COMMISSIONING OF THE ECR ION SOURCES AT CNAO FACILITY

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Abstract

The Centro Nazionale di Adroterapia Oncologica (National Center for Oncological Hadrontherapy, CNAO) of Pavia is the Italian center for deep hadrontherapy. It will offer treatments with active scanning both with proton and carbon ion beams accelerated up to 400 MeV/amu by a synchrotron.

At CNAO two ECR sources of the Supernanogan type (built by the Pantechnik company according to specifications set by INFN) have been installed. They run continuously and in parallel, allowing fast change of the particle species. The two sources are identical and can provide both beams after a simple switching of gases. This feature allows running the facility with only one source, which is particularly useful in emergency cases. Each source is equipped with a dedicated beam line including a spectrometer and beam diagnostics. Optimisation of beam emittance and intensity is of primary importance to obtain the necessary current in the RFQ-LINAC. The factory tests have shown the complete fulfillment of the specifications in terms of beam current and emittance. A description of the source design and performance will be presented along with the description of the commissioning tests under way.

INTRODUCTION

The Italian national hadrotherapy facility for deep tumor treatment, called CNAO (Centro Nazionale di Adroterapia Oncologica,) uses ion beams produced by two electron cyclotron resonance ion sources (ECRIS).

The 8 keV/amu beam is analyzed and transported through a Low Energy Beam Transport line (LEBT), to an RFQ which accelerates the beam up to 400 keV/amu and is followed by a LINAC, reaching 7 MeV/amu, and finally, through the Medium Energy Transport line, to the Synchrotron which accelerates it up to the energy of 400 MeV/amu.

Two ion beams will be used: $^{12}C^{4+}$, with intensities exceeding 160 μA, and H_3^+, with intensities exceeding 700μA, in order to keep the same charge to mass ratio in the beam line. Alternatively H_2^+ ions can also be used. The beam normalised emittance ($4*\varepsilon_{rms,n}$) has to be below 0.75π*mm*mrad for both the beams. The two ion sources have been installed on two independent beam lines and can work simultaneously; in case of a beam trip, the system may switch from one source to the other.

Such an operating mode will allow scheduling different periods of maintenance for each source while the other is working, thus permitting to provide the requested beams to the accelerator without any interruption. Due to the particular application of the ion beam and taking into account the requirements in terms of intensity, beam quality and stability, the ideal choice for the two ion sources is the electron cyclotron resonance ion source (ECRIS); in particular two SUPERNANOGAN ECR sources made by Pantechnik have been chosen.

SUPERNANOGAN (fig.1) is a 14.5GHz ECR ion source with both the axial and radial magnetic field generated by permanent magnets, obtaining an axial mirror ratio about two times higher than the ECR resonance magnetic field. Typical performances for the beam of interest for the CNAO project are 200 eμA of C^{4+}, 800 eμA of H_3^+, 1 emA of H_2^+ and 500 eμA of He^+.

Figure 1: One of the two ECRIS installed at CNAO.

THE SUPERNANOGUN SOURCE

The SUPERNANOGAN source is a reliable tool for the production of multiply charged ions, which is based on permanent magnets to create the magnetic trap for the plasma where ions are created, and then it offers three advantages for a hospital based facility:

1) it does not require any electrical power for the magnetic field.

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2) it is quite compact

3) the absence of electronics at high voltage (power supplies, controls, etc..) improves the reliability and long term stability.

The source body, placed at a positive potential (up to 30 kV) includes:

- A double wall, water cooled plasma chamber with a 7 mm diameter aperture for the beam extraction.
- The permanent magnets system that provides axial and radial confinement (maximum axial field is 1.2 T, minimum axial field is 0.37 T, maximum radial field is 1.1 T, which is ideal for 14.5 GHz operation).
- A copper made “magic cube” for the microwave injection system which consists of a waveguide to coaxial converter with a tuner to minimize the reflected power.
- A RF window that makes the junction between the magic cube at high vacuum and the waveguide at atmospheric pressure coming from the generator.
- A gas injection system.
- A DC bias system to add electrons to the plasma and decrease the plasma potential.

An RF generator of about 400 watts at 14.5 GHz is required to run the SUPERNANOGAN ECR ion source (the effective power used in operation is below 300W). In the case of the CNAO sources we have chosen frequency variable travelling wave tubes amplifiers (TWTA) because of their flexibility.

IMPROVEMENTS

The SUPERNANOGAN weight is about 210 kg.

The power consumption of the source is just the one of the RF transmitter, of the high voltage supplies and of the pumping system (in total about 8 kVA maximum).

The plasma chamber needs cooling provided by 20°C water flow of 200l/h at 2 to 3 bars to evacuate the heat coming from the RF power and the plasma.

Small improvements have been applied to the SUPERNANOGAN source design in order to fulfil the requirements set by INFN, including the ones permitting to get a better distribution of components for the maintenance:

1) the gas injection system has been modified in order to improve the stability.

2) a new extraction system to improve the beam emittance and stability.

3) a lead shield 10 mm thick all around the source, instead of a 5 mm one, for improving radiation safety. Moreover, in order to keep the X-rays dose below 2,5 μS/h (public limit) further lead may be added around the source bench, mostly after the extraction system.

4) The noise of electronics has been reduced.

Additionally during the preliminary experiments a clear dependence of the C^{4+} extracted current from the microwave frequency was observed, that was called ‘frequency tuning effect’ and it was explained by numerical simulation as an effect of the electromagnetic field distribution inside the plasma chamber [1,2]. After these results an additional improvement, consisting in the use of a tuneable signal generator that drives the main TWTA, was implemented.

The extraction system of the CNAO ECR ion source has been object of a deep study in order to improve its reliability for meeting the requirements of a hadrontherapy facility, which needs to operate continuously without beam interruption. The original extraction system presented a mean time between failures (MTBF) which was still not acceptable.

The improvements were focused on the shape of the electrodes and on the decrease of their relative distances, decreasing the zone where the beam is uncompensated. Such modifications recently permitted to achieve higher values of MTBF meeting the original requests. In particular, the reduction of the gap between the plasma electrode and the puller electrode, as well as the gap to the focus electrode, according to the simulations carried out with the KOBRA3D –INP code (fig. 2), significantly improved the quality for all the beams (especially for H_3^+) and decreased significantly the sparks in the extraction region.

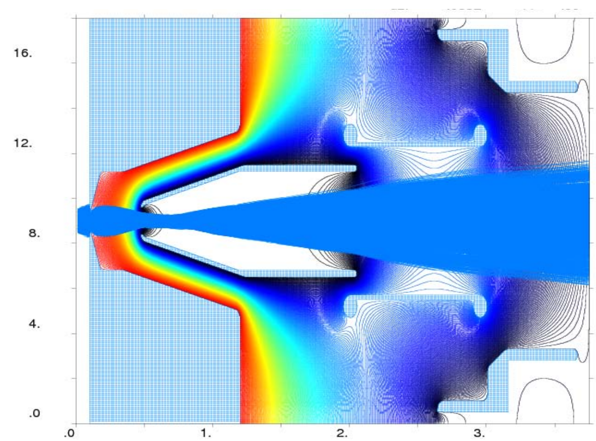

Figure 2: Simulation of the beam through the extraction system of the CNAO sources.

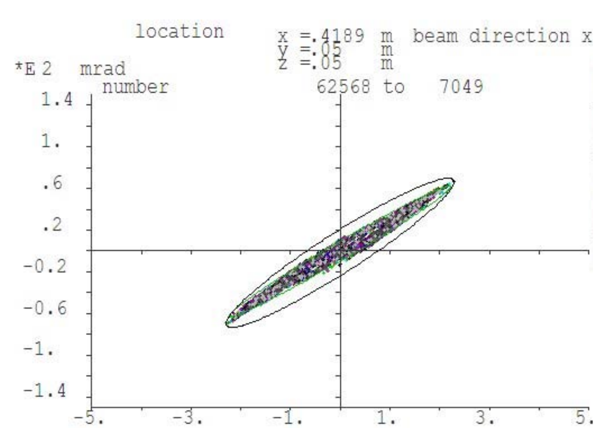

Figure 3: The emittance in the y-plane at the end of the simulation for C^{4+}: the rms-normalized value is 0.53 π mm mrad.

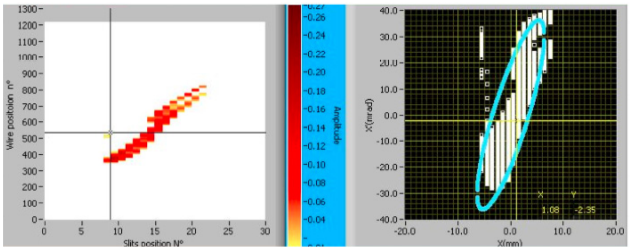

Figure 4: Measured emittance for 250 eμA beam of C^{4+}: the rms-normalized value is 0.52 π mm mrad.

Finally, the present geometry consists of a plasma electrode positively biased at 24 kV, a screening electrode to avoid electron backstreaming to the ECR ion source, an electrostatic lens and finally the ground electrode.

The results of the simulation are shown in fig. 2 and 3. They can be compared with the experimental results in fig. 4. A good agreement has been found. In particular, for the presented case of fig. 4, the emittance was 0.52π mm mrad for the whole beam, 0.45π mm mrad for 90% of the beam in the best case and below 0.75π in any case (for H_3^+ the emittance is usually larger than for C_4^+).

ACCEPTANCE TESTS

The acceptance tests at the factory have been carried out successfully in the fall of 2006. Particular attention was paid to the emittance measurements and to the stability tests. While the acceptance tests of the first source were less satisfactory, because of instability in the gas flow, the test of the second source after the solution of such problem was easier. Minor sparks and no break down of the source were observed. Finally the test of stability over 36 h for C^{4+} (200μA) has given a positive result, accounting a total availability figure of 99.7%, well above the contractual limit (98%), that was barely passed by the first source (98.2%). The lack of stability observed for the 1st source because of the poor thermal shielding of the UDV gas valves has been corrected by using the electrically controlled thermal mode of the valves, and by placing them in a box with a thermal insulation. No other problems have been observed.

Finally the current was well above the requirements, i.e. 250 eμA for C^{4+} (25% more than requested) and 1100 eμA for H_3^+ (50% more than requested). As a consequence we decided to decrease the plasma electrode hole diameter to 6 mm, allowing to have better emittance figures of the extracted beam.

INSTALLATION, TESTS AT CNAO AND FUTURE DEVELOPMENTS

The sources were moved to Pavia and installed according to the plan view shown in fig. 5. The first beam was obtained at CNAO, Pavia, in late spring 2007 and it was transported up to the Faraday cup. Unfortunately the full completion of the installation was delayed to 2008 because of the unavailability of some technical services, not completed in the due time by an external contractor.

Only recently it was possible to have the beam diagnostics working. The in-site acceptance tests are presently in progress.

Additional improvements are scheduled for the next future, according to the results of the systematics on frequency tuning effects to be performed in the next summer. In particular the use of multi frequency heating tests is considered.

Moreover an improvement of the RF injection system can be made by replacing the existing microwave injection by a simplified one, through a rectangular or circular waveguide. Considering that a TWT will be used to feed the ECR ion source and that the oven is not used for the CNAO standard operations, this change will permit a simpler RF tuning over a wide frequency range as already experienced at INFN-LNS (PANTECHNIK-Hypernanogan type) and GANIL.

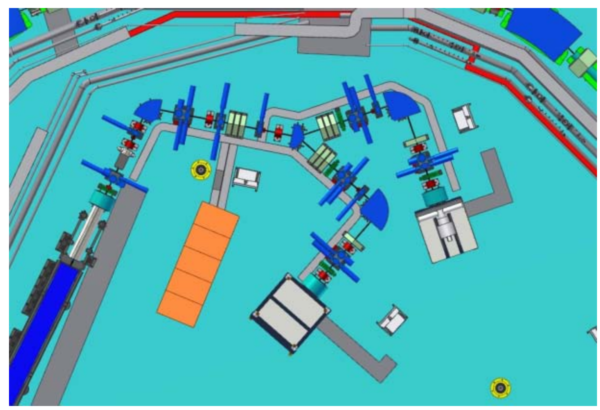

Figure 5: The CNAO injector with two ECR ion sources.

ACKNOWLEDGMENTS

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