STATUS OF AISHA ION SOURCE AT CNAO

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Abstract

CNAO is one of the few centres all around the world able to treat patients affected from cancer by proton and carbon ions beams. The clinical beams are produced by a synchrotron equipped with two ECR (Electron Cyclotron Resonance) sources. A third source, based on the AISHa (Advanced Ion Source for Hadron therapy) source of the INFN-LNS laboratory, has been installed in order to produce new species that will be interesting both for clinical and R&D purposes. This paper shows the most important results along with the issues occurred and the solutions found during the first phase of the commissioning of the source with helium ions beams.

INTRODUCTION

Medical application systems installed in hospitals must deliver ions with enough current to keep patient treatment times short, as well as ensure high reliability, stability, and reproducibility of the produced and accelerated beam. Additionally, sources designed for hospital use should be easy to optimize and maintenance should be straightforward and efficient. Fondazione CNAO uses two Supernanogan ECR (Electron Cyclotron Resonance) sources to produce proton and carbon ions for daily treatments. To generate new ion species, a third ion source called AISHa-CNAO has been installed. This system is based on the design developed at INFN-LNS [1-2], but it includes several enhancements intended to allow continuous operation for several months without requiring maintenance stops. The source has been integrated in the whole CNAO layout by a dedicated low energy beam line (LEBT) shown in Fig. 1 and described in [3].

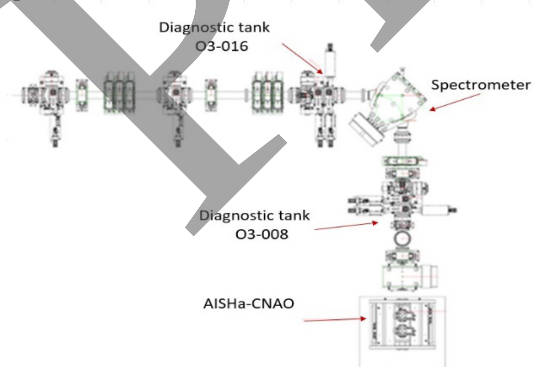

Figure 1: AISHa-CNAO LEBT layout, where magnets and diagnostics tanks are showed.

AISHa has been developed to operate effectively within both clinical environments and nuclear physics laboratories. Its engineering specifically allows it to accommodate an oven for producing metallic ions. CNAO has received approval to generate Helium, Carbon, and Oxygen as gas beams, as well as Lithium and Iron as metallic beams. Since AISHa was installed at CNAO, it has primarily been used to produce Helium—commissioning of which is still underway [4]—so that Helium beams can eventually be used in CNAO's treatment rooms for patient care.

MAINTENANCE AND DC-BIAS UPGRADE

Plasma confinement is realized in AISHa by a permanent hexapole magnet and four superconducting solenoids whose currents are set to proper adjust the longitudinal magnetic field profile. Plasma is generated by radio-frequency (RF) delivered by a klystron with adjustable frequency; the extraction voltage is set to match beam energy to the LINAC acceptance. A negative biased puller electrode is used to protect the plasma lens. A DC-bias electrode is positioned inside the plasma chamber to increase the plasma density and stabilize the beam extracted current. CNAO is the first centre that experienced a long-term operation with AISHa source. For this reason there was not a precise maintenance plan except of the maintenance of standard parts (vacuum components and so on). An accurate supervision of source parameters was needed to understand source behaviour over time.

A particular attention has been paid to monitor the HV power supplies. Since the beginning some discharges have been observed on the repeller electrode. The control system just gives a warning if the puller overcurrent lasts less than 2 seconds, while it gives an interlock and switches off the klystron if the overcurrent lasts for more than 2 seconds. After one month of operations, we observed that the warning occurred more frequently day by day and that sometimes the interlock was triggered. Since it was not possible to service the source we tried a cleaning procedure with a high-pressure oxygen flux, but the problem came back again when raising the microwave power to values higher than 1 kW.

An inspection of the plasma chamber showed that the chamber was dirty and that the effect was due to the erosion of the DC-bias material. Furthermore the extraction insulator had discharge spots caused by the material sputtered from the DC-bias in correspondence of the plasma loss lines. This was a clear evidence that the sputtering of the beam on the bias was excessive for source long-term

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operations. Considering that the DC-bias was made of Titanium, a simulation study was performed exploiting SRIM (Stopping and Range of Ions in Matter) software [5] in order to find the best material for the electrode. Considering that the DC-bias voltage is 60 V, simulations were performed with a beam of 0.12 keV He^{2+}; to maximise the sputtering effect, an angle of 30° with respect to the DC-bias surface has been considered. The sputtering yield (i.e. the ratio between the number of sputtered atoms and the number of incoming ions) was simulated for Titanium, Tantalum and Tungsten. The number of particles used in the simulations did not allow to distinguish Tantalum from Tungsten so other simulations were performed at a higher energy giving the following results:

- Titanium Sputtering Yield = 0.0338 (0.1266) at 0.12 keV (0.3 keV).
- Tantalum Sputtering Yield = 0 (0.00015) at 0.12 keV (0.3 keV).
- Tungsten Sputtering Yield = 0 (0.00001) at 0.12 keV (0.3 keV).

A market search was performed for a firm able to produce a DC-bias in Tantalum or Tungsten. All the firms declared great difficulties in realizing a DC-bias made of either one of these materials due to the internal water-cooling circuit and the soldering of two parts. Considering these difficulties, the decision was taken to produce a Tantalum DC-bias via a 3D-printing process [6-7].

The DC-bias was installed in the source during maintenance conducted in September 2025. Following this, neither warnings nor interlocks have been triggered throughout six months of uninterrupted operation. Figures 2-4 present the conditions of injection and extraction during a rapid opening in December 2025. The chamber was clean, but some marks were still present on the extraction insulator. The extraction electrode support has been slightly adjusted to provide better shielding and further reduce these spots.

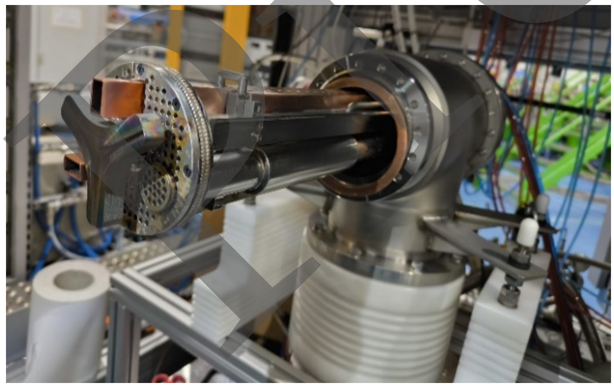

Figure 2: The injection assembly.

The source exhibited distinct behaviour with the new DC-bias from various perspectives: the DC-bias current was reduced by nearly half compared to previous levels, the standard deviation of the beam current decreased and the same beam current was achieved with only half the DC-bias current and 2 dBm less power. Additionally, horizontal beam emittance decreased by a factor of 1.5, while vertical beam emittance decreased by a factor of 1.2.

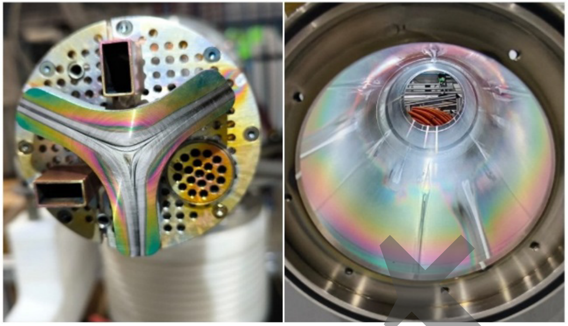

Figure 3: The detail of the AM made Tantalum DC-BIAS (left) and of the plasma chamber (right).

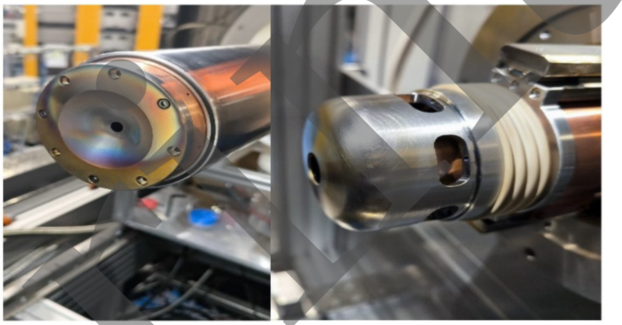

Figure 4: The extraction electrode (left) and the movable system of the repeller and ground electrode (right).

The primary drawbacks observed after implementing the new DC-bias were the appearance of oxygen in the source spectrum, as presented in Fig. 5 where optics is optimized for the He^{2+} beam, and an increased baseline injection pressure relative to prior conditions.

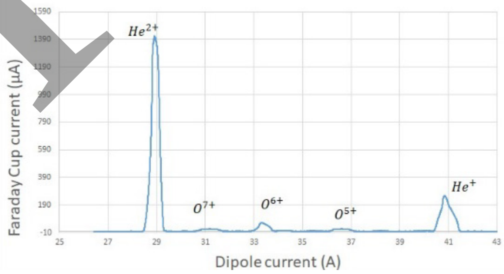

Figure 5: AISHa-CNAO Helium ions beam spectrum.

It took four months for the basic injection pressure to return to its pre-maintenance level, and the spectrum to be restored to its previous state, featuring only the He^{2+} and He^{+} charge states. The underlying causes of these two issues remain uncertain; they may stem from the 3D-printing technique or potential errors during plasma chamber cleaning. Further clarification is expected following the upcoming replacement of the DC-bias.

SOURCE PARAMETERS

The AISHa-CNAO source requires careful adjustment of several parameters to optimise beam current and beam emittance. The extraction system employs a conventional ACCEL-DECEL configuration, featuring repeller and ground electrodes that are fixed relative to each other but may be moved longitudinally to modify their distance from the plasma electrode. Figure 6 illustrates the impact of varying the separation between the plasma and extraction electrodes on both horizontal and vertical emittances, as well as the He^{2+} currents measured in the diagnostic tank O3-008 for different beamline solenoid settings. Measurements were taken when the Titanium DC-bias was mounted, so just the trend can be considered: the measurements will be repeated in the next future with the Tantalum DC-bias to obtain the exact numbers. A zero distance in the plots represents the maximum separation between the puller and the plasma lens (42 mm).

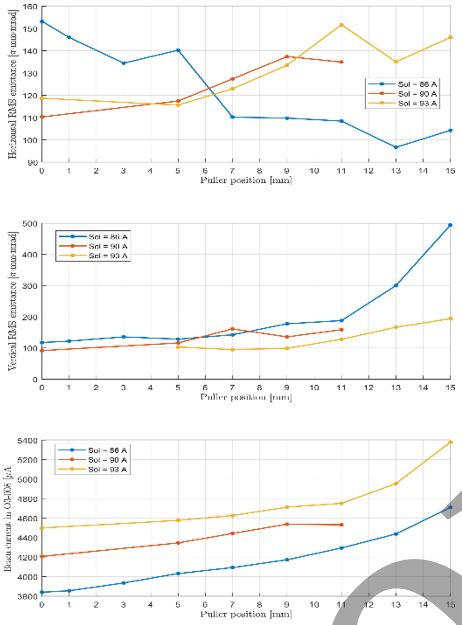

Figure 6: Emittances (top graphs) and beam current (bottom graph) in O3-008 for different puller positions (on X-axis) at three different solenoid currents.

Puller position and solenoid current were set to balance beam current and emittance in both planes. Despite this, transverse beam emittances remained high, causing losses in the LEBT due to space charge effects. To address this, the beam was scraped by partially closing horizontal and vertical slits after the solenoid and spectrometer, improving repeatability of beam characteristics at the end of LEBT regardless of source fluctuations.

Table 1 shows beam currents ("Current O3-008" is total beam current after the solenoid; "Current O3-016" is He^{2+} current after the spectrometer) and rms geometrical emittances in the transverse planes after the spectrometer with and without slits scraping (refer to Fig. 7).

Table 1: Beam Parameters

Beam Parameter	Total	With Slits Scraping
$\epsilon_{rms,x}$ [π·mm·mrad]	56	54.77
$\epsilon_{rms,y}$ [π·mm·mrad]	123	15.66
Current O3-008 [μA]	3500	1440
Current O3-016 [μA]	1600	1090

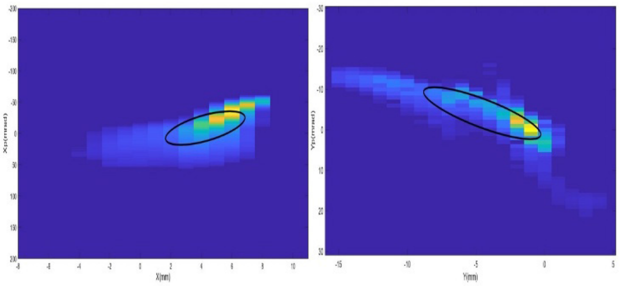

Figure 7: Horizontal (left) and vertical (right) emittance in O3-016 with Tantalum DC-bias and slits scraping.

Table 2: Twiss Parameters Summary

Twiss Parameter	Horizontal	Vertical
ϵ_{rms} [π·mm·mrad]	54.77	15.66
α	0.7903	-1.427
β[m]	0.1232	1.161
γ [m^{-1}]	13.19	2.615

A fine tuning of RF power and Helium pressure is needed to optimize current stability: an accurate tuning allows to obtain an average current of 1100 μA with a standard deviation of 8-10 μA. Table 2 summarizes Twiss parameters in O3-016 with Tantalum DC-bias, while Table 3 lists the typical settings of AISHa-CNAO source.

Table 3: Summary of AISHa-CNAO Settings

Property	Value
Injection Pressure [mbar]	$2.5 \cdot 10^{-7}$
Extraction Pressure [mbar]	$4.3 \cdot 10^{-8}$
Cryogenic Magnets Currents [A]	118/114/111/107
RF Output Power [W]	400
RF Reflected Power [W]	16
RF frequency [GHz]	17.812
Source Voltage/Current [V/mA]	16000/4.5
Puller Voltage/Current [V/mA]	-3000/-0.03
Puller position [mm]	0
DC-BiasVoltage/Current [V/mA]	60/12
LEBT pressure [mbar]	$5.7 \cdot 10^{-8}$

CONCLUSION

CNAO installed a third source to produce new clinical beams. The source is called AISHa-CNAO and it is now used to produce continuously Helium beams H24 7/7 with a six months maintenance plan. Helium beam has been commissioned up to treatment rooms where it is under characterization to begin in vitro biological tests.

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