

## COMMISSIONING OF THE AISHa ION SOURCE AT INFN-LNS

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### Abstract

At INFN-LNS, the superconducting ECRIS named AISHa (Advanced Ions Source for Hadrontherapy) started in fall 2016. Highly charged ion beams with low ripple, high stability and high reproducibility are the most important features for the ongoing commissioning. In this work, a general description of the source is given together with the preliminary results of the commissioning.

### DESCRIPTION

The AISHa ion source was funded within the framework of the program of Sicilian Government named PO FESR 2007-2013 and a pool of Sicilian small enterprises was associated with INFN for the realization of this new source. It was designed taking into account the typical requirements of hospital facilities, in order to provide highly charged ion beams with low ripple, high stability and high reproducibility. The minimization of the mean time between failures is also a key point together with the maintenance operations that should be fast and easy. The features included in the design exploit all the knowledge acquired from INFN-LNS in last decades in the ion source design and realization. The assembly of the source and of the first part of the LEBT has been carried out in the fall of 2016 and it has been completed in the first months of 2017. Figure 1 shows a view of the experimental area containing the source together with the

low energy beam transfer line for its characterization; the main features of the source are listed in Table 1.

The hybrid magnetic system, consisting of a permanent magnet hexapole and of four superconducting coils, is able to minimize the hot electron component and to optimize the ECR heating by a fine control of the field gradients and of the resonance length. The compact cryostat is equipped of two double-stage cryocoolers that allow to reach the operating conditions in ~40 hours [1].

The RF injection system was designed to operate in both single and double frequency mode in order to exploit at the same time the Frequency Tuning Effect (FTE) and the Two Frequencies Heating (TFH) mechanism [1].

The plasma chamber is placed at high voltage (up to 40 kV). It was designed to operate at a maximum power rate of 2 kW. A 20 mm thick glass and carbon fiber tube, surrounding the hexapole, allow insulating the chamber in order to keep the superconducting magnets and the yoke at ground potential [2]. The microwave amplifier located at ground is insulated from the plasma chamber by a waveguide DC break, designed to permit reliable operation up to 50 kV.

Figure 2 shows a side view of the RF injection system. The beamline consists of a focusing solenoid placed, downstream the source, a 90° bending dipole for ions selection and two diagnostic boxes. A Faraday Cup, a beam wire scanner and slit made each diagnostic box that allow the characterization of the beam.



Figure 1: The Advanced Ion Source for Hadrontherapy at INFN-LNS in Catania.

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Table 1: AISHa Features

Feature	Value
Radial Field (max)	1.3 T
Axial field ( $B_{inj}/B_{mid}/B_{extr}$ )	2.6 T / 0.4 T / 1.7 T
Operating frequencies	18 GHz
Operating Power	1.5 kW
Extraction Voltage	40 kV
Cryostat length/diameter	620mm / 5650mm
L-He	Free
Plasma chamber $\varnothing$	92 mm
Extraction hole $\varnothing$	7.2 mm

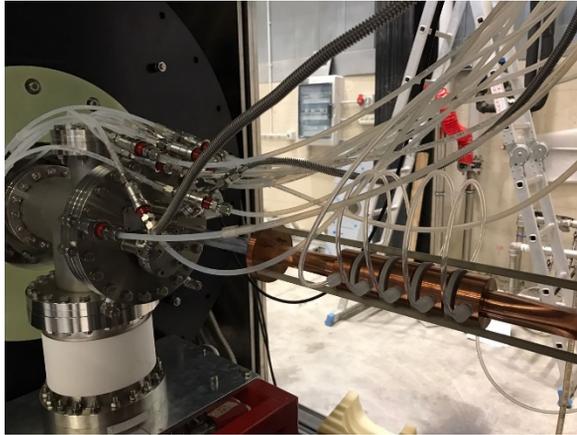


Figure 2: Side view of RF injection system.

### PRELIMINARY PHASE

Before to start the beam commissioning, it has been necessary to test the functionality of individual ancillary equipment by a preliminary commissioning phase.

The first plasma was ignited by a RF power at low power and then gradually boosted up to 1000 watt in some days in order to clean up and outgassing the plasma chamber. This operation allowed decreasing the base vacuum down to  $4 \cdot 10^{-8}$  mbar. In the preliminary phase, no extraction voltage was applied.

The microwave matching was tested with high accuracy by means of a high directivity directional coupler for an accurate measure of the forward and the reflected power. Typical reflected power value did never exceed 2% but more after it was below 1%. At the same time, the cooling system was tested paying great attention to the plasma chamber temperature.

The RF injection system consists of one high power klystron amplifier operating in the 17.3-18.4 GHz frequency range that allows to finely tune the frequency by a Digital Fast Tuner System (DFTS). The operative microwave frequency will be upgraded to higher frequency in the second phase of commissioning. The magnetic trap were tested with their operational design current without quenching and the measured full axial magnetic field profile confirmed the design specifications [3].

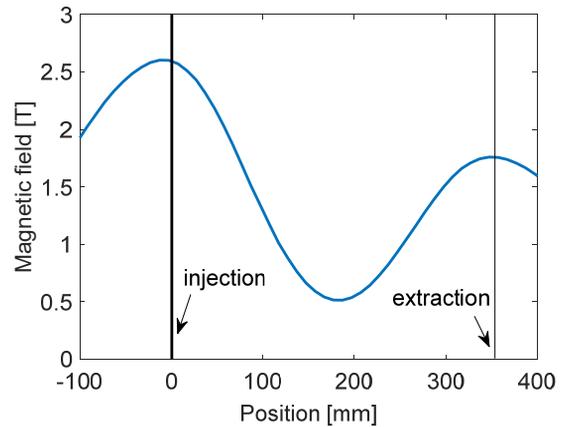


Figure 3: Magnetic field of the AISHa ion source when all 4 coils are run at maximum current (130 A).

The maximum operative current for the 4 coils is 130A. Figure 3 shows the measured magnetic field when all coils were run at maximum current.

The control and safety systems were debugged continuously during the first months of 2017 in order to provide the highest security and the highest detailed description of all issue events. The user interface, as well as being a friendly interface for the final use, provide additional functionalities that will help in the parametrized study of the source.

### COMMISSIONING PHASE

After the usual outgassing, the extraction voltage has been fixed at 20 kV and klystron frequency fixed at 17.3 GHz. The commissioning phase continued by means of the slow adjustment of the magnetic field profile. In a first stage, we fluxed Argon gas in the source, then substituted by  $CH_4$  in order to characterize the carbon Charge State Distribution (CSD). Typically working pressure is in the range  $1-4 \cdot 10^{-6}$  mbar.

Figure 4 shows the CSD measured after the 90° analysing magnet in a biased Faraday cup during the early steps of commissioning phase in 4 different configurations aimed to optimize  $C^{4+}$ . Every configuration change in magnetic field profile, microwave power and neutral pressure. The CSD of carbon is peaked on  $C^{3+}$  and  $C^{4+}$  ( $C^{3+}$  peak is contaminated by the  $O^{4+}$  pick). A current of around 160  $\mu A$  has been obtained at the end of the session (configuration 4). The source still contained oxygen and nitrogen as contaminants but their concentration decreased during the hours.

The continuous optimization of the magnetic system, working pressure and microwave power finally enabled to extract up to 260  $\mu A$  of  $C^{4+}$  beam. This result is relevant because it was obtained without any use of the well-known techniques devoted to increase the mean charge state (bias disk, gas mixing, frequency tuning, two frequencies heating).

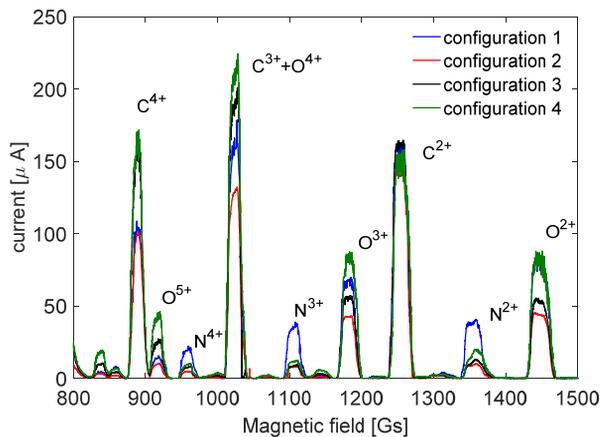


Figure 4: Preliminary spectrum of a carbon beam.

## CONCLUSIONS AND NEXT STEPS

The first results obtained in the early commissioning phase of the AISHa source permitted to generate up to  $260 \mu\text{A}$  of  $\text{C}^{4+}$  beam. The concentration of contaminants is going to decrease during the operations. The next steps concern the characterization and optimization of the source for different species as reported in the following:

- **Evaluation of the frequency tuning effect:** Up to now, AISHa has been operated at fixed frequency. The frequency tuning is expected to boost the extracted current by improving the plasma-microwave coupling.
- **Gas mixing:** the insertion of an opportune support gas (typically helium for light ions and oxygen for heavy ions) allows to enhance the mean charge state of the extracted beam.
- **Bias disk:** the installation of a bias disk in the injection flange will allow to increase confinement time and indeed the mean charge state.
- **Two frequencies heating:** the use of two different operational frequencies allows to improve the particle confinement. This result will be obtained with the installation of a second klystron in the range 21-22 GHz.
- **Optimization of plasma electrode position:** the electrode position affects the total extracted current and the beam optics and requires to be optimized.

The transverse emittance will be measured by means of an Allison emittance scanner, already installed in the Aisha beam line. Its commissioning is planned for the next month.

Systematic studies of the extracted beam and emittance are planned with the aim to optimize the brightness of the beam as a function of the different ion source parameters. A second AISHa source is going to be built for the National Center of Hadron Therapy. The cryostat with the

superconducting coils has been delivered and the permanent magnet hehropole will be available at the end of 2017.

## ACKNOWLEDGEMENT

The authors would like to acknowledge the support of INFN technical staff and of the mechanical workshop for the valuable work done in the design and manufacturing of several items of the AISHa facility.

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