A study of the secondary electrons yield produced by laser induced ions on Faraday cups as a function of beam angle

V Nassisi\textsuperscript{1,2,3}, D Delle Side\textsuperscript{1,2}, L Velardi\textsuperscript{1,2}, G Buccolieri\textsuperscript{1,2}, A De Benedittis\textsuperscript{1} and F Paladini\textsuperscript{1}

\textsuperscript{1} LEAS - Dipartimento di Matematica e Fisica “Ennio De Giorgi”, Università del Salento, Via per Arnesano, 73100, Lecce - Italy
\textsuperscript{2} INFN Sezione di Lecce, Via per Arnesano, 73100, Lecce - Italy

E-mail: vincenzo.nassisi@le.infn.it

\textbf{Abstract.} We analyze the dependence of the Secondary Electron Emission yield on the beam incidence angle ($\theta$) in the case of Faraday cups used for diagnosis of laser-plasma. We show that this dependence follows a $\sec^2(\theta)$ law, consequently $\theta \neq 0$ situations (i.e. non-normal incidence) should be treated with care to avoid wrong measurements.

1. Introduction
Faraday cups (FCs) are widely used as charged particle detectors for characterizing ion and electron beams\cite{1}. In such devices, the charged particles reaching the conductive (metal) surface of the detector induce a current, generally recorded on oscilloscopes or other digital devices. Although the working principle is very simple, the impact of energetic charged particles on the conductive surface is a rather complicated process. In particular, the interaction of the charged particles with the electrons of the surface could causes excitation of electrons and ionization both in the incident and the target species. When this excitation happens near the surface it mainly results in the emission of electrons. This process is called Secondary Electrons Emission (SEE) and could potentially lead to wrong estimation of currents in FC detectors. Indeed, secondary electrons leaving the surface of the detector could be erroneously interpreted as a net positive charge, overestimating ion currents or underestimating electron ones. To overcome this problem, polarized grids in front of the detector surface are generally used\cite{2}, in order to suppress electron escape. The aim of this work is to study how SEE depends on the angle of incidence of the projectiles, in order to explore if new geometrical configurations of FCs are applicable.

2. Theory
FCs’ theory is quite simple. Charged particles impinging on the detector surface generate a proportional current that is transmitted to the recording electronics by means of a transmission line. This line has generally a $R = 50$ $\Omega$ characteristic impedance, to avoid any reflections during the propagation of the signal. At the same time, also FCs should exhibit the same impedance. For example, a simple FC housed within a vacuum pipe constitutes a capacitor together with the housing. In particular, one should take care of reducing the FC capacitance ($C_c$) as much as possible through an

\textsuperscript{3} To whom correspondence should be addressed
ad hoc design. In effect, this parameter influences the damping time of the transmission line (TL), given by $R \times C_c$, that has to be small with respect to the duration of the beam under exam, otherwise it would add to it, compromising its diagnosis. In figure 1 two circuits used for FC are presented.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{circuit.png}
\caption{Circuit schematics of Faraday cups for: a) charged beams; b) plasma beams. These devices measure the current $i(t)$ generated by the charges impinging on the detector plate.}
\end{figure}

Using FCs for diagnosis of a plasma flux requires polarization of the surface of the detector in order to ensure that only (for example) ions reach the FC. This imposes the use of a second capacitor, $C_s$, in order to separate the polarizing voltage from the signal to be diagnosed, as shown in figure 1b.

Let’s suppose that we want to diagnose an ion beam (the same applies also to electrons). If the beam ions have sufficient energy, the interaction with the surface of the detector could lead to SEE. This process is the result of the excitation of the electrons of the external shells both of the detectors and of the ions. If the excited electrons are produced near the surface of the detector, depending on their energy, they could escape from the surface, leading to wrong current and total charge measurements. In particular, the total charge registered will be given by

$$Q = (1 + \gamma)Q'$$

where $Q$ represents the charge registered, $Q'$ the real charge of the species under exam and $\gamma$ is the SEE coefficient (in the case of ions $\gamma > 0$, while $\gamma < 0$ for electrons). For this reason, FCs generally use almost transparent electrodes in order to suppress SEE, as shown in figure 2.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{grid.png}
\caption{Example of a FC with a grid that acts as SEE suppressor. In the case of plasma ions diagnosis, for example, the suppressor is put at a negative voltage, greater (in absolute value) than the one applied to the metal plate of the FC detector.}
\end{figure}

The setup illustrated in figure 2 allows to safely consider $\gamma = 0$ in equation (1) at the cost of lower recorded charge/current. Indeed, the suppressor electrodes are generally realized with grids with meshes that stop a share of the charged particles directed towards the FC detector.

An important parameter that has to be considered when dealing with SEE induced by ion beams, is the orientation of the surface with respect to the propagating beam. If we indicate with $\theta$ the angle between the beam and the normal to the plate (therefore, $\theta = 0$ represents the case of normal incidence), it could be shown that SEE coefficient depends on $\theta$ as

$$\gamma(\theta) = \gamma(0) \sec^a(\theta),$$

where $a$ is a constant.
with $\alpha$ representing a characteristic of both the incident ions and of the plate material[3]. It is worth noticing, that this dependence works only when SEE is given to the kinetic energy of the beam (Kinetic Electron Emission). When the energy of the beam is low, another phenomenon took place, Potential Electron Emission and it behaves differently[3].

3. Materials and methods
The apparatus used during our measurements is the PLATONE setup[4,5]. PLATONE is an electrostatic linear accelerator coupled to a laser ion source (LIS). It uses a Compex 205 excimer laser ($\lambda = 248$ nm and $\tau_{FWHM} = 23$ ns) to generate a plasma inside a vacuum chamber. In particular, the plasma is generated within an expansion cylinder (EC, 18 cm long) isolated from ground and connected to an high voltage generator. In this way, plasma expands freely in EC until it reaches a 1.5 cm diameter extraction hole where it starts being electrostatically accelerated by the voltage applied on EC. A pierce ground electrode was placed at a distance of 3 cm from the extraction hole. After this electrode, at a distance of 2 cm, we placed a FC, as the one described in figure 2.

The target used to generate plasmas was a commercial disk of copper, 99.8% pure, placed on the opposite basis of EC with respect to the extraction hole. The laser beam, characterized by an energy of 12 mJ per pulse, was focused in a spot area of 0.005 cm$^2$, corresponding to an irradiance of $1.0 \times 10^8$ W/cm$^2$. In particular, the beam entered the EC through a quartz window placed on the lateral surface of EC.

To analyze the dependence of SEE yield on the angle $\theta$, we used 4 different FCs, one made by a simple aluminium plate and three made by worked aluminium rods, cut with different tilting, corresponding to $\theta = 30^\circ$, $45^\circ$ and $55^\circ$, as shown in figure 3.

![Figure 3. Picture of the tilted collectors housed within the FC used during experiments. The corresponding $\theta$ angle is: a) $30^\circ$, b) $45^\circ$ and c) $55^\circ$.](image)

For each collector, measurements have been performed both with the suppressor grid polarized in order to avoid SEE and with the grid connected to ground. This method has been used to obtain respectively $Q'$ and $Q$, which have been deduced integrating the corresponding current signal obtained from the FC. Each value has been calculated 10 times, in order to obtain mean and standard deviation. Then, these values have been used to compute $\gamma$, solving equation (1) for it. Moreover, the measures have been conducted applying different accelerating voltages to EC, up to 40 kV.

4. Results and discussion
After cleaning in a ultrasound bath and then with acetone, each collector has been put inside its housing within PLATONE and used as FC with the beams obtained from the LIS. The voltage applied...
to EC has been raised in order to the understand how $\gamma$ increases as the beam energy increases. Results of these tests are reported in figure 4.

The value of $\gamma$, in the range of voltages tested, increases as a power law, $x^m$ with $m \approx 0.70 \pm 0.08$. Furthermore, for each voltage, we analyzed the behaviour of $\gamma$ as a function of the beam incidence. For this reason, we normalized each dataset to the corresponding value obtained at normal incidence ($\theta = 0$), in this way the values should follow a $\sec^{\alpha} \theta$ law. This analysis revealed an interesting characteristic. In the range of voltages 3-20 kV, the normalized values appear to grow rapidly as a function of the angle (figure 5), while in the range 25-40 kV the growth is somewhat slower (figure 6). Instead, at 0 kV, the normalized $\gamma$ decreases (figure 6).

Figure 4. Behaviour of $\gamma$ as a function of the accelerating voltage, for the various beam incidence angles tested.

Figure 5. Incidence angle dependence of the normalized SEE yield in the range of 3-20 kV on EC. Dashed lines represent $\sec^{\alpha} \theta$ for various exponents.
Despite of the fact that the measurements have been repeated several times, this behaviour persisted. Since aluminium oxides develops spontaneously when the metal is left in air, we concluded that at low voltages SEE yield is increased by the oxide present on the surface of the collectors[8]. As the measurements proceed, the surface gets cleaned by the ion beams, reducing the SEE yield registered. Consequently, since we started measures using a lower voltage and then we progressively increased it, the growth of $\gamma$ slows at the higher voltages used. Furthermore, the behaviour at 0 kV could appear unexpected. However, in this case the energy of the beam is very low (below 100 eV), consequently SEE should be ascribed only to Potential Electron Emission, which behave differently from Kinetic Electron Emission[3].

![Figure 6](image-url)

**Figure 6.** Incidence angle dependence of the normalized SEE yield in the range of 25-40 kV on EC. Dashed lines represent $\sec^\alpha \theta$ for various exponents. Moreover, it is presented also the dependence of the 0 kV case.

5. Conclusions

We showed that the SEE yield on FCs used for laser-plasma diagnosis follows a $\sec^\alpha \theta$ law with respect to the beam incidence angle. This suggests that whenever non-normal incidence is used, particular care should be taken in order to consider the increased SEE yield. Moreover, we showed also that a good preventive cleaning has to be performed before any measurements, due to metal oxides developed on the surface of the collectors when exposed to air.

References

[1] Luches A, Nassisi V and Perrone M R, 1985 *Rev. Sci. Instrum.* **56** 759-760
[2] Pearlman J S, 1977 *Rev. Sci. Instrum.* **48** 1064-1067
[3] Ferrón J, Alonso E V, Baragiola R A ad Oliva-Florio A, 1981 *Phys. Rev. B* **24** 4412
[4] Velardi L, Siciliano M V, Delle Side D and Nassisi V, 2012 *Rev. Sci. Instrum.* **83** 02B717
[5] Nassisi V, Delle Side D and Velardi L, 2013 *Appl. Surf. Sci.* **272** 114
[6] Dionne J F, 1975 *J. Appl. Phys.* **46** 3347