Study of Faraday cups for fast ion beams provided by a LIS source

D. Delle Side, L. Velardi, E. Giuffreda, G. Buccolieri, A. De Benedittis, F. Paladini and V. Nassisi

Department Mathematics and Physics, University of Salento, LEAS Laboratory and INFN, Via per Arnesano, Lecce, Italy
Email: vincenzo.nassisi@le.infn.it

Faraday cups are widely utilized to characterize ion and electrons beams. Owing to the secondary electron emission (SEE) induced by the collision of beams with collectors, wrong measurements could emerge from these detectors. To overcome this problem a polarized grid is utilized in front the cup collector at a negative voltage with respect to the collector. Unfortunately, the high voltage connection of the Faraday cups is hard to obtain. Then, in this work we want to study the secondary emission on different Al ion collector designs having tilted surfaces with respect to beam axis. Tests were performed using ion beams accelerated by a power supply up to 40 kV. The results by the modified collector surfaces were compared to the ones performed with a simple flat collector. The results we obtained point out that the secondary electron emission enhanced on incident beam energy and on the angle with respect to the normal direction of the surface. The ratio of the SEE to angle value results constant for the accelerating voltage and the possibility to design an ion collector able to reset the SEE seems not to be reached.

Introduction

The characterization of ion beams by conventional Faraday cups [1] can easily induce wrong measurements owing to the secondary electron emission (SEE). This behavior is mainly due to the beam energy. When ion beams are provided by laser plasma also soft X rays by the plasma, hitting the cup collector generating electrons by photoelectron effect. To overcome this problem a polarized transparent electrode is placed near the cup collector at negative voltage with respect to the collector one to capture the generated electrons [2]. We want to study new configurations of the cup in order to avoid the application of the suppressing electrode because of we will utilize the Faraday cup also as third electrode [3, 4] being a demand presents in accelerator devices with post accelerating multiple stage scheme. In fact, applying a high voltage on this electrode we further can accelerate the beam particles.

Theory

The Faraday cup theory is very simple. It becomes complex if the beam pulse is very fast or if the collector dimension is large more that the value of light velocity times beam duration. Further, the signal due to ion beams must be transmitted to the oscilloscope by a transmission line.

The transmission lines utilized in laboratory have characteristic impedance of 50 Ω and in order to assurance a good transmission, by theoretical considerations, also the Faraday cup structure must present the same impedance. A simple Faraday cup inserted in a beamline forms a capacitor, C_c, with the chamber walls. The value of the capacitance must be very little in order to have a damping time, 50xC_c, lower than the time duration of ion beam, Fig. 1*a*.

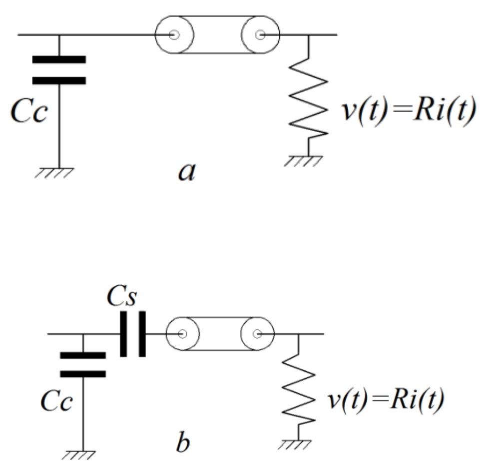
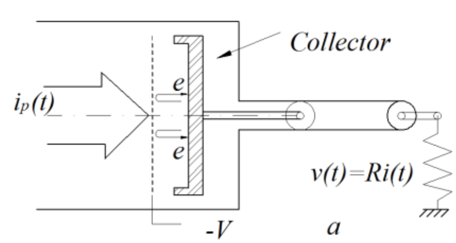


Fig. 1: Faraday cup schemes suitable for: a) charged beams; b) plasma beams.

The use of the Faraday cup to diagnostic plasma flux needs to bias the collector and this induces the inserting of a separation capacitor, C_s, between the cup and the oscilloscope, Fig. 1*b*.

Generally, Faraday cups are composed of an ion collector where the beam particles impinge into it. If the cup is preventively connected to ground by an impedance of very low characteristics, a current proportional to arriving signal is provoked. If the arriving signal on the cup is transmitted by a conductor, then it would be necessary to conserve the impedance value for the arriving signal and for the cup circuit. Indeed, particle beams determine an impedance value depending on propagating velocity which is less than *c* and as a consequence the system impedance is very high. Nevertheless, signal reflections can't be observed because of the Faraday's law for variable currents due to forward charge cannot be applied[5]. In fact, when the particles streak the collector they never are reflected but they stay inside the conductor providing a current versus ground, and just after the beam interaction with the cup collector, the system must be considered like a transmission line. Usually, the output signal of the cup is transferred to oscilloscope by a 50 Ω coaxial transmission line.

When the beam energy is sufficient to provoke SEE the cup is modified inserting the suppression electrode or changing the collector configuration with a cone as showed in Fig. 2.



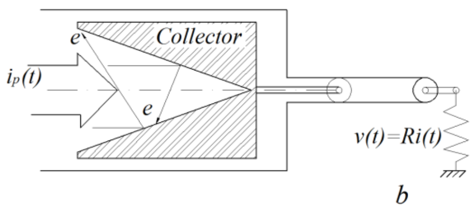


Fig. 2: Faraday cup: a) with suppression electrode; b) with cone collector.

In Faraday cups without any artifice the output current will be decreased for a forward electron beam, while increased for a forward ion beam:

$$i(t) = (1-\gamma)i_p(t) \qquad \textit{for electrons} \qquad [1]$$

$$i(t) = (1+\gamma)i_p(t) \qquad \textit{for ions} \qquad [2]$$

Where $i_p(t)$ is the incident current.

On the contrary, for a Faraday cup configuration like Fig. 2a it is necessary to modify the response with the optical transmission attenuation β of the grid:

$$i(t) = \frac{1}{\beta}(1-\gamma)i_p(t) \qquad \textit{for electrons} \qquad [3]$$

$$i(t) = \frac{1}{\beta}(1+\gamma)i_p(t) \qquad \textit{for ions} \qquad [4]$$

The response of Faraday cup designed in Fig. 2b is like those above but with $\beta = 1$.

Unfortunately the cup configuration showed in Fig. 2*a* cannot be used to perform experiments at the Platone accelerator because of it is necessary to polarize it up to 60-100 kV to power the second acceleration gap which comports non little problems to polarize the grid. Again, the cup configuration of Fig. 2*b* doesn't allow performing precise time of flight (TOF) measurements due to the uncertainty of the position collision inside the cone collector. Then to resolve the problem it is indispensable to understand the behavior of SEE emission on different collectors.

Materials and methods

The device used in these experiments is the accelerator Platone at the LEAS laboratory[6]. The accelerator consists on a vacuum chamber and an excimer laser. This last is a Compex 205 excimer laser operating in the UV range. Its output beam was of 600 mJ maximum output energy, 248 nm wavelength, 25 ns pulse duration and a maximum repetition rate 50 Hz. The laser beam streaks the solid targets to generate plasma in the vacuum chamber. In particular, inside the vacuum chamber an expansion chamber was placed tightly closed around the target support. Plasma expands inside the expansion chamber but, being no electric fields breakdowns are absent. The length of expansion chamber (18 cm) was sufficient to decrease the plasma density. The target, tougher to expansion chamber is connected to a power supply of positive bias voltage. Four capacitors of 1 nF each stabilized the accelerating voltage during the fast ion extraction. Owing to the plasma expansion the charges reach the extremity of the expansion chamber. This extremity was drilled by a 1.5 cm hole to allow the ion extraction.

A pierce ground electrode was placed at 3 cm distance from the expansion chamber. After this electrode another electrode, placed at 2 cm from the ground electrode and connected to a power supply of negative bias voltage, was utilized as third electrode and also as Faraday cup collector.

The laser beam direction impressed the target at an angle of 70° with respect to the normal to the target surface. During our measurements the laser spot area onto the target surface was 0.005 cm^2 for all experimental conditions. In this experiment all measurements were performed with the only first accelerating gap and without the expansion chamber. In front the ground electrode the Faraday cup was placed.

Experimental results and discussion

The ion beams we used to study the cup behavior were provided from a Cu target and a laser energy of 25 mJ per pulse. We used three different ion collectors made of Al tilted at 30°, 45° an 55° with respected to optics axis and a plane (0° tilted). Measurements were performed without any suppressing electrode and with the suppressing electrode. Fig. 3 shows the tilted cup collectors.

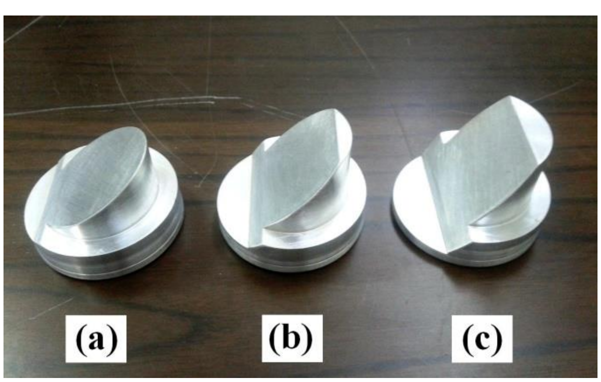


Fig. 3: Photos of cup collectors.
a) collector tilted at 30°;
b) collector tilted at 45°;
c) collector tilted at 55°.

The re
the su
of the
while with the suppressing electrode showed, approximately, the same signal for all collectors used. This former points out that the recorded signal is referred at the only accelerated ions of the beams. Fig. 4 shows the output current recorded by our collectors, with and without the suppressing electrode.

The output current at zero accelerating voltage was very low (see Fig. 4).-

It was the same for all collectors. Instead, increasing the accelerating voltage, the extracted charge increased owing to the stream lines of the electric field becomes more concentrated inside the plasma [6]. With suppressing grid the current increased of about two times from 5 kV to 40 kV, while without suppressing grid current increased almost linearly with the accelerating voltage, how it shows in Fig.4. The observed difference must be attributed to the ion energy. It is responsible of the ion depth penetration inside the collector surface. The SEE at zero accelerating voltage is not evident owing to the low ion energy in these conditions. It is just some tens eV with a tail of about 600 keV [7].

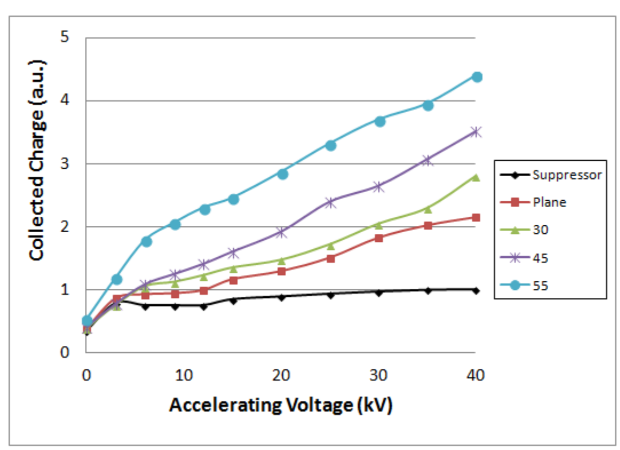


Fig. 4: Output results by a cup having the collector; plane, and tilted at 30°, 45° and 55°, and with the suppressor grid.

Analy[...]le to note [...]ane, 30°, 45° and 55°) are approximately constant on accelerating voltage, excluding the first part (from 0 to 5kV). It could confirm, hypnotizing an ion extraction constant, that the SEE is proportional to the penetration depth. In fact, by the theory [8] the electrons generated by an ion of energy E_o is proportional to the energy lose along its propagation. Generally, these electrons have a high energy and are responsible of the secondary electrons generation. The number of secondary electron per incident ion is n_{se} it depends on energy of the ion. The fraction of electrons that can escape from the target is:

$$d\gamma = n_{se} P(x) dx$$

where $P(x)$ represents the probability of the electron generated at depth x to reach and escape the surface.

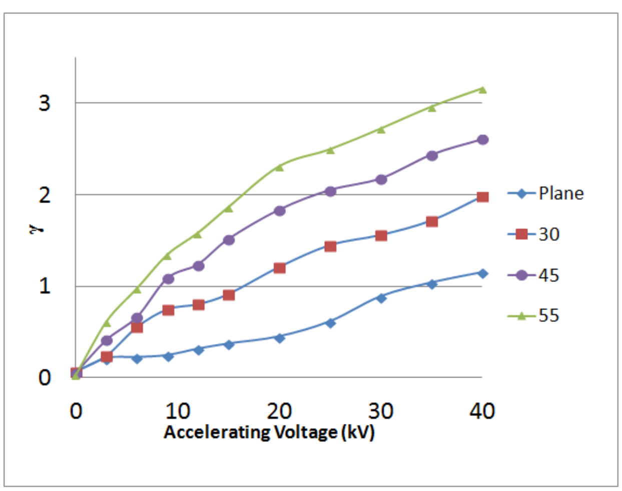


Fig. 5: SEE γ parameter for plane, tilted at 30°, 45° and 55° as a function of the accelerating voltage.

This probability depend: on the transmission coefficient, T, of the electron to overcome the surface; on the initial velocity distribution of the secondary electrons; and number of collisions, A; and on the free path length on the electrons, L_s.

We have: $P(x) = TAexp(-x/L_s)$. Therefore, increasing the incident energy of the ion increases n_{se}.

For a tilted collector we found that the secondary emission increases as the angle increased as reported even in Ref [9]. Fig. 5 shows the experimental results of the γ value. The dependence of γ was estimated to be:

$$\gamma = \gamma_o \sec(\theta)$$

where γ_o is the SEE value at $\theta = 0$.

In fact, plotting our experimental data at 40 kV accelerating voltage the gamma factor has a trend similar to $\sec(\theta)$.

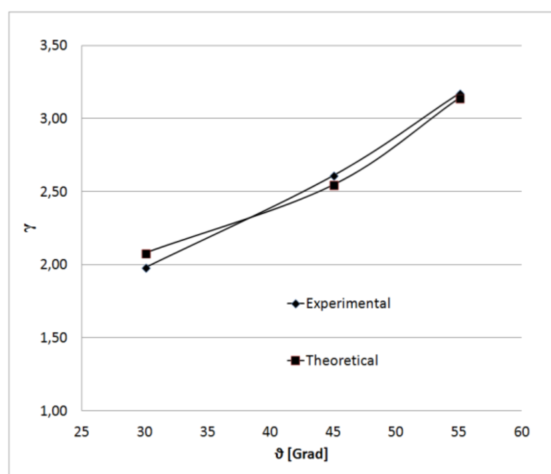


Fig. 6: Fit of data at 40 kV by a function sec(θ).

Further, from data in Fig. 5 we observe that fixing the accelerating voltage, γ increases on tilted angle and the ratio γ/ϑ is about constant.

Table I: Ratio γ/ϑ.

	10 kV	20 kV	30 kV	40 kV
30°	0.025	0.040	0.052	0.066
45°	0.024	0.041	0.048	0.058
55°	0.025	0.042	0.050	0.058

The mean valor and the deviation are reported in the Table II.

Table II: average values

	10 kV	20 kV	30 kV	40 kV
Mean Value	0.0247	0.041	0.050	0.061
STD	0.0005	0.001	0.002	0.005

Before the present work we tried to realize an efficient collector to capture the secondary electrons modifying the surface. The result was discouraging because of the emission of electrons increased on angle surface.

Conclusions

We have studied the behavior of different Faraday cups utilized to perform time of flight measurements. The secondary electron emission during the beam interaction with ion collector modifies the true current because the read values are strongly dependent on the beam incident angle. So, a suppressing grid is indispensable. If the Faraday cup must be utilized even as accelerating electrode, then to perform current measurement it is necessary to know previously the value of γ at different voltages.

References

[1] A. Luches, V. Nassisi and M.R. Perrone, Rev. Sci. Instrum. 56, 759-760 (1985)

[2] J. S. Pearlman, Rev. Sci. Instrum. 48, 1064-1067 (1977)

[3] V. Nassisi, M.V. Siciliano, "Cu and Y ion beams by a new LIS generator", Nucl. Instrum. Meth. B 269, 2919-23 (2011)

[4] A. Lorusso, M:V: Siciliano, L. Velardi, V. Nassisi, Low emittance plasma ions beam by a new double accelerating configuration, Nucl. Instr. and Meth. A 614, 169-173 (2010)

[5] V.Nassisi, Principi di Fisica II, Onde Elettromagnetismo e Ottica, Gruppo Editoriale L'Espresso s.p.a., (2014)

[6] L. Velardi, M.V. Siciliano, D. Delle Side and V. Nassisi, Production and Acceleration of Ion beams by Laser Ablation, Rev. Sci. Instrum. 83, 02B717 (2012)

[7] V. Nassisi, A Pedone, Physics of eplanding plasma ejected from a small spot illuminated by an ultraviolet pulser laser, Rev. Sci. Instrum. 74,68-72 (2003)

[8] E. J. Sternglass, Phys. Rev., 108, p. 1-12 (1957)

[9] J.S. Allen, Physical Review, 55, 336 (1939)