Preliminary study of novel Faraday cup for fast ion beams generated from a LIS source

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Abstract

In this work we present a study on Faraday cups. These devices are utilized to perform time of flight measurements in order to characterize charged beams in different situations particularly for accelerator by double stage configuration. 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. To eliminate the suppressing grid, we tested new cup collector surfaces and we compared the results to the ones performed using the flat collector. For this purpose, we performed experiments utilizing simple tilted collectors at 30°, 45° and 55° determining the gamma factor of the secondary electron emission. Tests were performed utilizing Cu ion beams at energy up to 40 kV

Introduction

The characterization of ion beams by conventional Faraday cups[1] can induce wrong measurements owing to the secondary electron emission (SEE). All this is mainly due to high beam energy and to generation of soft X rays. 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 a new configuration in order to avoid the application of the suppressing electrode because we want to utilize the Faraday cup also as a third electrode[3, 4], a useful improvement in multiple stages accelerator devices. In fact applying a high voltage on this electrode we can further accelerate the beam particles.

The theory behind a Faraday cup is very simple. It becomes complex when diagnosing fast pulses where the resulting signal due to ion beams must be transmitted to the oscilloscope by a transmission line.

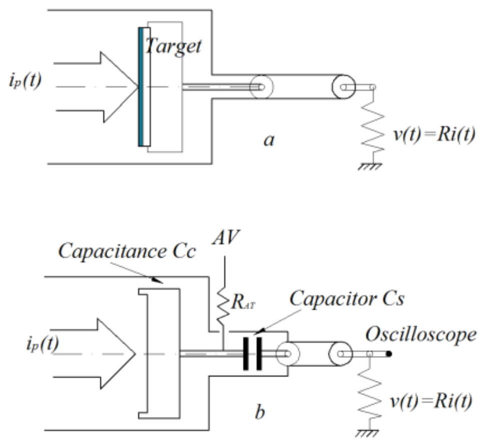


Fig.1: Faraday cup: a) for electron and ion beam; b) for plasma.

The transmission line utilized in laboratory has a characteristic impedance of 50 Ω and in order to ensure a good transmission also the Faraday cup structure must present the same impedance.

Very simple Faraday cup configurations are sketched in Fig. 1, suitable for electron and ion beams (a) and for plasma beam (b), both without the suppression electrode. Generally, Faraday cups are composed of an ion collector where the beam particles impinge inducing a current proportional to the incoming signal if the cup is preventively connected to ground by a resistor equal to characteristic impedance. In fact, Faraday law for variable currents due to charge density cannot be applied. Just after the beam interaction with the cup collector, the system must be considered like a transmission line. Generally, the output signal of the cup is transferred to oscilloscope or resistor divider by the diffuse 50 Ω transmission line. When the beam energy is sufficient to provoke SEE the cup generally is modified inserting the suppression electrode or changing the collector configuration with a cone as showed in Fig. 2.

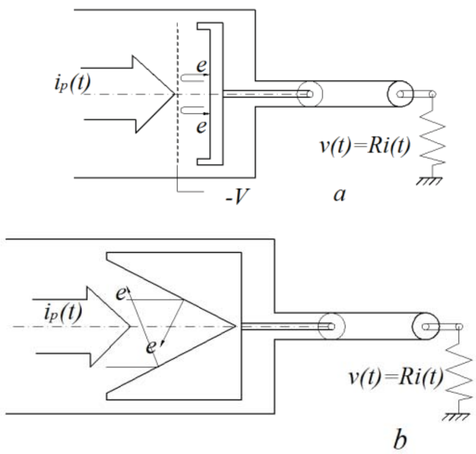
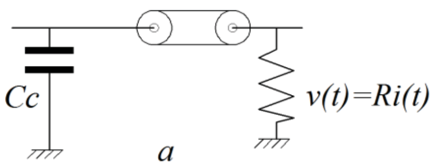


Fig. 2: Faraday cup: a) with suppression electrode; b) with cone collector.

The electric scheme of the cup suitable for charged beams or plasma is illustrated in Fig. 3.



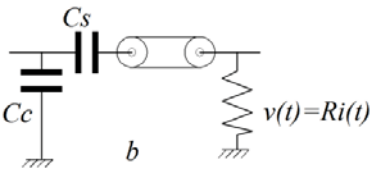


Fig. 3: Faraday cup schemes suitable for: a) charged beams; b) plasma beams.

The current $i(t)$ provides the beam current by the following relation:

$$i_p(t) = \frac{i(t)}{\beta(1-\gamma)} \qquad per \qquad elettroni$$
$$i_p(t) = \frac{i(t)}{\beta(1+\gamma)} \qquad per \qquad ioni \tag{1}$$

Where β is the optical transmission of the grid (if absent it is equal to 1) and γ is SEE parameter.

Materials and methods

The device used in these experiments is the accelerator Platone at the LEAS laboratory. The accelerator consists on a vacuum chamber and an excimer laser (a Compex 205 operating in the UV range). Its output beam has 600 mJ maximum output energy, 248 nm wavelength, 25 ns pulse duration and maximum repetition rate 50 Hz. The laser beam streaks the solid targets to generate plasma in the vacuum chamber. Particularly, inside the vacuum vessel an expansion chamber was placed tightly closed around the target support. The 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, together with the expansion chamber, is connected to a power supply of positive bias voltage. Four capacitors of 1 nF 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 fixed at 0.005 cm^2 for all experimental conditions. In this experiment all measurements were performed with the only first accelerating gap. In front the ground electrode the Faraday cup was placed.

The preliminary experiments were performed with three cups of different conformation: we call DZ the collector by double zig-gaz Fig. 4, 90° the collector with surface by single tilted of 45° with respect to main axis, Fig.5, and 45° the collector with single surface tilted of 22.5° with respect the main axis, Fig. 6.

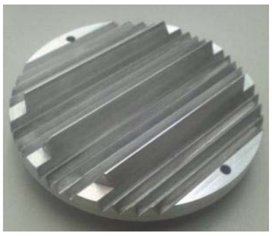


Fig. 4: Faraday cup collector double zig zag.

Fig. 5: Faraday cup collector 90°.

Fig. 6: Faraday cup collector 45°.

Results

The target used in this experiment was pure Cu disks and the laser energy 25 mJ.

The total charge collected with the three cups and the one obtained with the plane one is shown in Fig. 7.

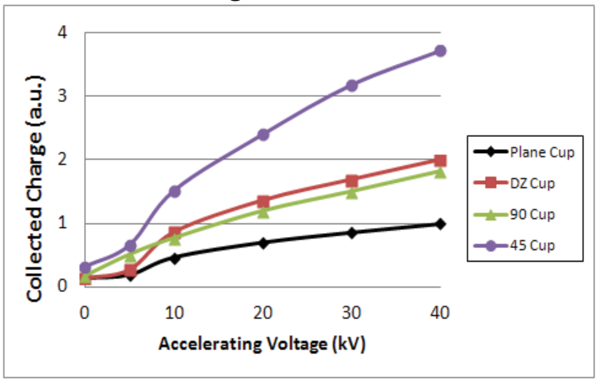


Fig. 7: Output charge with the plane collector and with DZ, 90° and 45° collectors.

It is well evident that the recorded current increases with the collector having the shortest angle. Nevertheless although the angle might reduce SEE electrons, it seems not sufficient and the reason could depend on the high intensity of SEE electrons. For this purpose we analyzed other three different cups composed by a simply tilted plane with respect to the ion beam axis. They were tilted of 30°, 45° and 55°, Fig. 8 a,b and c.

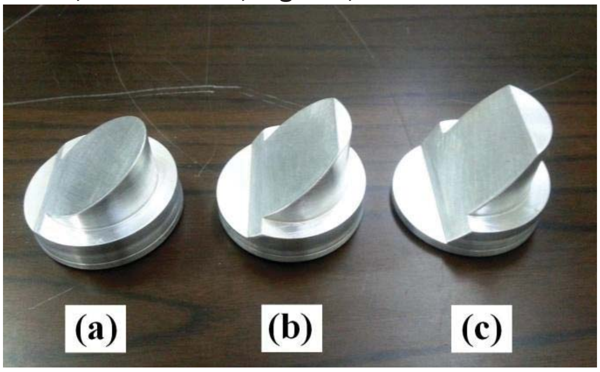


Fig. 8: Photos of cup collectors. a) collector tilted at 30°; b) collector tilted at 45°; c) collector tilted at 55°.

The measurements, performed with and without the suppression grid, were compared with the one obtained with the plane collector, Fig. 9.

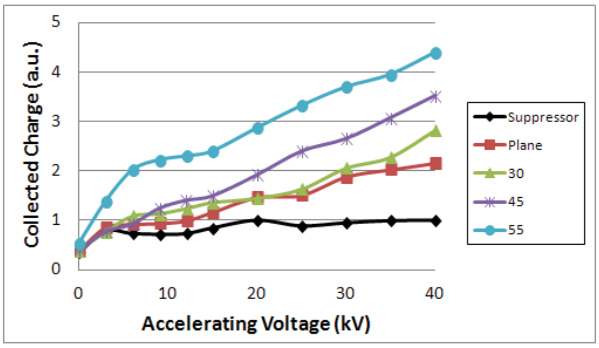


Fig. 9: Output results by a cup with the collector; plane, tilted at 30°, 45° and 55°, and with the suppressor grid.

These results confirm that the SSE increases on tilted angle, as pointed out in [5]. Indeed, it is known that SEE should increase as a function of the tilt angle following a law of the type

$$\gamma(\theta) = \gamma_0 \sec(\theta)$$

where θ is the tilt angle and $\gamma_0$is the SEE coefficient at normal incidence. This behavior depends on the fact that a variation in the angle induces an increase in the path of the ions inside the metal plate where the escape of electrons is easier. It is worth noticing that our results show a dependence on the tilt angle that is nearly exponential due to the energy spread of the beam. Therefore, to get correct results it is necessary to apply the suppression grid. In fact in Fig. 9 are reported the collected charge obtained with the suppression electrode applied to the tilted cups. The results are very similar with the three cups for a free plasma expansion (ion energy up to 1 keV), and we can conclude that, without the suppressor grid, real values cannot be read in post acceleration mode. This configuration cannot be used as third accelerating electrode because it is impossible to apply the suppressing electrode to an electrode placed at high voltage.

By means of the experimental data we computed the γ parameter of SEE (see equation (1)) as a function of the tilt angle, for various accelerating voltages, Fig. 10.

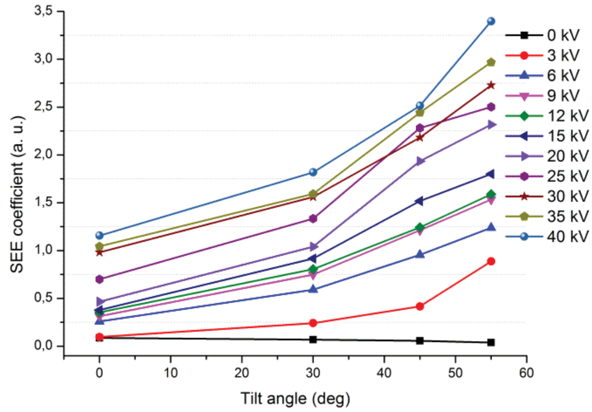


Fig. 10: SEE Gamma parameter for various accelerating voltages as a function of the tilt angle.

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 real current because the read values are strongly dependent on the beam incident angle. So, a suppressing grid is indispensable.

References

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