STATUS OF THE COMMISSIONING OF THE CENTRO NAZIONALE DI ADROTERAPIA ONCOLOGICA (CNAO)

G. Bazzano (on behalf of the CNAO collaboration), Fondazione CNAO, Pavia, Italy

Abstract

The National Centre for Oncological Hadrontherapy (CNAO) will be the first Italian facility for the treatment of deep located tumours with proton and carbon ion beams and active scanning technique. The accelerator complex consists of an injection system, a synchrotron and 5 extraction lines. By the end of 2009 the ECR sources, Low Energy Transfer Line (LEBT), RFQ and LINAC where fully commissioned; in December injection and first turns in the synchrotron were also successfully achieved. Full installation of machine and extraction lines was completed in early 2010.

The recent advances in the commissioning and performance of the CNAO complex are being reported in this contribution.

INTRODUCTION

The CNAO synchrotron will provide beams with range of 3 – 27 g/cm^2. This corresponds to an extracted particle energy spanning between 60 and 200 MeV for protons and 120 and 400 MeV/u for carbon.

Acceleration is performed in three stages: the 8 keV/u beam coming from the sources is transported into the RFQ to reach 400 keV/u and then into the LINAC where it reaches the synchrotron injection energy of 7 MeV/u. In the synchrotron the beam gains the energy prescribed for the treatment. Further details on the accelerator complex can be found in [1], the layout of the accelerator complex is shown in Figure 1.

During the last year the whole hospital building was completed; the Patient Positioning System was installed and successfully tested in the three treatment rooms; medical imaging, Treatment Planning System, and Oncological Information System were also put in place.

SOURCES, LEBT AND RFQ UPDATE

The two ECR sources and Low Energy Transfer Line commissioning was carried out in 2008-2009 and is reported in [2] [3]. Design beam currents and emittance were obtained for both ion species. A notable feature of the sources and of the transfer line is their repeatability. Even after weeks of shutdown, the beam is transported to the RFQ entrance simply applying the same settings to sources and magnets (correctors included). Beam profiles, emittances and transmission along the line are stored daily and their consistency with default values is a prerequisite to allow the beam to enter the RFQ. The only steering procedure routinely applied involves the last two correctors of the LEBT to optimise the beam entrance in the RFQ.

Figure 1: CNAO accelerator complex layout.

LINAC COMMISSIONING

The CNAO LINAC is an Interdigital H-mode Drift Tube Linac (IH-DTL) approximately 3.8 m long and 30 cm wide. It consists of 56 accelerating gaps and 3 magnetic triplet lenses integrated into the structure. It is designed to accelerate to 7 MeV/u species with mass to charge ratio of 3. An in depth description and full account of the LINAC commissioning can be found in [4].

LINAC commissioning was performed in cooperation with GSI and INFN staff and lasted 4 weeks. Design beam energy of 7 MeV/u was met; currently, though, we are working with a beam energy of 7.2 MeV/u.

Transmission long the LINAC

A key issue in the IH commissioning was the determination of settings that would maximise the transmission efficiency. LEBT-RFQ transmission is 60%, most likely limited by the RFQ longitudinal acceptance (see [3]). In transport mode (i.e. with no beam acceleration) transmission efficiency through the IH of nearly 100% is reached. In acceleration mode the optimised overall LEBT to LINAC transmission is of the order of 48% for both species, i.e. an efficiency of about 80% in the IH section. After the stripper foil, a ~ 1 μm thick carbon layer that removes residual electrons from the ions, the following currents were obtained in the final set-up: 900 μA of H^+; 115 μA of C^{6+}. It has to be noted, though, that the source mainly used for carbon ion was working below its standard during LINAC commissioning; in normal condition we would expect 180 μA of C^{6+}. Design values are, respectively, 670 and 120 μA.

Emittance Measurements

During the LINAC commissioning a specifically designed temporary beam diagnostic Test Bench (TB3) was installed after the stripper foil. This tank was equipped with Faraday cups, phase probes, for Time of Flight measurements, emittance slits and profile grids. TB3 enabled detailed study of the beam emittance at the LINAC exit.

LINAC set-up was optimised aiming at maximum transmission and minimum beam emittance. Constraints on the Twiss parameters at the LINAC exit were not an issue: the MEBT was specifically designed to allow enough flexibility to match the beam coming from the LINAC starting from the measured emittances.

The emittance growth effect of the stripper foil was also studied. Typical values for emittance growth are of the order of a few per cent for carbon, both in the horizontal and vertical planes; for protons scattering is larger, up to 40% (see [4]). Figure 2 and 3 below show horizontal and vertical rms emittances measured for carbon, with and without stripper foil, respectively.

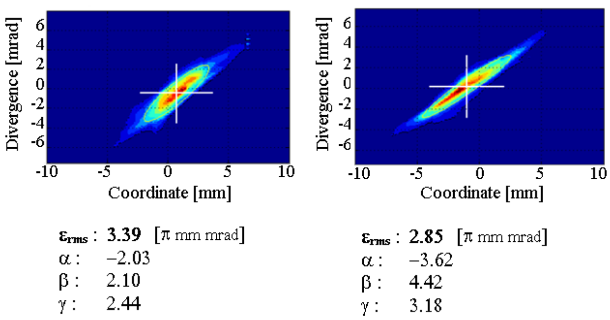

Figure 2: Horizontal (left) and vertical (right) emittance of C^{4+} beam measured in TB3 **without** stripper foil.

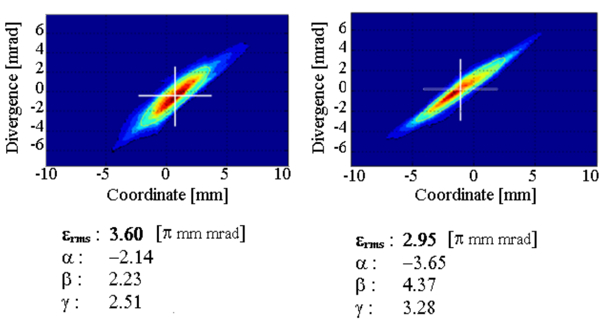

Figure 3: Horizontal (left) and vertical (right) emittance of C^{6+} beam measured in TB3 **with** stripper foil.

MEBT DESCRIPTION

The Medium Energy Beam Transfer line (MEBT) brings the H^{+} or C^{6+} beam from the stripper foil at the end of the LINAC to the electrostatic septum, where it is injected into the synchrotron. This line's task is to transport the beam without losses and to match the beam to the injection condition. Figure 4 shows the layout of the line. Two dipole magnets divide the line into three sections (M1, M2 and M3). M1 is equipped with four quadrupoles to allow a proper matching of the Twiss parameters at the end of the line with minimum disturbance to the dispersion. M2 is the section where, with the slits, the last selection of ion species can be done, ensuring the maximum ion purity of the beam. M3 is the longest section, used to prepare the beam for the multiturn injection and here most of the steerers and the diagnostics are placed. A debuncher, a 2-gaps RF cavity, allows adjustment of the momentum spread; the degrader, a set of 3 movable grids with different transmission factor, adjusts the beam current. A current transformer (ACT) and a pick-up provide non destructive measurements of the injected beam.

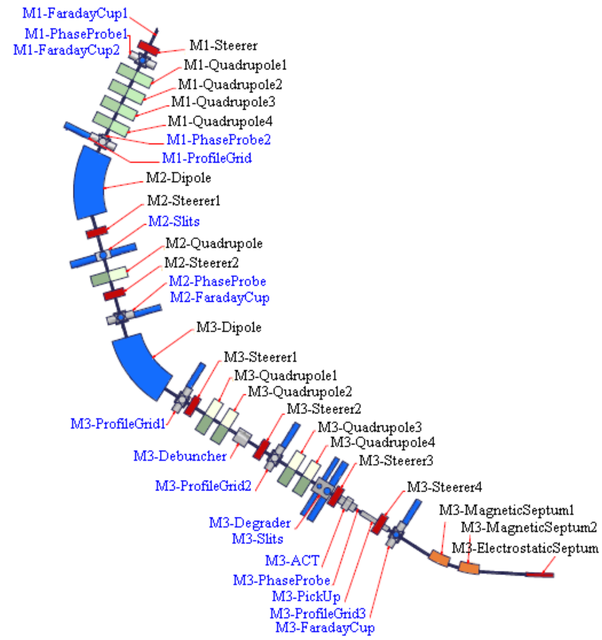

Figure 4: MEBT layout. Magnetic and diagnostic elements of the line are labelled.

MEBT measurements

MEBT commissioning and optimisation are ongoing. High transmission efficiency (~90%) was already achieved for both proton and carbon ions.

Horizontal and vertical emittance measurements were performed in M3 region with the quadrupole scan method. Figure 5 shows how as M3-Quadrupole2 current is varied the horizontal and vertical beam sizes reach a minimum. Using these measurements an optimisation of the beam parameters at the MEBT end was done, obtaining a round beam in M3 useful for diagnostic tools commissioning. Figure 6 shows beam profiles before and

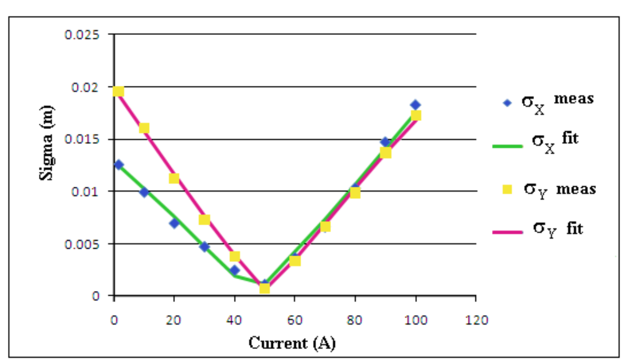

Figure 5: Horizontal and vertical beam size measured on the M3-ProfileGrids2 varying M3-Quadrupole2 current.

after the optimisation: FWHMs move from 4.5 mm and 18.6 mm (horizontal and vertical, respectively) to 14.3 mm and 14.1 mm.

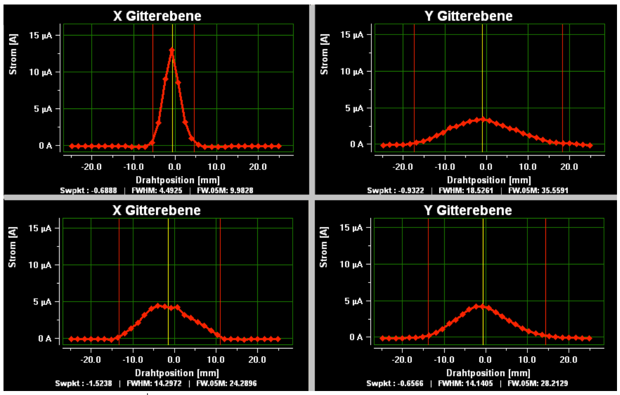

Figure 6: H^+ beam profiles in M3-ProfileGrid3 with nominal settings (above) and after optimisation (below).

FIRST INJECTION AND TURN IN THE SYNCHROTRON

MEBT line terminates with magnetic and electrostatic septa that bring the beam into the synchrotron. After the electrostatic septum a scintillating zirconium screen (similar to those used at CERN [5]) can intercept the beam and the light produced is seen by a TV camera. Digital processing of the image allows estimation of the beam dimensions.

This device is called TV60. A twin device (TV45) is placed on the synchrotron line before the electrostatic septum and light seen on this screen marks the completion of one full turn in the synchrotron.

The CNAO synchrotron is made by two symmetric achromatic arcs joined by two dispersion free straight sections that host the injection/extraction region, the resonance driving sextupole and the RF cavity. The total length of the ring is approximately 78 m and accelerates particles up to 400 MeV/u.

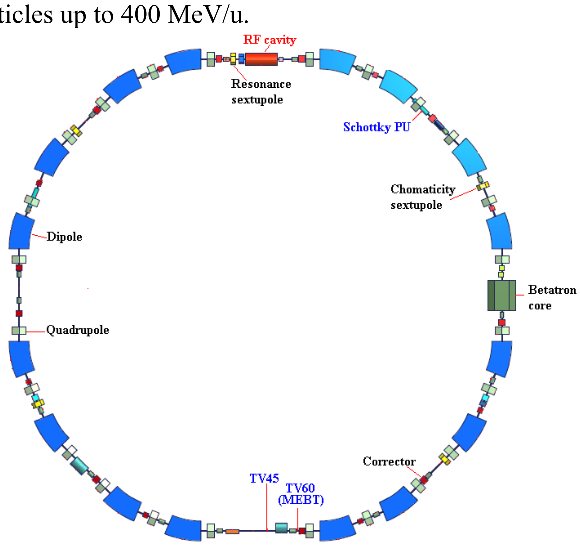

Figure 7: Schematic layout of the synchrotron. The main magnetic element types, the RF cavity and some diagnostic devices are highlighted

The total bending of 360° has been divided in 16 identical dipoles powered in series. The focusing action is provided by 24 quadrupoles grouped in three families and the chromaticities are controlled by four sextupoles grouped in two families. A fifth sextupole is used for resonance excitation. Orbit correction is guaranteed by 20 steering magnets, 11 horizontal and 9 vertical. Figure 7 shows the layout of the ring.

In December 2009 injection and first turn were obtained with proton beams; figure 8 shows the pictures taken from the two scintillating screens. Beam size estimated from these pictures is: 12 × 7.5 mm^2 (at the MEBT end) and 6 × 9 mm^2 (after the first turn). When the RF cavity was switched on the modulation effect on the beam (at 0.44 MHz) could be appreciated on the Schottky Pick-Up time-domain signal. Given the relative position of the RF cavity and Schottky PU we can conclude that the beam actually made at least two full turns of the synchrotron.

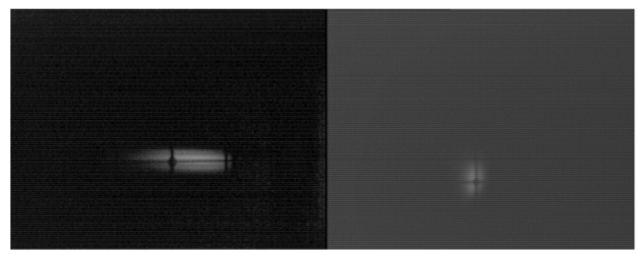

Figure 8: TV60 (left) and TV45 (right) pictures of proton beam. On the TV60 picture the sharp, right-side border of the beam is due to the electrostatic septum.

CONCLUSIONS

Recent results from the CNAO commissioning confirm the very positive behaviour of the accelerator. Sources and LEBT confirmed their performance and high repeatability. LINAC commissioning was successfully concluded achieving, and even exceeding, the design beam currents at the stripper foil level. MEBT commissioning is still ongoing. Up to now measurements are satisfactory and injection and first turn in the synchrotron could be obtained even before the optimisation of the MEBT was completed.

ACKNOWLEDGEMENTS

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REFERENCES

[1] M. Pullia, EPAC08, TUOCG02.
[2] G. Ciavola et al., EPAC08, MOPC145.
[3] E. Bressi et al., PAC09, TU6PFP005.
[4] B. Schlitt et al., MOPEA003, these proceedings.
[5] C. Bal et al., CERN-AB-2005-067 BDI.