SUPPRESSION OF SECONDARY EMISSION IN A MAGNETIC FIELD USING A SAWTOOTH SURFACE

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Abstract

The effect of surface roughness on the secondary electron emission from a sawtooth surface in a magnetic field under electron bombardment is investigated using a Monte-Carlo method. Some of the secondary electrons emitted from the sawtooth surface return to the surface within their first few gyrations, resulting in a low effective secondary electron yield. A sawtooth surface in magnetic field can significantly reduce the secondary emission yield below the multipacting threshold.

INTRODUCTION

Electron cloud due to multipacting can cause transverse beam instabilities, beam loss, vacuum pressure rise, transverse beam size increase and heat load deposited on the chamber wall due to the lost electrons. Multipacting is induced by beam itself. Electrons gain energy from the beam. Therefore, multipacting happens in high intensity rings where electrons can gain sufficient energy for multipacting. The electron cloud have been observed in almost all the recent intensity rings, such as the LANL-PSR, SNS at ORNL, B-factory at KEK, PEPII B-factory at SLAC, SPS at CERN, RHIC and AGS at BNL[1].

A weak solenoid is a good remedy to suppress the electron multipacting in a drift region by confining the electrons near the pipe surface[2, 3]. However, it doesn't work in a magnet where strong multipacting can happen. Clearing electrodes may work as a possible remedy. A tradition stripline type electrode has been proposed in SPS[4]. Simulation shows that a wire type electrode works perfectly in all types of magnets [5]. In practice, the secondary emission yield (SEY) can be reduced by coating of the metal surface, surface cleaning and beam scrubbing. Surface roughness is another type of remedy to reduce the SEY. The surface roughnees effect on the secondary emission in field free case has been studied[6-8]. A triangular grooved surface in a strong magnetic field is not effective on suppression of the SEY [8].

A new sawtooth surface is proposed in this paper. To simulate the secondary electrons' emission from the surface we apply a Monte Carlo program CLOUDLAND, which includes the detail model of electron-surface interaction and electron motion in magnetic field. Program CLOUDLAND is a 3D particle in cell code for the simulation of electron multipacting with various charged beam, electric and magnetic fields. Simulation shows that a sawtooth surface can significantly reduce the SEY by restricting the secondary electrons near the surface.

MONTE CARLO SIMULATION

The basic idea of the Monte-Carlo model of secondary electron emission used here is to simulate trajectories of primary and secondary electrons in electric or magnetic field. When the primary electrons interact with surface, secondary electrons are generated using a series of random numbers to determine their energy and velocity according to given secondary emission parameters. Two series of secondary parameters are considered here:

1) A maximum SEY 1.40 at 190 *eV*
2) A maximum SEY 1.74 at 330 *eV*

The angular distribution of the trajectories of the secondary electrons as they emerge from the surface is described by a cosine function when the electron is incident normally on the surface:

$$\delta(\theta) = \delta_0 \cos\theta \tag{1}$$

Where θ is the angle between the surface normal and the direction of the measurement, and δ_0 is the value of δ along the surface normal. The initial energy distribution of the true secondary emission is taken to be a half-Gaussian centered at 0 with an rms spread of 5 *eV*. The detail model of secondary electron emission of CLOUDLAND is described in [9, 10]. The effective SEY are calculated by the ratio of electrons coming out from the surface to the primary electrons. In each step, the secondary electrons are generated by 10^5 primary electrons.

The electron multipacting in magnetic fields happens only at the location where the field lines are prependicular to the surface. For example, inside dipole magnets, two stripes of multipacting occurs near the middle of horizontal accodrinate [9, 11]. Multipacting in quadrupole magnet occurs at the middle of the magnetic poles. Therefore, a dipole magnetic field which is prependicular to the surface is assumed in this paper. The results of this paper straightly apply to quadrupole magnet and others. In this paper, we assume a dipole magnetic field of 0.2 Tesla, which is dipole field in the damping ring of the Internactional Linear Collider(ILC). It is also close to the dipole magnetifc field of B-factories. The gyration radius of an electron in magnetic ffield B_0 is

$$r_0 = \gamma m_0 v_\perp / eB_0 \tag{2}$$

r_0=37.7μm for a 5eV electron in a 0.2 Tesla field.

MECHANISM

Figure 1 shows the geometry of a saw-tooth surface. Its surface is a sawtooth function

$$S(x) = h * frac(\frac{x}{W} + \phi), \tag{3}$$

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Where *frac* is the fractional part $frac(x) = x - \lfloor x \rfloor$, *h* is the height, *W* is the period of the surface, and ϕ is its phase.

The vertical edges parallel to the magnetic field lines. If an electron hits these edges, it makes a half circle like motion and then hits the surface again with a low SEY due to its low energy. The period of electron's gyration motion $2\pi m_0 \gamma / eB$ is 0.179 ns in a 0.2 Tesla magnetic field, while the bunch spacing of ILC damping ring and B-factories ranges from 3 to 8ns. Therefore, the secondary electrons can hit the surface dozens times with small SEYs. In principle, these edges can completely suppress the secondary emission, which means the secondary electrons cannot go up and return to the beam chamber. There is a similar mechanism to suppress the electrons using a weak solenoid in field free regions.

The tilted edges with a slope angle of α cannot trap all the secondary electrons. Some secondary electrons make gyration motion and hit the surface several times, then go up. Parts of secondary electrons can directly go up and enter the beam chamber without any collision with the tilted edges. The effect of this surface strongly depends on the slope angle α. The electrons' orbits in Figure 2 clearly show the clearing mechanism.

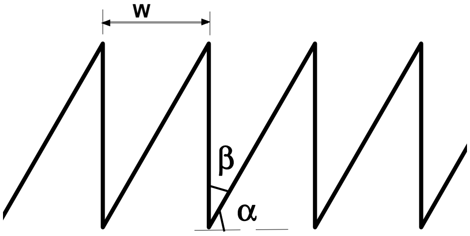

Figure 1 Sawtooth surface ($\alpha + \beta = \pi / 2$). The period is *W* and height is *h*.

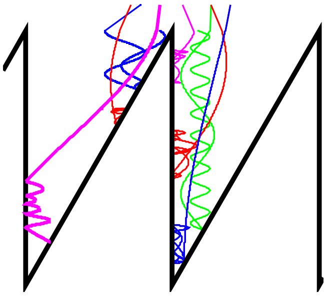

Figure 2: Orbits of electrons show the mechanism of confinement of secondary electrons.

RESULTS AND DISCUSSION

Slope Angle Effect

The orbit of secondary electron is a helix. If the orbit of a secondary electron emitted from the tilted edges intersects with the surface, the secondary hits the tilted edges and then generate tertiary electrons with a smaller charge due to the small electron yield. The probability of secondary electron hitting the tilted edge is sensitive to the slope angle α. The larger the slope angle α, the bigger the probability. Figure 3 shows the effective SEY from a sawtooth surface with α=0°(flat surface), 60°, 70° and *W*=0.28mm in a 0.2 Tesla magnetic field. The peak effective SEY with a flat surface is about 1.9, which is bigger than δ_0=1.40 due to the effect of grazing angle φ: the SEY is roughly proportional to $1/\sin(\varphi)$. A saw-tooth surface with α=60° reduces the peak effective SEY below 0.9. A α=70° reduces it further with a peak SEY of 0.6. Therefore, for a surface material with δ_0=1.4, a saw-tooth surface with α=60° and *W*=0.38mm is enough to suppress the electron multipacting.

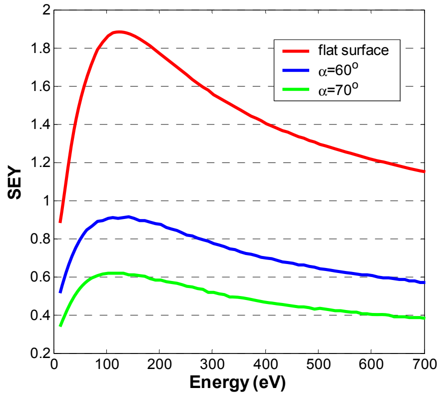

Figure 3: Effective SEY from saw-tooth surface in a dipole magnetic field. δ_0=1.40, B_0=0.2Tesla, *W*=0.38 mm.

Effect of W

Figure 4 shows the effective SEY from the sawtooh surface with different *W* and α. The material of the surface has a δ_0 of 1.74 at 330eV. The magnetic field is 0.2Tesla. The suppression effect of SEY from the surface is not monotonic. With a smaller *W*, the primary electrons cannot deeply enter the swatooth surface due to their lager gyration motion radius comparing with *W*. Therefore, the secondary electrons have more probability to go up and enter to the beam chamber. If *W* is very bigger, the primary electrons have more chance to hit the tilted edges instead of the vertical edges. Therefore, a surface with big *W* has bigger effective SEY. The optimized *W* is about the gyration motion radius at the energy with peak SEY. With a large α, the effect of *W* becomes smaller as shown in Figure 4. There are small effective SEYs (<0.76) when *W* ranges from 0.38mm~1.89mm with α=70°. The SEY gets saturated near *W*=1.89mm. A special case with δ_0=2.5, α=70° and *W*=0.38mm is also shown in Figure 4 (Cyan colour). There is still no multipacting even with δ_0=2.5.

Magnetic Field Effect

Figure 5 shows the effective SEY from the sawtooh surface in a 0.3 Tesla magnetic field. The SEY of the surface material is the same as Figure 4. The comparison of Figure 5 with Figure 4 shows the effective SEY is the same if $W * B_0$ is a constant, which indicts that the ratio of *W* to the gyration motion radius is the same. Therefore, a smaller *W* is required in a stronger magnetic field.

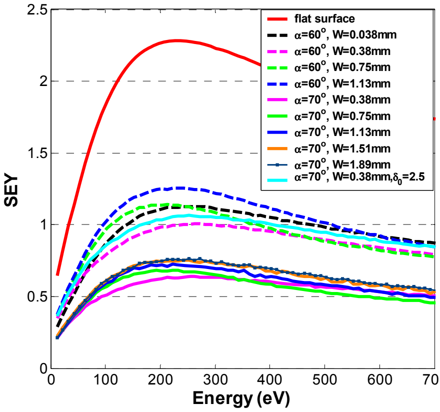

Figure 4: Effective SEY from saw-tooth surface in a dipole magnetic field. δ_0=1.74, B_0=0.2Tesla

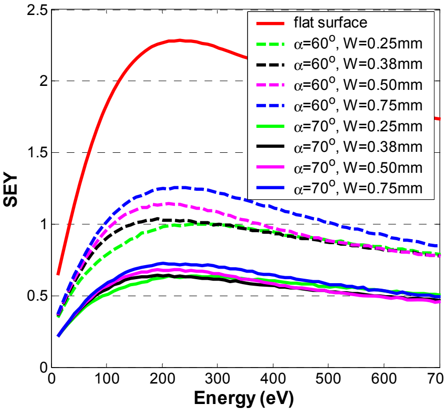

Figure 5: Effective SEY from saw-tooth surface in a dipole magnetic field. δ_0=1.74, B_0=0.3Tesla.

APPLICATION TO ILC DAMPING RING

In a general multipole magnet, the magnetic field can be expressed as

$$B_r^n = (-1)^{n-1} C r^{n-1} \sin n\theta , \qquad (4)$$

$$B_\theta^n = C r^{n-1} \cos n\theta , \qquad (5)$$

where *2n* is the number of poles in order to excite the nth multipole, *n*=1 for dipole, 2 for quadrupole and so on. *C* is constant value for each type of magnets. In a strong magnet, electrons can drift to the chamber center only along the magnetic field lines with stronger radial field component. These field lines are close to position which satisfies

$$\sin n\theta \sim \pm 1 . \qquad (6)$$

These points are the middle position of magnet poles. Therefore, the sawtooth surface should locate near these positions to suppress the electron multipacting there, while smooth surface can be used in other regions in order to reduce the total impedance of beam chamber.

Figure 6 shows the transverse distribution of electron cloud in a dipole magnet of ILC positron damping ring. Two multipacting strips near the horizontal center are clearly visible in the figure. The width of multipacting region is only 10mm where the sawtooth surface at both bottom and top of the chamber is required. The required sawtooth surface is only 15% of the total surface. A rectangular grooved vacuum chamber cover the whole chamber surface increases the impedance by a factor of 48% [12]. Therefore, the increase of the impedance due to the sawtooth is only 7.2% assuming the sawtooth has the same impedance with rectangular one. Following the same way, the electron cloud in quadrupole, sextupole and wiggler can be reduced by replacing the smooth surface with the sawtooth surface near the magnet poles or multipacting regions.

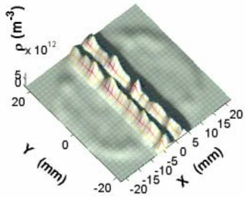

Figure 6: Transverse distribution of electron cloud in the dipole magnet of ILC damping ring.

SUMMARY

The effective SEY from a sawtooth surface in a magnetic field has been simulated using Monte Carlo method. A sawtooth surface can significantly reduce the effective SEY below the multipacting threshold. The effect depends on the slope angle α and *W* of the surface. A larger α is more effective. The optimized *W* is about the gyration motion radius at the energy with peak SEY. When α is 70° or more, the effect of *W* and *h* becomes less sensitive. The optimized *W* for ILC damping ring ranges 0.4~1.9 mm. Therefore, it is easy to be fabricated and it is cheap. Such kind of surface can suppress the multipacting up to a δ_0=2.5. A stronger field requires a smaller *W*. The impedance enhancement due to the sawtooth surface is small due to the small percentage of the coverage of the sawtooth surface. A realistic calculation of the impedance is under the way. The sawtooth surface can suppress the electron multipacting in various magnets, such as dipole, quadrupole and wiggler.

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