ESTIMATION OF PHOTOELECTRONS GENERATED IN LARGE ELECTRON AND POSITRON ACCELERATORS

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ABSTRACT

This paper shows a first step in understanding the photon induced outgassing mechanism in large electron and positron accelerators where high energy photons are incident in glancing angle. The calculation is based on reflection and penetration of photons, production of secondary electrons and escape of them as photoelectrons.

INTRODUCTION

Outgassing in the vacuum ducts of the accelerators for the electrons and positrons depends strongly on the quality of synchrotron radiations emerged from the stored particles. O'Neil first pointed out the outgassing in the accelerator was not caused by the direct photon stimulated desorption but by electron stimulated desorption based on photoelectrons generated by photon irradiation of the vacuum ducts[1]. Fisher and Bernardini measured independently the electron stimulated desorption and discussed the designs of vacuum system for electron accelerators[2,3]. Photoelectron yields is the important measure for evaluating the surface cleanness of the vacuum systems. As the accelerators become bigger and photon energy is higher, incidence angle of photons to the vacuum ducts becomes glancing and photoelectron yields are expected to change as inverse of sine function of the incidence angle. This extraporation for the incidence angle gives huge amount of photoelectrons, so very large pumping speeds of the system need to keep the pressure in desired values and special pretreatments for the duct materials should be developed for reducing the photoelectron yield. Moreover, higher energy photons can penetrate more deeply into the materials and are expected to enhance the diffusion from the bulk to the surface. This effect is also detrimental to the vacuum. Experimental measurements have been continued and it has been clear that the inverse sine function relation of the incidence angle is not always appreciable[4,5].

This paper gives theoretically the photoelectron yield and its incidence angle dependency, and moreover shows the photoelectron yield as a function of the beam energy. These results are important to design the vacuum systems of future large accelerators.

THEORETICAL TREATMENTS

In the storage ring for electrons and positrons, synchrotron radiation are generated and its quantum spectrum is given by

$$\frac{d^2N_e}{dEdt} = \frac{9\sqrt{3}}{8\pi}\ \frac{W}{E_c{}^2}\int_x^\infty K(5/3)dy \qquad (1)$$

$$W = (4\ /3)(r_e/e)(E_b/E_o)^3 E_b I/r \qquad (2)$$

where $x = E/E_c$, $E_c = (3/4\pi)hc(E_b/E_o)^3/r$. E_c is the critical photon energy, E_o is the electron rest energy, E is the photon energy, I is the beam current, E_b is the machine energy, r is the bending radius and K(5/3) is the second kind of the modified Bessel function[6]. A part of photons can reflect on the surface of the duct and the reflection coefficient $R_f(n(E),\ k(E))$ is a function of the optical constants of the materials[7]. The linear absorption coefficient for photons $A_p(E)$ is also a function of photon energy. As the photons penetrate in the bulk, they are adsorbed and generate

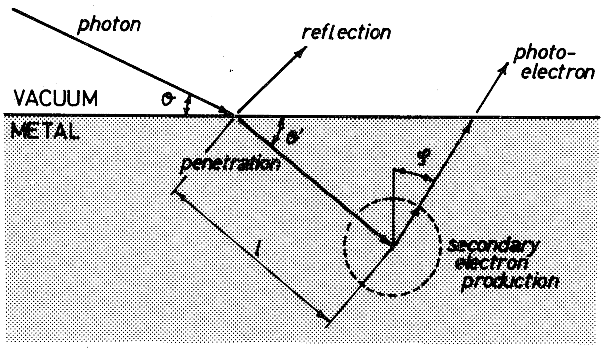

Fig. 1 The schematic drawing of photoelectron production.

secondary electrons around the photon trace. This conversion is said to be proportional to the absorption coefficient and photon energy[11]. The angular distribution of the secondary electrons is expressed as

$$F(\Theta) \propto \sin^2\Theta\cos^2\Theta/(1-\cos\Theta)^4 d\Omega \qquad (3)$$

where Θ is the angle between the photon penetration and the secondary electron emission[8]. Thus when the photons irradiate the surface in one mrad divergence, as shown in Fig. 1, the number of photoelectrons emitted N_e is expressed as follows,

$$N_e = \int (1-R_f(E))N_p(E)e^{-Ap(E)\ell}A_p(E)d\ell$$

$$\times\ EAF(\Theta)e^{-A_e(E)\ell\sin\theta'/\cos\phi}(d\Omega/4\pi)dE \qquad (4)$$

where A is a constant.
The reflection coefficient R_f for aluminum is obtained from the following expression,

$$R_f = |(n+ik)\sin\theta' - 1|^2/|(n+ik)\sin\theta' + 1|^2 \qquad (5)$$

and

$$(n+ik)\cos\theta' = \cos\theta \qquad (6)$$

and $n = n(E)$ and $k = k(E)$. The values of n and k were obtained from "Physics Data"[8]. The linear absorption coefficients were obtained approximately from the data of extinction coefficients[9] and are shown in Table 1. The linear electron absorption coefficients for secondary electrons were obtained as $A_e = 10^8/\lambda_e(E)$ from the data of electron mean free path in the metals[10] and were approximated as is shown in Table 2. The generation rate of photoelectrons is assumed to be proportional to A_p*E but A_p only[11]. Equation (4) is expected to give the photoelectron yield at normal incidence and the calculated results should be compared with the experimental results[11]. Thus, A is assumed to give good correspondence of the calculated photoelectron yield with the experimental ones.

CALCULATED RESULTS AND DISCUSSIONS

Photoelectron yield is obtained by using Eq. (4) and the results are shown in Fig. 2. In this calculation, $F(\Theta)$ is assumed that $F(\Theta) = 1$ for simplifing the integration as is shown in Fig. 1. The results for 73 < E < 100 eV depend on the approximate values of A_p. General tendency with photon energy is fairly good compared with the experimental curve[11]. The values of fitting factor A used in calculation are $9E^{(-0.213)}$ for E < 73, $1.8E^{(-0.554)}$ for 73 < E < 300, $0.026E^{(0.189)}$ for 300 < E < 1560 and $7.5\,E^{(-0.48)}$ for E > 1560. The results agree with the experimental results. Figure 3 shows the number of photoelectrons produced at 1 mrad

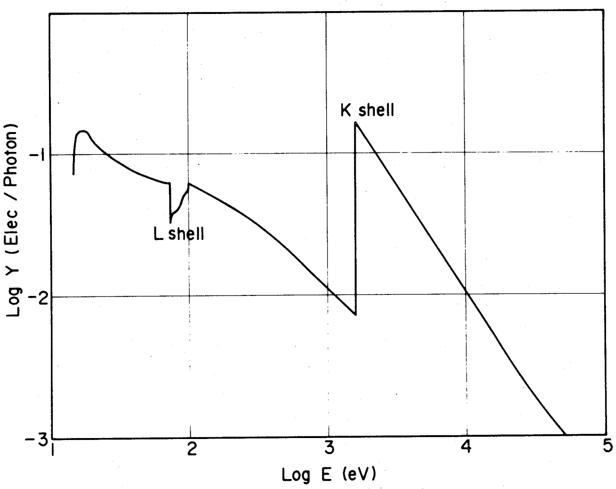

Fig. 2 The photoelectron yield at normal incidence for aluminum.

Table 1

The Linear Absorption Coefficients Used in the Calculation

E_p (eV)	A_p
15 ∿ 73	$6.84 \times 10^5 E^{-1.8}$
73 ∿ 100	$3.57 \times 10^3 E$
100 ∿ 300	$1.81 \times 10^8 E^{-1.33}$
300 ∿ 1500	$4.49 \times 10^{11} E^{-2.7}$
1500 ∿ 60000	$4.83 \times 10^{12} E^{-2.7}$

Table 2

The Linear Secondary Electron Absorption Coefficients Used in the Calculation

E_e (eV)	λ_e (Å)
< 73	$10^{\{0.6323+0.9499(\log E_e-\log 80)^2\}}$
73 ∿ 1560	$10^{\{0.4999+0.1513(\log E_e-\log 10)^2\}}$
1560 <	$0.131E_e^{2/3}$

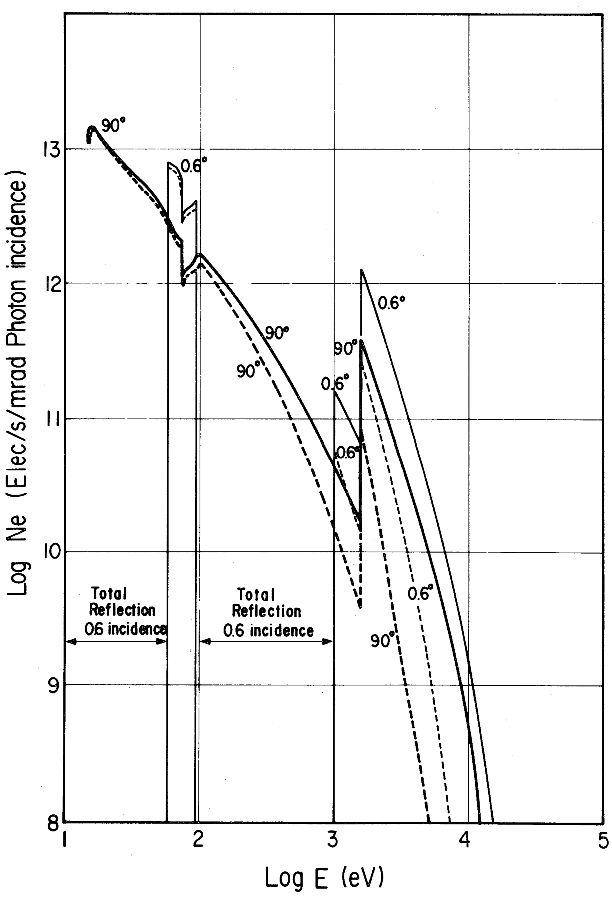

Fig. 3 The number of photoelectrons produced at 1 mrad photon angle of incidence.

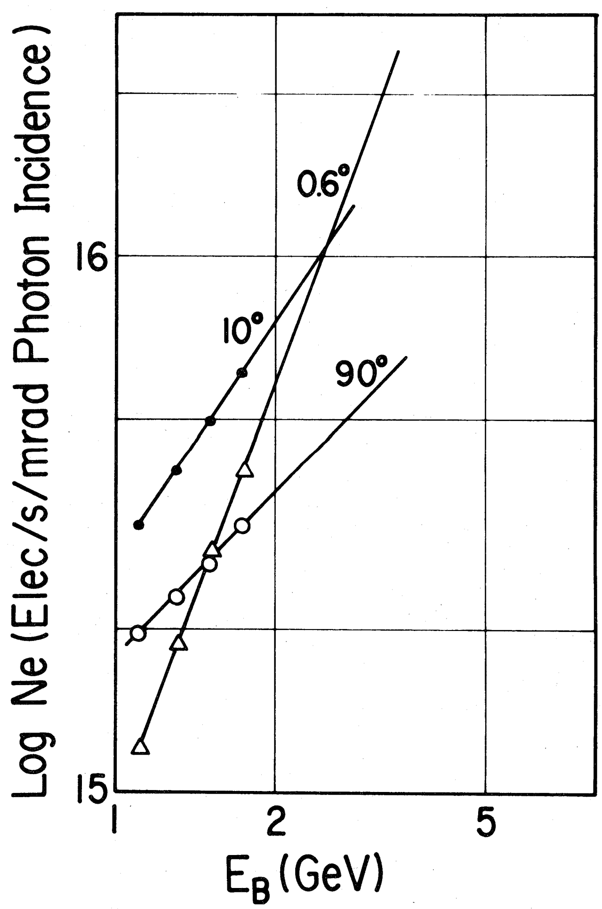

Fig. 4 The beam energy dependence of photoelectrons for 90°, 10° and 0.6° angle of incidence.

photon angle of incidence. The photon distribution parameters are assumed to fit those in the electron positron storage ring (DCI) at the Laboratoire de l'accelerature Lineaire, Orsay, France, and for a stored current of 100 mA because of comparing the calculated results with the experimental ones[5]. At 0.6 glancing angle of incidence, the values of n(E) and k(E) give total reflection of photons for E < 68 eV and 94 < E < 1000 eV[12]. The beam energy dependence of photoelectrons is shown in Fig. 4 for 90, 10 and 0.6 deg angle of incidence. The 0.6 deg angle of incidence gives a relation $Ne \propto E_b^{2.7}$, while the experimental results were $E_b^{2.8} \sim E_b^{2.9}$ which wre obtained in October 1983 at Orsay[5]. Both calculated and experimental results agree quite well. However the absolute values obtained experimentally were roughly 2-orders lower than those calculated. The photoelectron yield was calculated as a function of the angle of incidence and is shown in Fig. 5. At glancing incidence the normalized yield does not obey a 1/sin(θ) law. The experimental outgassing rate is also shown in the figure[4]. The outgassing rate can be obtained by using Δp is the pressure increment by photon irradiation.

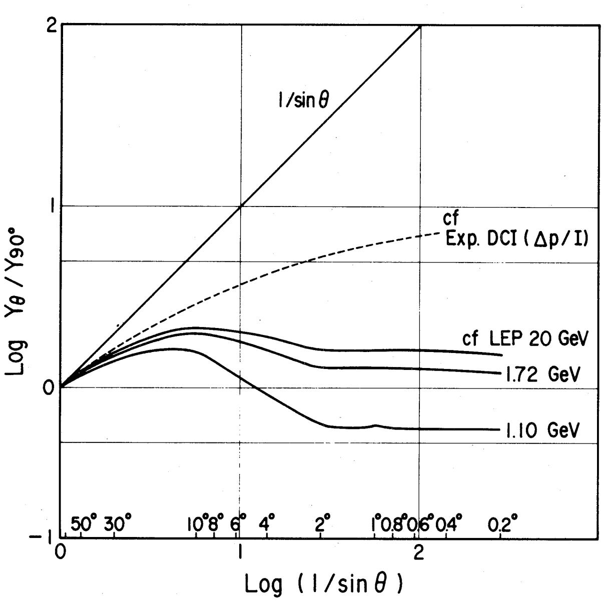

Fig. 5 The angle of incidence dependence of the photoelectron yield. The dashed line shows experimental outgassing rate.

This Δp is considered to be proportional to the number of photoelectrons. So, $\Delta p/I_b$ is related to the photoelectron yield Y. The scattered and reflected photons in the experimental vacuum chamber are considered to produce photoelectrons in the other positions and experimental outgassing rate is considered to be higher than the calculated results. If a uni-directional detector with high directivity[13] is used for observations of outgassing at the position of the first photon incidence, the experimental $\Delta p/I_b$ results will change and there may be a better correspondence with the angular dependence of the photoelectron yield. These results indicate that in designing of the vacuum systems of the future accelerators in higher energy and with very large size, this calculation method can open the way to estimate the outgassing rate caused by photoelectrons. Further developments of the theory will continue and give the results of outgassing rate combined with the bulk diffusion enhanced by photon irradiation.

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