SECONDARY ELECTRON EMISSION DATA FOR THE SIMULATION OF ELECTRON CLOUD

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Abstract

The secondary electron yield is one of the determinant parameters entering in the simulation of the electron cloud phenomenon. As secondary electron emission is a surface process, it is strongly influenced by slight modifications of the materials outer layers. This presentation will try to summarize various numerical formulae describing the main input data needed for the simulation of the electron multiplication in the electron cloud process

1 INTRODUCTION

The electron cloud effect [1-3] is a possible limitation for the operation of LHC and of its injector, the SPS. Apart from dissipating an excessive power on the LHC beam screen, it can induce detrimental oscillations of the proton beams which degrade their emittance and hence the achievable luminosity in the interaction points. Accurate simulation programs are necessary to predict the behaviour of future machines and adapt possible cures, e.g. surface treatments, to meet the expected performance. The electron cloud mechanism depends partly on the generation of secondary electrons by electron impact on the vacuum chamber hence it is important to provide, for the simulation programs good fits to analytical formulae able to represent the main characteristics of the secondary electron emission. This paper presents various equations from the existing literature and their comparison to data collected for the copper surface of the future LHC.

2 EMPIRICAL FORMULAE AND NUMERICAL VALUES FOR SIMULATIONS

For the simulation of the electron cloud phenomenon, it is necessary to use various analytical formulae reproducing the variation of different characteristics of the secondary electron emission. These formulae are also very important in the field of surface physics e.g. for the prediction of contrast in scanning electron microscopy[4], or for the study of electronic devices using electron mutiplication [5]. For this reason the mechanisms leading to the secondary electron emission have been studied in details and appropriate analytical formulae either based on physical models or purely empirical have been published. They describe the main features of the secondary electron emission, namely : the variation of the secondary electron yield (S.E.Y.) as a function of the primary electron energy (E_p) or the secondary electron energy distribution. In such formulae, fitting parameters must be determined by measurements of samples corresponding to the material investigated. This is especially true in the case of accelerators as the surfaces involved are far from being ideal but are technical surfaces processed according to procedures applicable to many square meters as this is the case for the copper cladded LHC beam-screen. The following paragraphs will give the fitting parameters that can be used to describe analytically the secondary electron emission of this surface. The copper samples were cleaned by immersion in an alkaline detergent (NGL Cleaning Technology 17.40) followed by rinsing in demineralised water and ethanol.

2.1 Variation of the S.E.Y. with the primary electron energy

The secondary electron emission can be described using a simplified two steps model [6, 7]:

- The deposition of energy by the primary electron at a constant rate along its trajectory [8, 9]
- The escape of the created excited electrons with a probability decreasing exponentially with the distance to the surface [10]

The use of reduced S.E.Y. (ratio of the S.E.Y. to the maximum S.E.Y., δ_m) and of reduced energy (ratio of the energy to the energy of the maximum S.E.Y., E_m) allows to replace difficult to obtain constants by two more accessible quantities δ_m and E_m. This useful

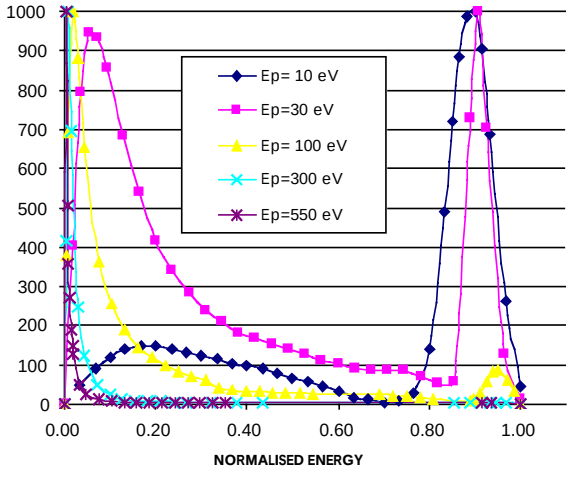


Figure 1: Normalised secondary electron energy distribution for conditioned copper

normalisation [11] was used to give an analytical expression for the variation of the S.E.Y.[4, 7, 12] which was simplified by M. Furman [2, 12] to be incorporated in simulation codes of the electron cloud effect. However this formula (1)

:

$$\delta_s = \delta_{MAX} \frac{s \times \left(\frac{E_p}{E_{MAX}}\right)}{s - 1 + \left(\frac{E_p}{E_{MAX}}\right)^s} \quad (1)$$

underestimates the S.E.Y. of primary electrons with very low energy [12]. This is due to the basic assumptions quoted before which do not consider the possibility of reflection. This event has a high probability for low

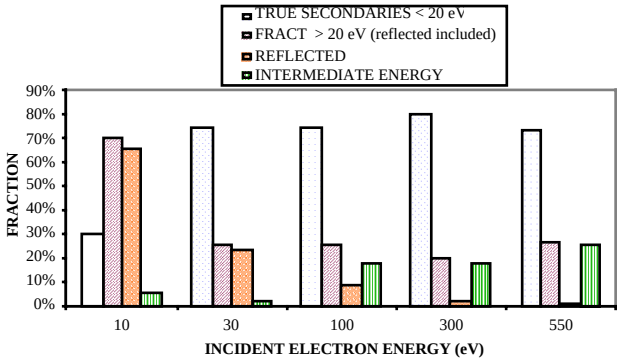


Figure 2: Variation of the energy repartition of reemitted electrons as a function of the primary electron energy (E_p)

energy incident electrons (E< 30 eV) as can be seen in figure 1 which shows the normalised intensity (1 for the highest peak) as a function of the normalised energy (1 for the incident energy). More generally, figure 2 gives

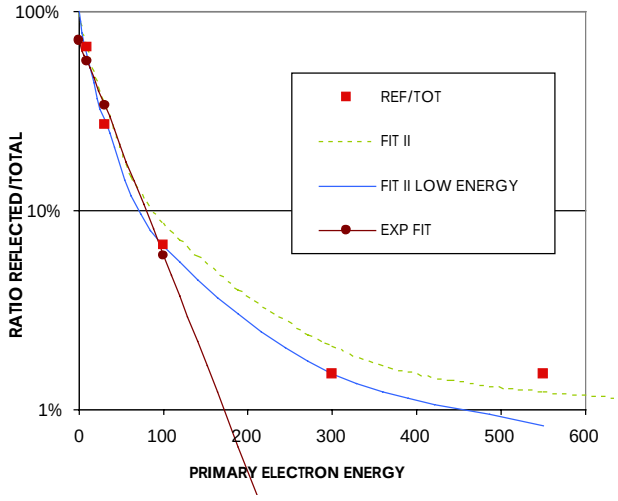


Figure 3: The ratio (f) between the reflected and the total number of re-emitted electrons for copper (squares) and the fitting laws

the ratio between the various categories of reemitted electrons for copper. These categories have been arbitrarily defined according to their energies (E) as "true secondaries": (E < 20 eV), "reflected": electrons: in the reflected peak and "intermediate": electrons with an energy between 20 eV and the reflected peak energy .

Table 1: Fitting parameters for the expression of the reflected fraction f in the case of copper

Fitting coefficient	Low energy (<300 eV)	Higher energy (<2000 eV)
A0	20.699890	0.300207076
A1	-7.07605	0.044915014
A2	0.483547	-0.155498672
A3	0	9.50318×10^{-4}
E0	56.914686	0
Curve label	FIT II low energy	FIT II

To improve the accuracy of formula (1) for electrons of low energy (< 100 eV), measurements of the secondary electron energy distribution have been used to evaluate the fraction (f) of reflected electrons in the total energy distribution. Figure 3 shows this fraction in the case of copper. To fit the experimental points (squares) the expression described by Scholtz et al [13] has been used :

$$\ln(f) = A_0 + A_1 \times (\ln(E_p + E_0)) + A_2 \times (\ln(E_p + E_0))^2 + A_3 \times (\ln(E_p + E_0))^3$$

where E_p is the primary electron energy and the other terms are fitting parameters given in table 1.

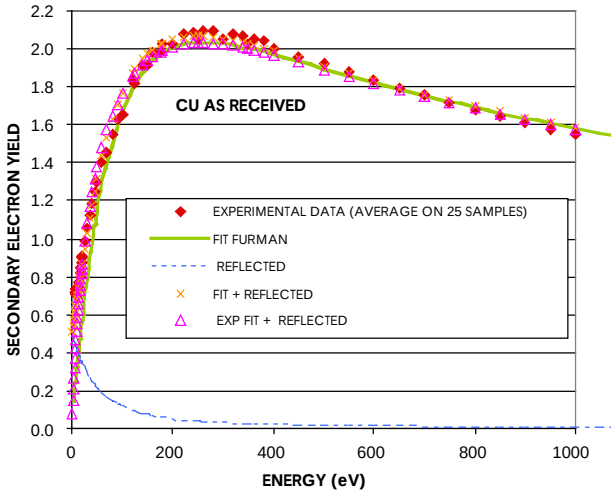


Figure 4: Comparison between fitting formulae and experimental data for as received copper.

The formula used to account for the reflected electron contribution f at low energy combined with formula (1) has been checked against the measured value of the total secondary electron yield (δ_t) in the case of as received copper. To calculate δ_t, the following formula was considered, where δ_S is the true secondary yield given by formula 1 and δ_R is the yield of reflected electron:

$$\delta_t = \delta_S + \delta_R ,$$

$$\delta_R = f \times \delta_t \Rightarrow \delta_t = \delta_S + f \times \delta_t$$

Hence: $$\delta_t = \delta_s \times \frac{1}{(1-f)}$$

A comparison of the fitting formula to experimental data is given in figures 4 and 5 for the case of as received copper. Figure 5 is an enlargement of figure 4 for low incident energies. These fits were obtained using for the

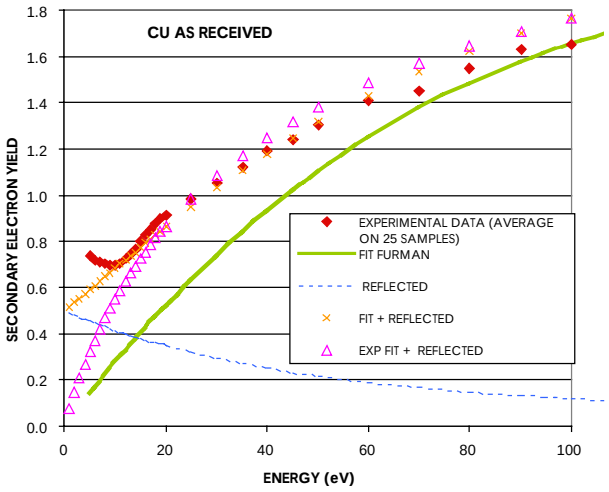


Figure 5: Comparison between fitting formulae and experimental data for as received copper at low incident energy

formula 1 the parameters listed in table 2. The curves in figure 5 show the importance of the reflected electron contribution to fit the low energy data with a good accuracy. The increase of the secondary electron yield at very low impact energy (below 5 eV) has been also measured for pure copper by Myers [14].

Table 2: Fit parameter for the true secondary electron yield (formula 1)

SAMPLE STATE	AS RECEIVED
δ_{MAX}	2.03
E_{MAX}	262
s	1.39

2.2 Fitting formula for the true secondary electron energy distribution

In reference [13] the following formula is proposed to fit the true secondary electron energy distribution i.e. the low energy electrons.

$$(2) \qquad D(E_s) = C \times \exp\left\{-\frac{\left[\ln\frac{E_s}{E_0}\right]^2}{2\tau^2}\right\}$$

where E_s is the secondary electron energy, E_0, τ and C are fitting parameters. To obtain a fit to our experimental data in the case of as received copper, the value of these constants are listed in the table 3. As already mentioned, this formula is only valid for true secondary electrons and an upper limit is given in table 3 for the validity of this expression. This limit is usually around 20 eV but at very low primary energy it can be as low as 5 eV because of the importance of the reflected peak at this low incident energy and of the corresponding electron depletion at energies immediately lower.

Table 3: Fitting parameters for various primary electron energies (formula 2)

PRIMARY ENERGY (eV)	C	E_0	τ	UPPER ENERGY BOUND (eV)
10	0.277	1.57	0.985	5
30	0.136	1.9	0.99	22
100	.126	1.58	1.16	22
300	.155	2.1	0.85	21
550	0.2	1.48	0.909	26

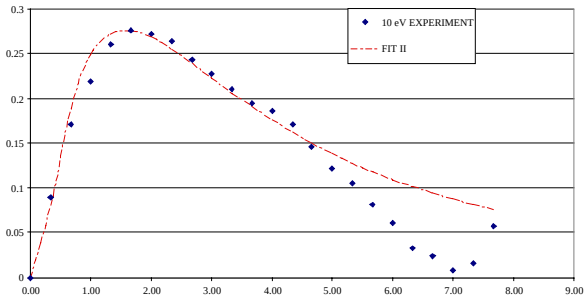


Figure 6: Comparison between the fitted curve and the experimental data for as received copper and 10 eV primary electron energy

This is illustrated in figure 6 where the result of the fit is compared to the experimental points for 10 eV primary electron energy. Figure 7 shows the good agreement obtained at higher primary electron energy (100 eV)

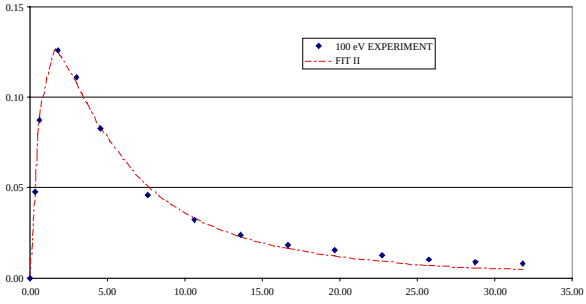
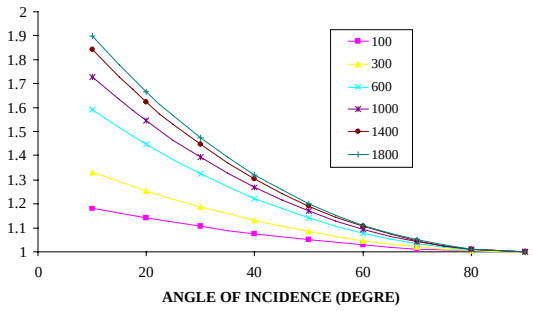


Figure 7: Fitted secondary electron energy distribution for 100 eV electrons impinging on as received copper

2.3 Fitting formula for the true secondary electron energy distribution

The effect of the angle of incidence of the primary electrons is also of great importance for the electron cloud generation as in accelerators arcs, the electrons spiral along the magnetic field lines. As the primary electrons dissipate their energy closer to the surface, an enhancement of the secondary electron yield can be expected when the angle of incidence decreases (90 degree corresponding to normal incidence). This effect is shown in figure 8 where the S.E.Y normalised to 1 at normal incidence is plotted for various primary energy as a function of the angle of incidence for a baked



niobium surface.

Figure 8: The variation of niobium secondary electron yield as a function of the angle of incidence

This dependence has been expressed analytically by several authors[7, 12, 15] following the simplified model depicted in 2.1. K is the fitting parameter:

$$\delta = \delta_{90} \times e^{K(1-\cos(\pi/2-\theta))} \quad (3)$$

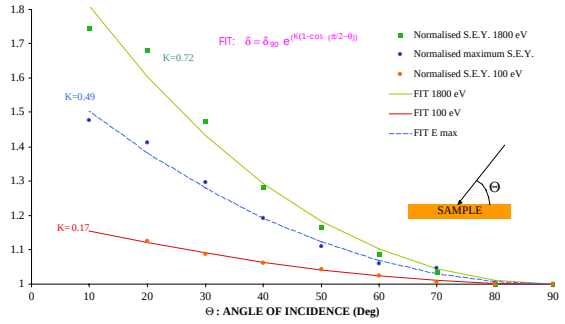


Figure 9: Fit of the secondary electron yield angular dependence for a niobium surface using (3)

The application of (3) in the case of a baked niobium sample is shown in figure 9 where the variation of the S.E.Y. is shown at 2 incident energies : 100 eV, 1800 eV and for the maximum yield. This graph demonstrate again the larger enhancement of the yield for small angles at higher energy and the validity of the approximations leading to equation (3). It must be stressed that at energies higher than some keV (3) is no more valid and a law as $\cos(\theta)^{-\bullet}$ becomes more appropriate [4].

3 CONCLUSIONS

Various equations have been fitted to experimental data in the case of copper and niobium. It was demonstrated that they represent with a good accuracy the main characteristics of the secondary electron emission. A combination of formulae representing the variation of the true secondary electron yield corrected for the reflected electron fraction gives a good approximation to the variation of the secondary electron yield with the incident electron energy at low energy. The angular dependence of the yield has been studied in the case of niobium and the proposed fitting expression was also found adapted.

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