. Residual gases are CH₄ and H₂ (with almost no CO and CO₂), comparing to H₂, CO and CO₂ in a conventional vacuum system.

The aim of this work was to investigate how an electron clouds in positron damping ring and the means of its suppression can affect DR vacuum and vacuum design.

HOW THE E-CLOUD AFFECTS VACUUM

An effect of the electron cloud and the electron multipacting is intensively studied now in a number of research laboratories both theoretically and experimentally (for example, see [3-9]). A free electron can appear inside a beam vacuum chamber due to different effects such as gas ionisation, photo-emission, thermal or field emission from the walls of vacuum chamber, etc. Such an electron can be accelerated by the bunch charge and hit the vacuum chamber wall, this hit may cause not only the secondary electron emission but the electron stimulated gas desorption as well. This gas desorption is proportional to the number of electrons hitting the walls in unit of time (electron flux) and increases with electron energy [10]. Alike the photon stimulated desorption, the electron stimulated desorption reduces with an integral electron dose [10-11]. For certain intensity of the electron bombarding the vacuum chamber wall (i.e. electron flux and electron energy) the electron stimulated desorption might become larger than photon stimulated desorption. It was estimated that the electron flux $\Phi \sim 10^{16} \text{ e}^-/(\text{s}\cdot\text{m})$ with $E \approx 200 \text{ eV}$ (which corresponds to $\sim 0.3 \text{ W/m}$) will cause an electron stimulated gas desorption flux approximately the same as the photon flux of $\sim 10^{18} \text{ } \gamma/(\text{s}\cdot\text{m})$ with photon critical energy of about 3 keV (as it is inside DR dipole), these calculations were performed with the same method as it was described in ref [12]. If the electron simulated desorption is comparable or larger than the photon stimulated desorption, that should be considered in vacuum design and machine conditioning scenario. In turn, large desorption causes the pressure to increase and therefore larger gas ionisation by the beam particles, which may accelerate the e-cloud build up and change e-cloud density to unacceptably high value. This requires the e-cloud build-up modelling which gives e-cloud density, impact electron energy, electron flux and corresponding power deposition on vacuum chamber walls.

E-CLOUD MODELLING RESULTS

An electron cloud build-up in the ILC damping ring was studied with FACTOR-2 code [7-8] for the following parameters: the Arc section is a circular beam pipe with

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diameter of 50 mm; bunch separation of 0.923 m, bunch length of 9 mm; and $2 \cdot 10^{10}$ positrons per bunch.

There are a few sources of electrons in the e-cloud in the DR vacuum chamber: (1) photo-electron emission due to synchrotron radiation, (2) secondary electron emission due to electrons accelerated by a beam charge hitting vacuum chamber walls and (3) due to residual gas ionisation. Photo-electron yield (PEY – a number of photo-electrons per passing positron per meter of vacuum chamber length), secondary electron yield (SEY – a number of secondary electrons per impact electron) and gas pressure were varied for OCS-6 beam parameters with the aim to find out what are the dominant sources of electrons for a particular design. Defining the main primary source(s) of electrons in ILC positron DR allows choosing the proper means of suppressing the e-cloud.

The main results for the Arc are summarised in Table 1. One can see that the maximum tolerated e-cloud density of $2 \cdot 10^{11} \text{ e}^-/\text{m}^3$ can only be reached when $\text{PEY} \leq 10^{-4} \text{ e}^-/(\text{e}^+ \cdot \text{m})$ and $\text{SEY} \leq 1.1 \text{ e}^-/\text{e}^-$. The corresponding power deposition of 0.3 W/m should be considered in the pumping scheme, as it was mentioned above. Another modelling result is that the effect of gas ionisation on e-cloud density can be neglected when $P \leq 10^{-8} \text{ mbar}$.

Table 1: Results obtained with FACTOR-2 code.

SEY [e ⁻ /e ⁻]	PEY [e ⁻ /(e ⁺ ·m)]							
	10 ⁻⁴	10 ⁻³	10 ⁻²	10 ⁻¹	10 ⁻⁴	10 ⁻³	10 ⁻²	10 ⁻¹
	Dipole q [e ⁻ /m ³]				Power [W/m]			
1.1	2·10 ¹¹	2·10 ¹²	1·10 ¹³	5·10 ¹³	0.3	3	30	80
1.3	3·10 ¹²	2·10 ¹³	3·10 ¹³	5·10 ¹³	2	30	80	100
1.5	3·10 ¹²	5·10 ¹³	5·10 ¹³	5·10 ¹³	80	80	100	100
	Wiggler q [e ⁻ /m ³]				Power [W/m]			
1.1	4·10 ¹⁰	–	–	5·10 ¹³	0.05	2	30	100
1.3	6·10 ¹¹	–	–	5·10 ¹³	1	30	80	100
1.5	3·10 ¹³	5·10 ¹³	5·10 ¹³	5·10 ¹³	100	100	100	100

The similar e-cloud modelling is required for the straights where, from one side, the photon intensity gradually reduces with distance from the dipole and requirements for maximum PEY and SEY can be different, from another side, the electron stimulated desorption could be the main source of gas in the presence of the beam.

PEY IN THE E-CLOUD MODELS

In surface physics the term photo-electron emission yield, κ is defined as a number of electrons emitted from the surface per incident photon. Attention should be paid to a similar term, photo-electron yield (PEY), used in e-cloud models has a different meaning: it is the number of electrons emitted from the surface due to photo-electron emission per one positron in the passing beam. The following data are used to calculate PEY:

- A photon flux hitting vacuum chamber walls: $\Gamma = 0.9 \gamma/(\text{e}^+ \cdot \text{m})$ in the arc and shortly downstream straight,

$\Gamma = 10 \gamma/(\text{e}^+ \cdot \text{m})$ in the wiggler and shortly downstream straight.

- Photo-electron emission yield [13]: $\kappa = 0.01\text{--}0.1 \text{ e}^-/\gamma$ depending on material, magnetic and electric field and photon energy, κ is not well studied for the NEG coating, only in ref. [9].
- Photons reflectivity/scattering after first hit with beam chamber walls: $R = 3\text{--}65\%$ (vary for different material, treatment, geometry) [13-15].
- Photon trapping efficiency of antechamber: The number of photons can be reduced to $F = 1\text{--}10\%$ (depending on beam size, ante-chamber size and geometry, as well as used material and treatments) [13-15].

In a tubular vacuum chamber without magnetic field the parameter PEY is calculated as:

$$\text{PEY} = \kappa \Gamma \tag{1}$$

In the presence of dipole magnetic field the electrons move along the magnetic lines, therefore the photo-electrons emitted at the direct photon impact place could not travel across the vacuum chamber and does not play a role in e-cloud in the beam path. Only the electrons emitted at the top and the bottom of the vacuum chamber are counted in this case and can be emitted there due to the reflected photons. In the assumption that all reflected and diffused photons cause uniform radial electron emission, PEY in a vacuum chamber in a dipole field is:

$$\text{PEY} = \kappa \Gamma R \tag{2}$$

The KEKB-type ante-chamber [6,9] helps in to reduce the number of photons which can be reflected and cause the photoelectron emission in the beam chamber by factor F . In vacuum chamber with an antechamber without magnetic field the parameter PEY is calculated as:

$$\text{PEY} = \kappa \Gamma F \tag{3}$$

In vacuum chamber with an antechamber in a magnetic field the parameter PEY is:

$$\text{PEY} = \kappa \Gamma R F \tag{4}$$

Table 2: PEY for different types of vacuum chamber: T – tubular, AC-antechamber, S – with a solenoid field.

Beam pipe	Inside magnets, B ≠ 0		Downstream straights near the magnet, B = 0		
	T	AC	T	S	AC
Calculated PEY					
Dipole SR	3·10 ⁻⁴ – 0.065	3·10 ⁻⁶ – 6.5·10 ⁻³	0.01– 0.1	0.01– 0.1	10 ⁻⁴ – 0.01
Wiggler SR	3·10 ⁻³ – 0.65	3·10 ⁻⁵ – 6.5·10 ⁻²	0.1–1	0.1–1	10 ⁻³ – 0.1
Required maximum PEY from e-cloud modelling					
Dipole	~10 ⁻⁴		to be studied		
Wiggler	~10 ⁻⁴		to be studied		

The comparison of PEY calculated with formulas (1)-(4) for different places of ILC DR with and without an antechamber is shown in Table 2. Comparing the PEY which can be expected to required ones we can conclude that an antechamber is required in dipole and wiggler vacuum chambers. Nothing can be concluded for the straight vacuum chambers until e-cloud modelling provides the required maximum PEY.

DEALING WITH E-CLOUD

To lower the e-cloud density, first of all one should minimise the number of generated (emitted or ionised) electrons, then minimise their chance of leaving the surface, minimise their probability to be presented on the beam orbit and their free lifetime; and finally, the beam parameters could be optimised to minimise the electron multipacting resonant parameters.

The number of photo-electrons can be reduced by surface treatment, conditioning, and coatings. If this is insufficient then the vacuum chamber shape could be modified to allow reducing or localising photoelectrons out of the beam orbit (saw-tooth surface or/and ante-chamber). A number of secondary electrons can be reduced by a number of means listed below. A number of electrons due to gas ionisation can be reduced by surface treatment and conditioning, low outgassing coating and better pumping.

As long as vacuum design and anti-e-cloud means affect each other, a complex solution should be found, where an e-cloud killer does not compromise UHV, and vice versa. The following anti-e-cloud means were discussed at a Workshop on Electron Cloud Clearing (ECL2) [3] and are placed in the order of priorities for vacuum design.

Passive means (coating or shape of vacuum chamber) are preferable:

- TiZrV NEG coating provides low κ and SEY. This is a preferred solution as an ideal for vacuum design due to low gas desorption and distributed pumping.
- Saw tooth surface allows reducing the photon reflectivity R in formulas (2) and (4).
- An antechamber allows reducing PEY (see Table 2). This design is more expensive as it requires a special shape of vacuum chamber and some additional expenses for more complicated coating equipment, larger and therefore more expensive in-line vacuum valves and bellows. Conditioning time to reach required vacuum will also increase. Alternatively, a larger number of UHV pumps will be required.
- Grooves along the beam chamber allow minimising the number of electrons emitted at the bottom of the channel to going out, therefore minimising the effective SEY of the grooved surface. This solution also increases the cost of vacuum chamber manufacturing. One should also study the quality of TiZrV coating in such design.
- TiN coating could be used instead of TiZrV coating only if the later does not allow the positron DR to run safely, because the cost of vacuum system will dramatically increase as TiN (unlike TiZrV coating) does not provide any pumping.

Active means (require controllers and power supply), should be avoided if possible:

- Solenoid field along the NEG coated straights.
 - Solenoid field along TiN coated straights.
 - Biased electrodes in wigglers and dipoles.
- Electrodes and insulating materials may dramatically increase the gas density in a vacuum chamber due to

thermal, photon, electron and ion induced gas desorption. Feedthroughs increase the chance of vacuum leaks to air. Choice of material for electrodes and insulating layer as well as in-vacua design must be UHV compatible, i.e. requires additional vacuum studies and testing.

CONCLUSIONS

In the ILC positron DR both photo-electron emission and secondary electron emission are equally important. Electrons due to residual gas ionisation are only important if the pressure is above 10^{-8} mbar. A complex solution for UHV and e-cloud suppression should be used. Passive means of e-cloud suppression are preferable: TiZrV coating is a first choice, an ante-chamber is required inside wiggler and dipoles, TiN coating should be only used if TiZrV coating does not allow suppressing e-cloud to the required level. Multipacting electrons in the positron DR will cause a pressure increase comparable or larger than photodesorption and should be considered in the vacuum design.

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