A "NOT-INTERCEPTIVE" FARADAY CUP IN THE CNAO LOW ENERGY INJECTION LINES

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Abstract

The CNAO, the first Italian synchrotron for deep hadron therapy [1, 2], is presently in its final step of installation. It will deliver beam of both Protons and Carbon ions, in three treatment rooms, in order to cure solid tumours with active scanning technique.

CNAO beams are generated by two ECR sources, able to produce both particle species, and transferred to a RFQ and a LINAC through a Low Energy Beam Transfer line (LEBT) at 8 keV/u and then accelerated up to 7 MeV/u before being injected in the synchrotron ring.

At the end of the LEBT line, just upstream the RFQ (L2-011A-IC1 in Fig. 1), an electrostatic Chopper deviates the beam on the vacuum chamber except for about 100 micro-seconds every 2 seconds, in order to shape the particles batch according to LINAC requirements and to minimize the beam losses at the RFQ entrance. An electrically insulated vacuum pipe section hit by the deviated beam allows reading the LEBT beam current: this detector is called Chopper Faraday Cup (CFC) and is based on the Faraday Cup working principle: it results a "not-interceptive" monitor that is able to measure, continuously, the source beam current ripples and stability, without affecting the beam delivered to the synchrotron. The CFC detector is presently under commissioning and preliminary results are presented.

CFC DESCRIPTION

The CFC is a detector installed in the LEBT line, devoted to monitor, continuously, source current ripples and stability, even during treatments, without affecting the beam delivered to the synchrotron: the goal is the monitoring of beam current slow variations due to sources instabilities and ripples. This implies that the system should be able, in the worst case, to have 1% resolution of the minimum nominal beam current, which corresponds to 1.5 μA, according to LEBT beam parameters at chopper level (Table 1).

The CFC key idea (Fig. 2) consists of insulating the vacuum chamber sector downstream the chopper and measuring the collected current: the cup measures the full beam intensity while the Electrostatic Chopper is powered. The result is an on-line monitor based on the Faraday Cup (FC) principle but not interceptive for the beam directed to the synchrotron: it will be blind only when the beam is directed into the LINAC section, that is nominally 100 μsec every 2 sec. Like a conventional Faraday Cup, the CFC is constituted by a body (A to B on Fig. 2), collecting the charge to be measured, and a repeller, aiming to push back the secondary emitted electrons produced by the beam-to-body interaction, whose escape would affect the measurement. The CFC body is the insulated section of the vacuum chamber where the beam is bent; it is showed grounded by a "resistance" in Fig. 2. The voltage across the "resistance" is proportional to the LEBT current. It is defined by inserting two insulating gaskets at its extremities. CFC length and diameter are optimized to the Chopper kick range and to the beam rigidity (Table 2).

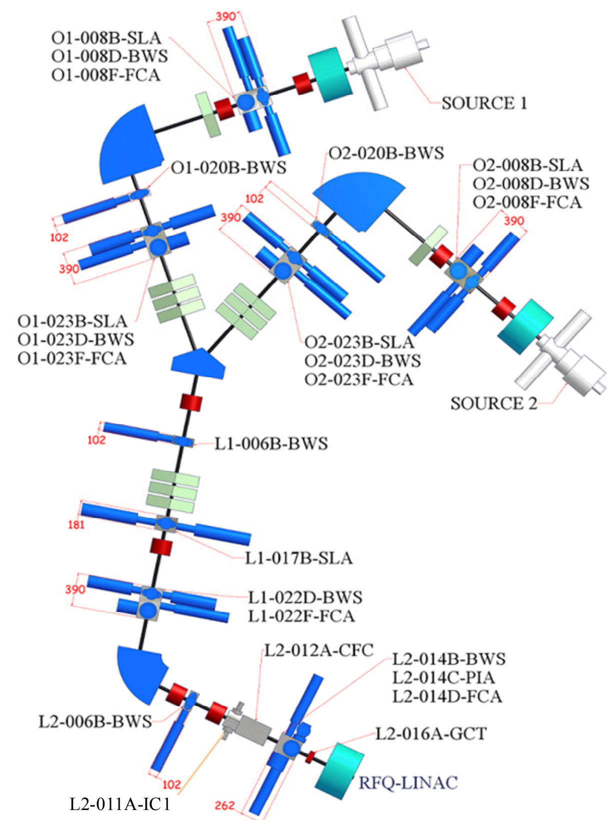

Figure 1: LEBT Instrumentation Layout with elements names. SLA are Slits, BWS are Wire Scanner in both planes, FCA is Faraday Cup, CFC is the Chopper Faraday Cup , PIA is Profile Grid, GCT is a current transformer and IC1 is the electrostatic chopper.

The repelling field, aimed to send back secondary electrons to the body, is generated by a metallic cylinder having an aperture where the beam is expected to pass (Fig. 2); this cylinder is inserted into the CFC tank and grounded, while the chamber is polarized with a positive voltage (V_{bias}= 50÷100V) and so protected with a Plexiglas cover (Fig. 3) for safety.

Table 1: Beam Parameters at LEBT Chopper

H_3^+ Current intensity at Chopper	0.70 mA
C^{4+} Current intensity at Chopper	0.15 mA
Beam Current stability	± 1.5%
Beam Current ripple	± 2 %
Beam before Chopper	Continuous
Beam after Chopper	100µs pulse at 0.5 Hz
Beam Energy	8 keV/u

Table 2: CFC Mechanical Parameters

	Material	Length	Inner diameter
Repeller	Al	360 mm	80 mm
Repeller support	Al	360 mm	65 mm
Body	Al	360 mm	90 mm
Insulators	Viton	3.53	156 mm

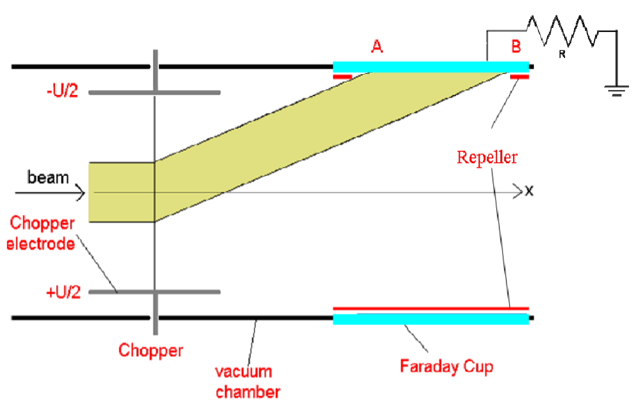

Figure 2: Schematic top view of the CFC working principle.

Figure 3: CFC with Plexiglas cover.

The beam enters the CFC continuously for most (99.995%) of the machine cycle time (2 sec) so over heating problem cannot be neglected. Large cooling fins (Fig. 3) on the outside of the CFC tank improve the air-cooling efficiency: at the maximum Carbon ion current the power to be dissipated is about 3.6 W. This kind of cooling is estimated to be sufficient to preserve the detector under these conditions. Moreover, two power feed-throughs (OFHC Copper, 1 pin, 9.5mm diameter) are used to ground the repeller and allow some heat transfer. Using Plexiglas shield, the air convection efficiency is reduced. On a test bench, a power of 150 W has been applied to the CFC: it reached the steady state temperature of 70°C, which is fully acceptable without any risk. Anyway, in order to increase the device safety, the CFC temperature is always monitored by an infrared thermometer remotely readable from the control room.

EXPERIMENTAL RESULTS

Particles deflection angle depends on the beam barycentre position and chopper electrodes polarisation value. It has been simulated by using the Simion 7.0 program. The first measurement is, indeed, the CFC current acquisition at different chopper deflection voltages (Fig. 5); a Proton probe beam of 100 µA, having a spot diameter of about 10 mm and positioned at the CFC mechanical centre, was available for such a test.

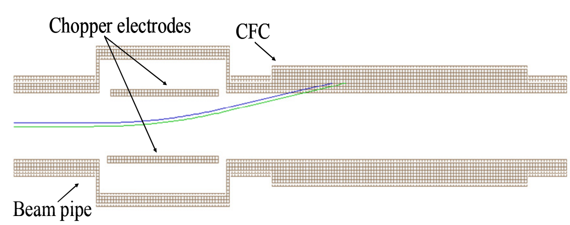

Figure 4: CFC Simion Code 7.0 simulation, top view: chopper electrodes polarized at ΔV=4kV.

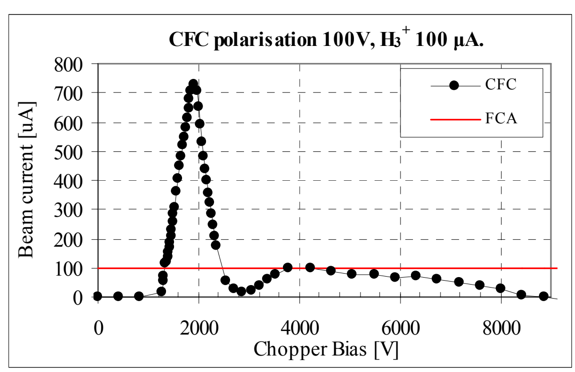

Figure 5: CFC measured current at different chopper deflection voltages (Chopper Bias [V] on abscissa) with a H_3^+ probe beam of 100 µA.

Figure 5 reports the average beam current read with the CFC body polarised at 100V at various chopper deflection voltages and also compared with the current read on the FC upstream the dipole (L1-022F-FCA) and downstream the CFC (L2-014D-FCA) where the measured beam current is the same. The CFC readout current value is coincident with the one obtained with the classical FCs when the chopper electrodes are polarised at 4 kV. The peak at lower deflection voltage (~2kV), which is not the normal working setting, could be due to the fact that the beam interacts in a region where, for mechanical reasons, the electric field is stronger: peak amplitude is CFC polarisation voltage dependant. With these parameters (chopper electrodes at 4 kV and CFC polarisation at 100V), the beam current measured on the CFC has been plotted versus the FC upstream the dipole current by changing beam intensity (Fig. 6) modifying the slit aperture at L1-017B-SLA.

The CFC has a linear response coefficient that is 5% below that of the normal Faraday-Cup; the error could be due to a not optimized secondary electrons repelling which could be improved increasing the CFC polarisation voltage. Looking at the horizontal profiles downstream the CFC (Fig. 7), it appears that the repelling field asymmetry affects the beam trajectory even at 100V polarisation, kicking the beam on the right with respect to the tank centre. In order to solve this problem, the CFC electronics has to be modified as described in following chapter.

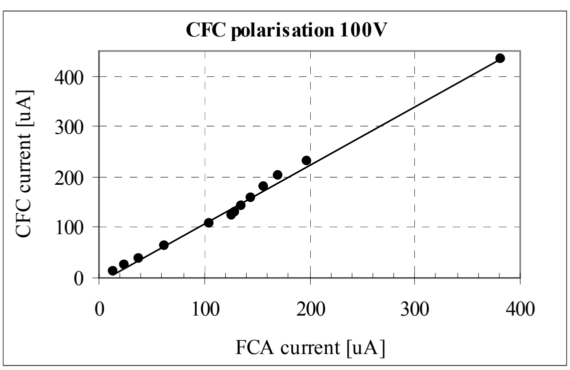

Figure 6: CFC current at different H_3^+ beam intensity.

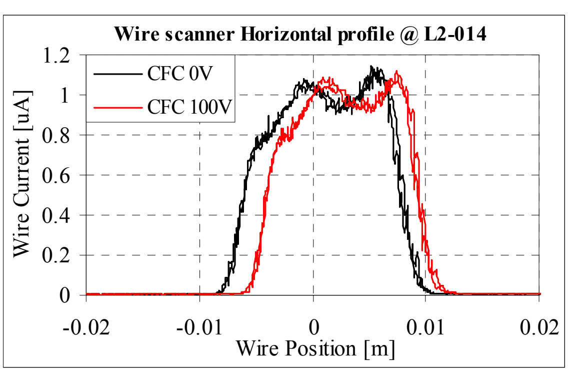

Figure 7: CFC polarisation effect on H_3^+ beam profiles.

ELECTRONICS CHAIN

Figure 8 sketches the electronic chain connected to the CFC is used to polarise the cup and to acquire the beam current. Appling on the CFC a polarisation (0÷1250V) through a voltage-regulated power supply like FUG MCP140-1250 with floating outputs, a DC current of few microamperes entering the cup can be read imposing the power supply to generate a current larger than the beam into a resistor (R2 in Fig. 8) to ground: the PS regulation reacts when beam adds to the normal current in order to keep the voltage constant. Measuring the variation of the power supply current monitor output ("IMON" in Fig. 8), the CFC beam current can be computed. Using a capacitor (C2), the monitoring of beam pulse duration injected in the RFQ and LINAC is also possible.

During the measurements, the relay that grounds the cup is opened; the problem of beam deflection due to the repeller could be solved closing the relay when the beam is no more bent by the chopper but sent into the LINAC. This solution is presently under investigation.

CONCLUSION

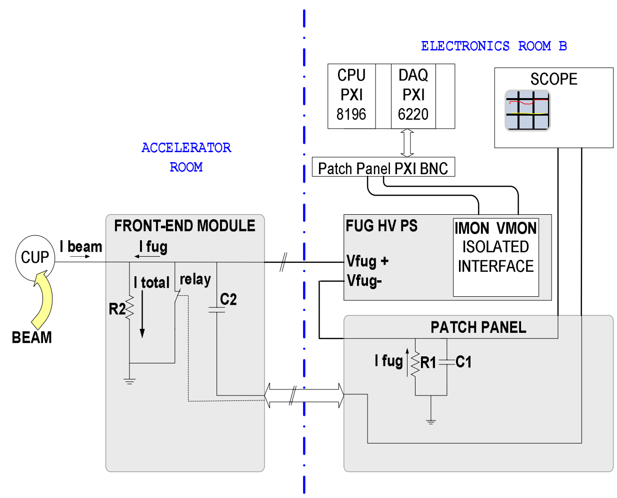

Figure 8: CFC electronics chain.

Insulating the vacuum pipe downstream the electrostatic chopper, it's possible to monitor a Proton beam current using the Faraday Cup working principle, without intercepting the beam for treatments: the preliminary results show that the CFC response is linear by 5%. Problems remain on the repelling field system that can perturb the beam trajectory: once solved with a modified electronic chain, the detector commissioning with a full, Carbon and Proton, beam, can be performed.

REFERENCES

[1] S. Rossi, "Developments in proton and light-ion therapy", EPAC 2006.

[2] M.Pullia, "Status Report on the Centro Nazionale di Adroterapia Oncologica (CNAO)", EPAC 2008.