A COMPACT AND VERSATILE DIAGNOSTIC TOOL FOR CNAO INJECTION LINE

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Abstract

CNAO, the first Italian center for deep hadrontherapy, is presently in its final step of construction. It will provide treatments with active scanning both with proton and carbon ion beams. Commissioning of the injection lines will be started by the time of the presentation of this report. CNAO beams are generated by two ECR sources, which are both able to produce both particle species. The beam energy in the Low Energy Beam Transfer (LEBT) line is 8 keV/u. A compact and versatile tank has been designed that contains a complete set of diagnostic tools. It is only 390mm long; it houses two horizontal and two vertical plates to suppress beam halo, measure emittance and eventually to limit beam size. It also comprises two wire scanners, for vertical and horizontal beam transverse profile, as well as a Faraday Cup for current measurement. Synchronous profile and intensity measurements and phase space distribution reconstruction can be performed with one tank monitors. Five identical tanks are installed in the LEBT, as consequence of a standardization strategy to facilitate monitoring and make maintenance easier. Expected performances and preliminary beam measurements are presented.

INTRODUCTION

CNAO accelerator is able to deliver carbon ions up to 400 MeV/u kinetic energy and protons up to 250 MeV/u, energies needed to treat deep seated tumours. Four treatment lines, in three treatment rooms, are foreseen in the first stage. For further technical details about CNAO cf. Ref [1] and [2].

The injection chain of the CNAO accelerator, placed inside the ring, is composed by a 8keV/u Low Energy Beam Transfer line (LEBT), followed by an RFQ accelerating the beam up to 400keV/u, a LINAC to reach synchrotron injection energy of 7MeV/u [3] and a Medium Energy Beam Transfer line (MEBT) to transport the beam to the synchrotron entrance.

LEBT

Description

Two ion sources are foreseen: one for carbon ions and one for protons. A first section (O1 and O2) is dedicated to each ion specie; a second section (L1 and L2), common to both lines, includes a beam chopper and a special Faraday cup (CFC) for beam current intensity monitoring. Figure 1 shows the schematic layout of LEBT line, with emphasis on the Beam Diagnostics (BD) elements.

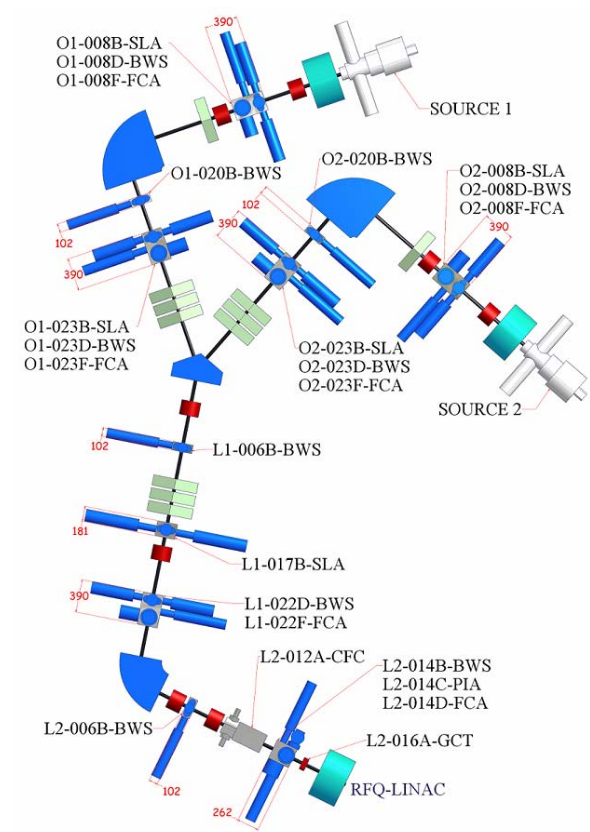

Figure 1: LEBT BD Instrumentation Layout with official elements names. SLA are Slits, BWS are Wire Scanner in both planes, FCA is Faraday Cup, CFC is the Chopper FC, PIA is Profile Grid and GCT is an AC beam current transformer.

In order to deliver 10^{10} protons and $4 \cdot 10^{8}$ carbon ions per extraction spill, with the assumed losses along the accelerator chain, the required minimum currents are 200 μA of C^{4+} and 450 μA of H_3^+.

The expected beam normalised total emittances are assumed to be less than 1 π mm mrad (240 π mm mrad geometrical). LEBT geometry allows measurement of one source while the other is in use. O1 and O2 sectors include a 90 degree dipole “spectrometer”, slits and profile and current monitors, before the switching magnet. When the Faraday cup upstream the quadrupoles triplet is inserted, the source can be monitored without disturbing the operation of the other source. Beam parameters can be measured also before the spectrometer dipole. The sources produce many different ion species at the same time; all together the total source current sums up to approximately 10 mA, depending on gas type used and source settings (Ref. [4]). Assuming a maximum total current of 20 mA, the very maximum total beam power is 480 W. Most of this power is lost into either the spectrometer vacuum chamber or in the Slits or Faraday Cup, if inserted into the beam path. In the final L1-L2 sectors the nominal intensity is 0.7 mA for H_3^+ and 0.2 mA for C^{4+}.

LEBT Beam Diagnostics instrumentation is designed in order to be small in terms of space occupancy, tolerant to high beam power deposit, in particular in the first sections, to cope with wide intensity range and to be standard. The main goals of the LEBT beam diagnostic are to select the ion specie, allow the sources fine tuning, monitor the beam profile, measure emittance up to the RFQ (LINAC) entrance.

A set of two slits (horizontal and vertical), two wire scanners (horizontal and vertical) and a Faraday Cup, are grouped in one common vacuum tank. The total longitudinal space occupancy of the tank is only 390mm. Five of these fully equipped tanks are permanently installed along the LEBT line; two additional tanks will be temporarely installed in place of the RFQ in order to measure emittance at its entrance. Each of them is able to measure beam profile, intensity and emittance. Additional four shorter tanks with a subset of the same BD instrumentation are also installed along the LEBT line.

Mechanical Issues

Each tank is machined from a unique Aluminium (Alloy AL6082T6) block; all the apertures are obtained removing material with a milling cutter; in order to minimize longitudinal space occupancy all the radial apertures are rectangular, except for the Faraday Cup. Each tank houses also a turbo molecular pump, two vacuum-meters and an injection gas dose valve; the LEBT working pressure is between $5\cdot10^{-6}$ and $5\cdot10^{-7}$ mbar, that can be worsened for beam neutralization studies by gas injection. Four pins are machined at the tank upper corners for alignment on the beam axis; a mechanically and optically qualified tank guarantee an absolute accuracy of the BD devices with respect to the tank external reference pins of 0.3mm. LEBT beam pipe internal diameter is 108.3mm, while tank one is 150mm; this latter value fixes BD monitors strokes and dimensions.

Slits

Four independent motorized copper plates compose the Slits. The four plates can create a vertical and a horizontal slit or can be positioned at the beam border, so to cut beam halo or to select ions species. A slit can also scan the beam keeping constant aperture in order to perform beam emittance measurements together with the wire scanner. A plate positioning precision is 30um. Due to the large power released by the beam, the plates are water-cooled. Secondary electrons emitted as a result of interaction between the beam and the plates could be suppressed by polarizing the plates up to 1kV. Slits plates are 1mm shifted longitudinally, so they can overlap. A special plate, with a precise cut inside, is used in the places where emittance has to be measured with high precision.

Wire Scanner (WS)

A profile measurement with a WS is performed by a synchronous acquisition of the current collected by the wire crossing the beam spot area (horizontally or vertically) and the wire instantaneous position. In the standard LEBT tank two wire scanners mounted at 90 degrees each other compose a beam profiler in H and V planes. An advantage with respect to multi-wire detectors is that only two electronics channels are needed for each plane. The wire is made by tungsten, 0.1mm diameter, and it's able to scan the beam path with a constant (±0.1%) velocity settable up to 250mm/s; such high velocity ensures the wire integrity as concerns heating. WS is also able to work in "watch dog" mode. The wire positioning precision is the same of the Slit plates, since the same motion hardware is used. Due to beam collimation by Slits, the beam intensity can be reduced by orders of magnitude; thanks to a multi-gain electronics, profiles can be retrieved with a maximum resolution of 1nA.

Faraday Cup (FC)

FCs are used as beam stoppers for the source beam not in use, to monitor beam current stability and ripple, to measure beam profile associated with the slits.

In order to withstand the large beam power for long time, they are water cooled; the cup integrity is guaranteed by an interlocked system on the water cooling.

A repeller ring electrode, in front of the cup, pushes back secondary electrons. Measurements with beam showed that a correct intensity measurement is made by setting the repeller voltage at -350V (or above). An extra grounded metallic ring between the repeller and the cup insulating spacers avoids that leakage currents deteriorate the beam intensity measurement.

Electronics Issues

For the sake of standardization the same brushless motion system was chosen for Slits and WS displacement.

Both FC and WS collect particles beam current; such signals enter a custom transconductance amplifier (Gain = Vout/Iin [V/A]). The front end amplifier allows checking the WS wire continuity by connecting its free end to a precise current source. In the case of the Faraday cup, such test current is injected into the amplifier input in place of the cup signal. FC and WS amplifier exhibit a linearity of 2% and an output voltage of ±10V on high impedance for each gain. WS version has gains from 10^4 up to 10^8 [V/A] and a bandwidth (@ -3dB) of 400Hz, that can be reduced remotely to 200Hz. The FC, intercepting more beam with respect to WS, needs amplifier gains from 10^2 up to 10^8 [V/A] and bandwidth of 15kHz up to gain 10^4, 1kHz for higher gains.

High Voltages (HV) power supplies, containing compact commercial HV components (Ref. [5] and [6]), were developed for both Slits plates and FC repellers; the Slits HV power supply is sized to withstand 30mA, while the FC version provides a maximum current of 1mA.

All the Control System hardware interface, including data acquisition and motion control, was chosen to be made using NI PXI products, running under Labview RT (Ref. [7]).

BEAM MEASUREMENTS

Ion Species Spectrum

The ion specie spectrum measurement is performed setting horizontal slits before and after the 90 degrees dipole spectrometer and acquiring the FC current downstream the magnet, at different feeding currents or during a linear ramp. A measurement is presented in Figure 2.

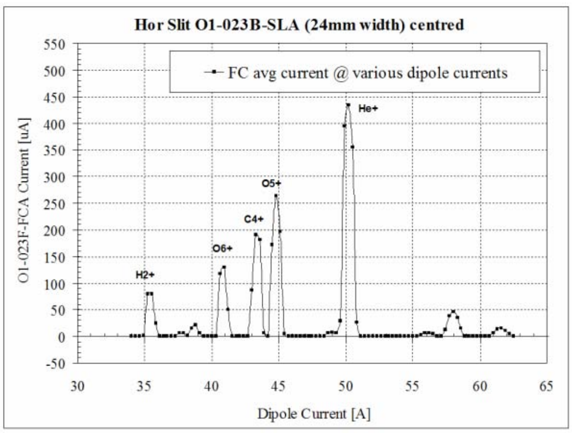

Figure 2 – Ion species spectrum of sector O1.

Profile

Beam profile can be measured in two different ways with different resolutions: using the WS, or acquiring the FC at different positions of the upstream Slit. The latter measurement is time-consuming, it has a lower-resolution with respect to the WS and needs for stable source current. Profiles obtained with WS and FC with Slits in the same tank are shown in Figure 3.

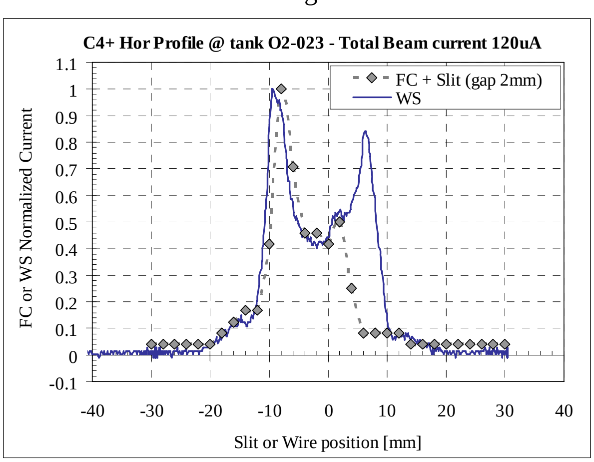

Figure 3 – Horizontal normalized profiles obtained with WS and with FC and 2mm Slit scanned across the beam.

Emittance

Beam emittance is computed from the phase space distribution measurement, obtained recording a sequence of particle beam divergences, using a WS, downstream a narrow Slit, positioned across all the beam spot area. That is made possible using every couple of Slit and Wire Scanner installed in the LEBT "compact" diagnostic tanks. A measurement is shown in Figure 4.

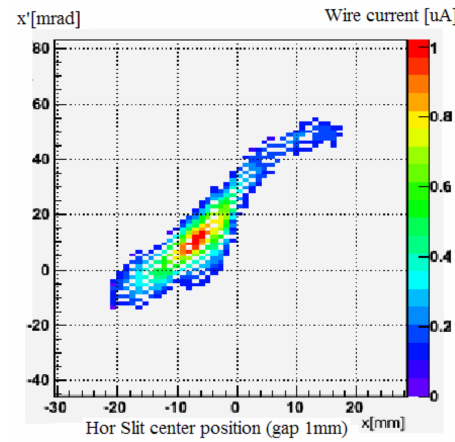

Figure 4 – Beam Horizontal phase space distribution at O2-023D-BWS. The total current on the FC was 700uA of H_3^+.

CONCLUSIONS

A total of ten compact beam diagnostic tanks, comprising five identical tanks with Slits, Wire Scanners and a Faraday Cup are presently in operation along the CNAO LEBT line during the commissioning. Mechanical and electronics issues, performances and first beam measurements of such Diagnostic tool were presented.

ACKNOWLEDGEMENTS

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