BEAM DIAGNOSTICS IN THE CNAO INJECTION LINES COMMISSIONING

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Abstract

The CNAO, the first Italian synchrotron for deep hadrontherapy [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 treat solid tumours with active scanning technique.

CNAO beams are generated by two ECR sources [3], 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 [4].

A compact and versatile tank containing a complete set of beam diagnostic tools has been intensively used for the LEBT line commissioning successfully concluded in January 2009. In a length of 390mm, the tank houses two wire scanners, aimed to measure vertical and horizontal beam position and transverse profile, a Faraday Cup, for beam current measurement, and two vertical and horizontal metallic plates for beam halo suppression, emittance measurements, beam collimation and particles selection.

Using one tank only, phase space distribution reconstruction can be quickly performed as well as synchronous profiles and intensity measurements.

Five identical tanks are installed in the LEBT line [5], as consequence of a standardization strategy to improve diagnostic monitor knowledge and make maintenance easier.

LEBT LINES GENERAL DESCRIPTION

LEBT lines Beam Diagnostic (BD) elements are schematized in figure 1: the two sectors, called O1 and O2, are dedicated to the respective source and are both equipped with two diagnostic tanks and one 90° dipole spectrometer in order to make the tuning of each source independent from the use of the second one. When one of the Faraday cups upstream the first quadrupole triplet is inserted, the source can be monitored without interfering with the operation of the other one. Beam parameters can be measured also before the spectrometer dipole. The two sectors called L1 and L2, common for both the lines, include the beam injection chopper and a special Faraday cup (CFC) for beam current intensity monitoring.

BD INSTRUMENTATION

Slits

Four Copper plates compose the slits: working two by two the plates create vertical and horizontal slits dedicated to beam scanning, phase space distribution measurements and particle specie selection (downstream the spectrometer).

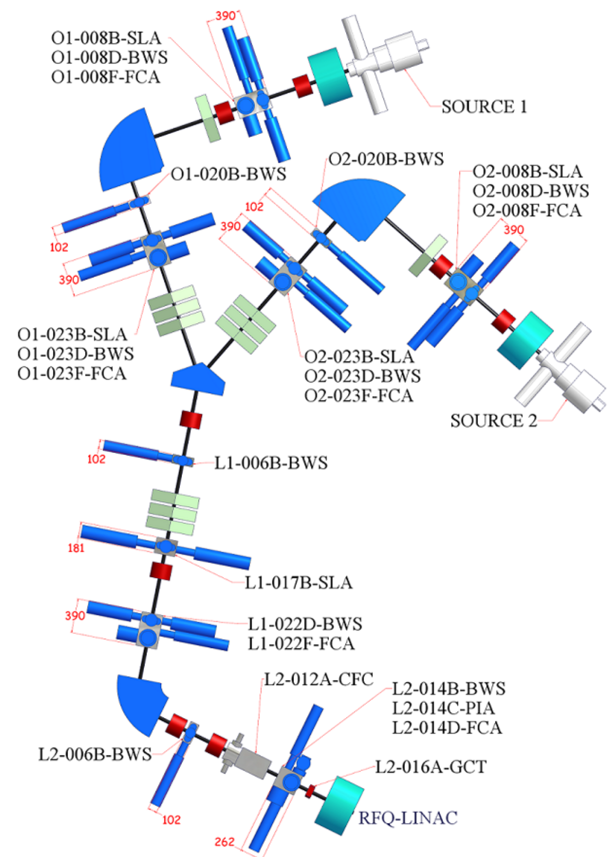

Figure 1: LEBT BD Instrumentation Layout with elements names. SLA are Slits, BWS are Wire Scanner in both planes, FCA is Faraday Cup, CFC is the Chopper Faraday Cup, PIA is Profile Grid and GCT is a current transformer.

Moreover, the plates positioning around the beam allows the beam halo suppression. Slits plates are 1mm shifted longitudinally in order to allow their overlapping; they are also water cooled to dissipate the large beam power (360W). Each plate is driven by a brushless motor at the maximum velocity of 250 mm/s with a position accuracy of about 20 µm: absolute position is read through a linear potentiometer. Secondary electrons emitted as a result of interaction between the beam and the plates can be suppressed by polarizing the plates up to 1kV.

Wire Scanner (WS)

Each 390 mm LEBT tank houses two WSs, one horizontal and one vertical, which can be used to get the beam profile, and in consequence its barycentre, in scanning mode or to measure the beam position stability in watch-dog mode once positioned at the beam border. Beam profiles are computed after having synchronously acquired wire position versus wire current: the motion mechanics is identical to the slits one so the same kind of potentiometer is acquired with the same results in terms of accuracy and resolution. The wire is made of 0.1 mm diameter tungsten wire: one of the two ends is connected to a custom multi-gain amplifier which measures current signals from 1 nA to 1 mA at the maximum frequency of 400 Hz.

Faraday Cup (FC)

The last installed element in the LEBT 390mm tank is a FC made with a Copper round 135 mm diameter cup moved by a pneumatic actuator: it can be used as beam stopper to close, for example, line O2 when the particle specie coming from O1 is required or to measure the beam current and ripple. If coupled with the upper stream slits the FC can performs profiles as well. A repeller ring electrode in front of the cup pushes back secondary emitted electrons while an extra grounded metallic ring between the repeller and the cup avoids that leakage currents deteriorate the beam intensity measurement. LEBT beam is continuous and its intensity is up to 15mA, before species selection; by consequence, the cup is water cooled in order to dissipate the beam power which can be up to 360W. The cup is directly connected to a custom multi-gain amplifier which has a bandwidth up to 15 kHz and a dynamic range from 100 nA to 100 mA.

EXPERIMENTAL RESULTS

Faraday Cup (FC)

The primary use of the FC is the beam current measurement, which is reliable once the effect due to the electrons back scattering is suppressed applying a voltage to the repeller ring. Figure 2 reports the beam current read on the FC versus the voltage applied to the ring: the correct intensity measurement is made by setting the voltage at -350V (or above).

A 390mm tank is also mounted downstream the chopper (tank called L2-014 in Figure 1) where the beam is normally pulsed by the electrostatic chopper. The electronic chain connected to all the FCs has been designed in order to follow the nominal chopped signal as well: one pulse of 100 µs duration every 2 seconds (Figure 3).

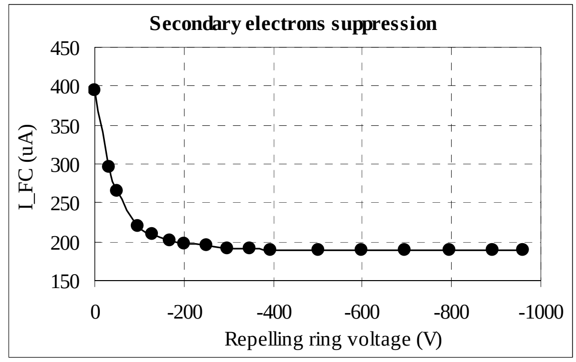

Figure 2: Secondary electrons suppression.

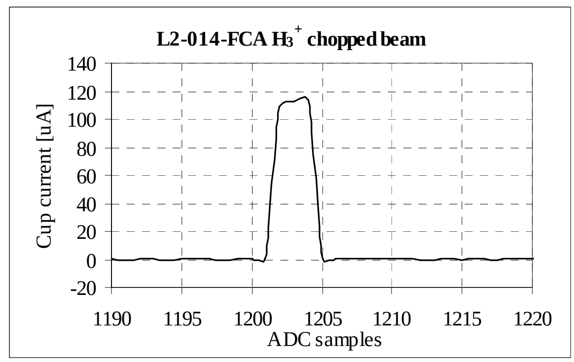

Figure 3: Chopped beam on FC acquired at 25 kHz.

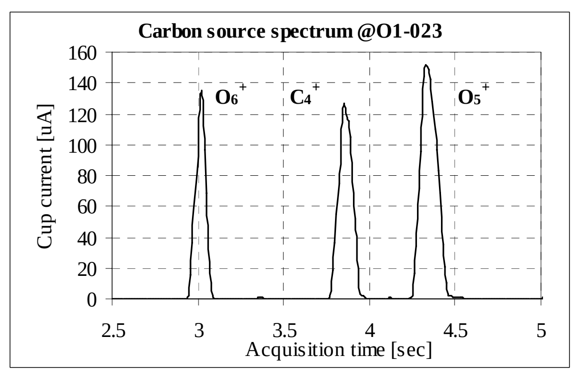

Figure 4: Carbon source spectrum obtained ramping the spectrometer during FC acquisition.

The FC called O1-023F-FCA just downstream the 90° dipole can be used to measure the source spectrum in two different ways: one is moving the upstream horizontal slit acquiring the current on the FC at all the positions; the other method is the acquisition during the dipole ramping current. Figure 4 reports the spectrum using this second procedure.

Wire Scanner (WS)

The two horizontal and vertical WSs, mounted on the 390mm tank, are used for beam profile, beam position and emittance measurements (once accomplished with the upstream slits): in order to increase the statistic, profile measurement consists of two scans, one entering and one coming out the tank. Figure 5 reports the two overlapped scans of the same measurement.

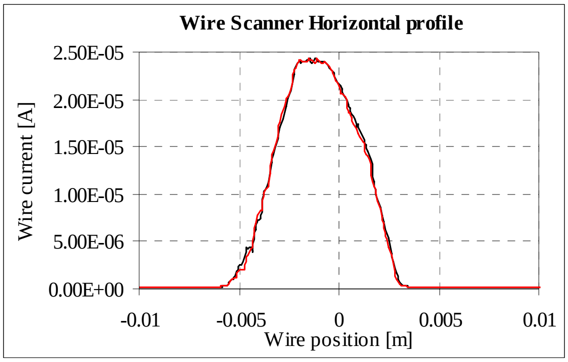

Figure 5: H_3^+ beam horizontal profile in the tank O2-023 with the horizontal plates positioned in ± 5mm respect to the vacuum pipe centre.

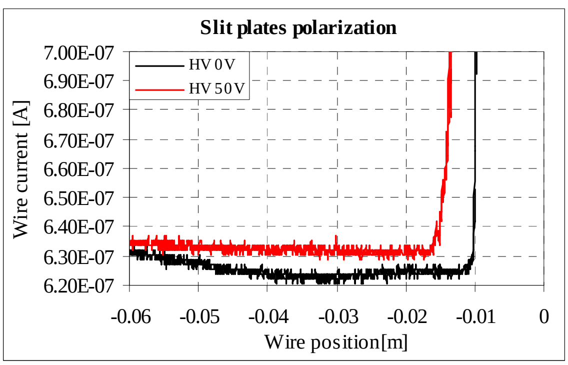

Figure 6: Zoom of two horizontal WS left end profiles for different Slit plates polarisation voltage with Carbon ions beam.

Another use of the WS mounted in the 390mm tank is the watch-dog mode where the wire stays in a fixed position, normally at beam border. In case the wire stays always at the beam centre at the maximum current, the measured wire temperature never exceeds 300 °C which is far from the Tungsten wire melting threshold.

Slit

The four plates of the 390mm tank are used as beam halo suppressor, as collimator for particle selections or as slits for emittance measurements. In order to minimize the effect of the secondary electrons emitted once hit by the beam, the copper plates are all connected to a high voltage power supply (0÷1000V, 30mA). Figure 6 reports the comparison of two horizontal profiles taken with the same WS having slit plates of the same tank polarized at 0V and at 50V. Exceeding 100V polarisation introduces distortions in beam trajectory and profiles.

CONCLUSION

In a single 390mm tank fully equipped with two WSs, four plates and a FC measurements of beam intensity, profile and source ripple can be performed. Moreover, combining different detectors of the same tank like WS and plates, horizontal and vertical emittance can be quickly measured. During LEBT line commissioning, the emittance was computed from a sequence of WS profiles for different positions of the upstream 1mm slit. With a slit step of 1 mm the measure, on one single axis, takes 15 minutes time. Figure 7 shows the vertical phase space distribution at the level of O1-023 tank. By using statistical emittance definition, RMS Twiss parameters and emittance value at 1 sigma are retrieved. The corresponding ellipse is draft on the plot with solid line. The dashed line ellipse is a reference ellipse the user can fix.

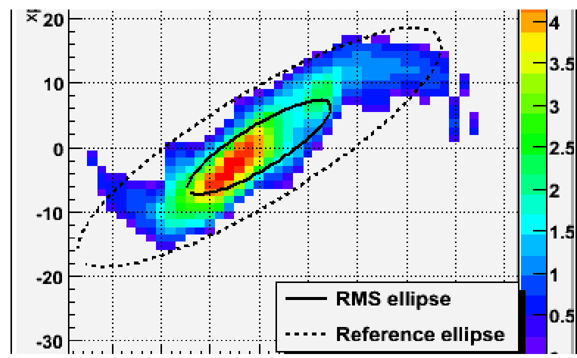

Figure 7: Vertical emittance (x, x') measurement obtained moving vertical slit from -30mm to +30mm and keeping horizontal plates at -5mm and +25 mm in order to select H_3^+ peak and stop all the other species.

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