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COMMISSIONING OF THE AISHA ION SOURCE AT INFN-LNS

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Abstract

The AISHa ion source has been designed to generate high brightness multiply charged ion beams for hadrontheraphy applications, with high reliability, easy operations and fast maintenance. In order to get a compact machine, the radial confinement is provided by a Hallbach-type permanent magnet hexapole structure, while axial confinement is allowed by four high field He-free superconducting magnets, allowing the optimization of the magnetic field gradient at ECR resonance. The present work shows the results of ion source commissioning along with next developments.

INTRODUCTION

The AISHa [1] 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 considering 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 [2]. 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. The main features of the source are listed in Table 1.

THE EXPERIMENTAL SETUP

The analysis of the costs and risks, taking into account the main beams of interest for such kind of application, clearly indicated that the optimal solution is a hybrid magnetic system. It consists of a permanent magnet hexapole and of four superconducting coils to minimize the hot electron component (to keep the superconducting magnets safe) and to optimize the ECR heating by a fine control of the field gradients and of the resonance length. The compact cryostat is equipped with two double-stage cryocoolers that allow reaching the operating conditions in around 40 hours, the magnetic field generated on axis is shown in fig. 1.

Parameter	**Value**
Axial field	2.7 T–0.4 T–1.6T
Radial field	1.3 T
Operating frequency	17.3-18.5 GHz
Operating power	2 kW (max)
Extraction voltage	40 kV (max)
Chamber dimensions	Ø 92 mm/360 mm
Warm bore diameter	274 mm
Weight	1400 kg

Table 1: AISHa Main Parameters

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.

The 2400 cm^3 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, allows insulating the chamber in order to keep the superconducting magnets and the yoke at ground potential [3]. The microwave amplifier located at ground is insulated from the plasma chamber by a waveguide DC break, designed to permit reliable operation up to 40 kV [4].

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 allow the beam characterization.

Figure 2 shows a view of the experimental area containing the source together with the low energy beam transfer line for its characterization.

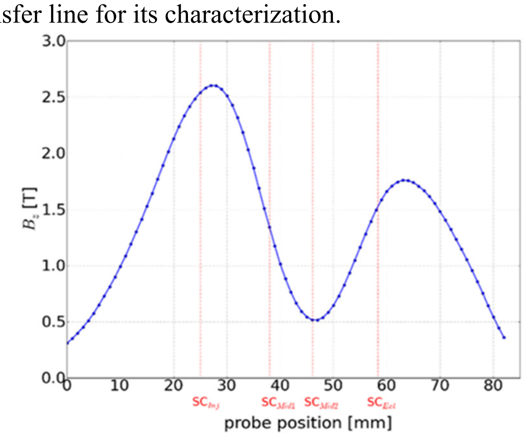

Figure 1: AISHa magnetic field profile

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Figure 2: The Advanced Ion Source for Hadrontherapy at INFN-LNS in Catania.

COMMISSIONING RESULTS

The beam commissioning has been slowed down from a number of minor obstacles during the phase of functional check of individual ancillary equipment; this was particularly evident when the plasma generator was operated above 1 kW at larger gas load, in order to understand their limits. Some mechanical components demonstrated to generate outgassing, which obliged to open and clean the inner parts twice.

After the refurbishment and minor changes, the base vacuum was always in the 10^{-8} mbar range and the optimization started satisfactorily.

The magnetic trap magnets have been operating routinely at their operational design current without quenching and the measured full axial magnetic field profile confirmed the design specifications [1]. The maximum operational current for the 4 coils is 130A.

Particular attention has been paid to the Quench Detection System of the He-free magnets. The system is fully operative and embedded inside the coil power supplies, but it took some time in order to test different solutions.

The microwave matching was tested with high accuracy by means of a high directivity (40 dB) directional coupler for an accurate measure of the forward and the reflected power. Typical reflected power exceed 2% but after a fast optimization it was 0.1 to 1%.

At the same time, the parameters of the cooling system are interlocked with the klystron to avoid increase of the plasma chamber temperature (permanent magnets are 0.2 mm far from the chamber).

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 control and safety systems were debugged continuously to provide the highest security and the highest detailed description of all issue events.

During the last six months, to gain experience on the source, it has been decided to begin the operations with Ar and O_2 gases at 20 kV, at the fixed frequency of 17.3 GHz and with 1kW of microwave power. We focused operations on the optimization of gas pressure and magnetic field to better understand the effect of the new approach to microwave-to-plasma coupling and to evaluate the stability of a plasma which is confined by a relatively high magnetic field ("High B mode" [4]) in a quite short plasma chamber.

Figure 3 shows the typical Charge State Distribution (CSD) measured after the 90° analysing magnet in a biased Faraday cup for O and Ar, in the first case He was used as mixing gas while in the second case O was used. The two configurations have different magnetic field profile, microwave power and neutral pressure.

The Oxygen and Argon currents achieved in such conditions are reported in table2.

Table 2: Oxgen and Ar currents @ 1kW power. the optimized values are marked with (*).

Parameter	Value [uA]
O6+ (*)	846
O7+	320
Ar11+	190
Ar12+	140
Ar13+	80
Ar14+	40
Ar16+	2

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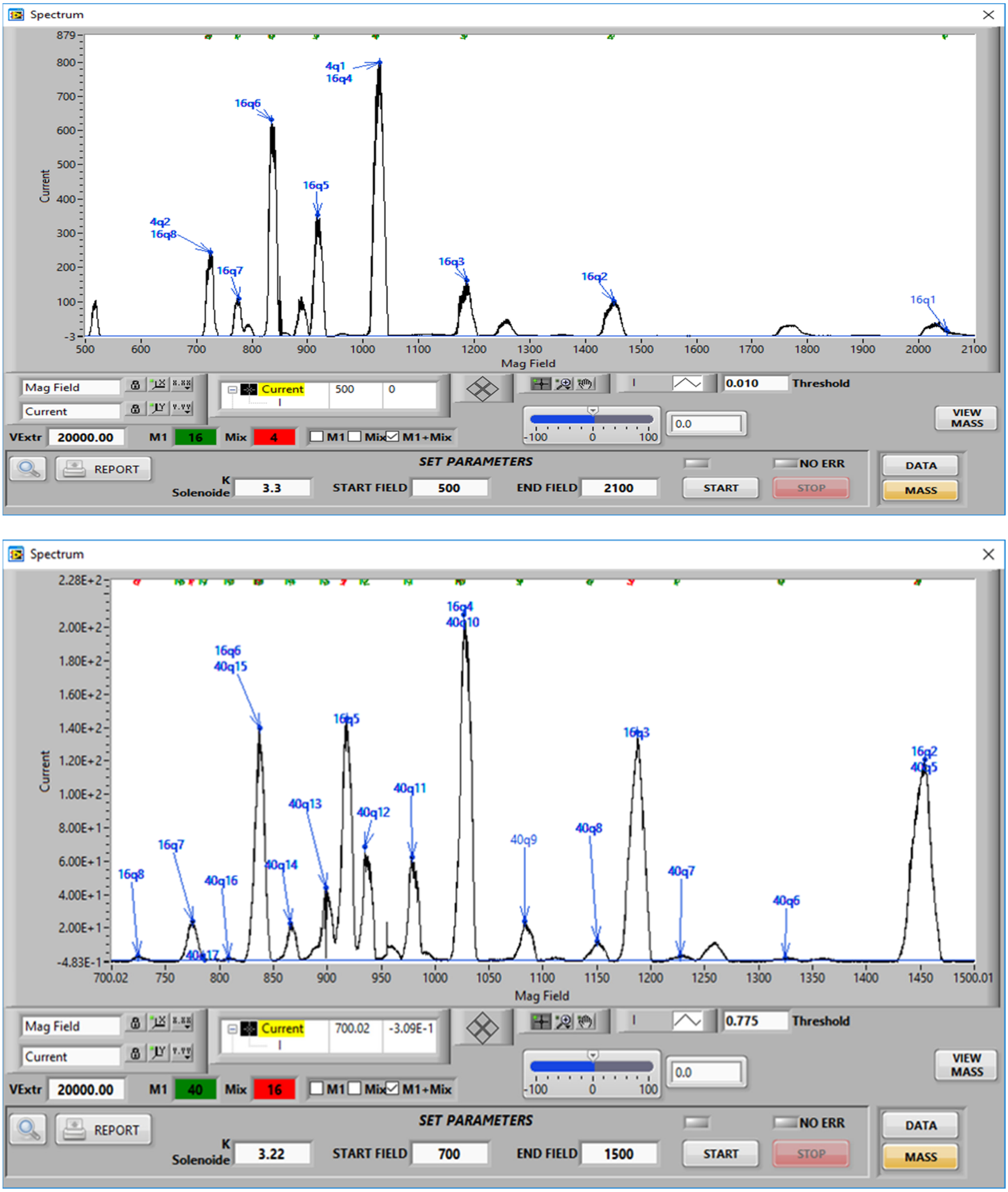

Figure 3: Charge State Distribution (CSD) measured for O and Ar,

CONCLUSION AND NEXT STEPS

The first results obtained in the early commissioning phase of the AISHa source permitted to understand that the source is well functional even if several steps are needed to optimize its performances for different species.

The first priority is to evaluate systematically the frequency tuning effect together with the possibility to heat the plasma with a second frequency up to 22 GHz.

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The bias disk as well as the use of gas mixing will certainly allow to enhance the mean charge state of the extracted beam.

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

The exceptional flexibility of AISHa trap and RF system is moreover suitable for implementing multi-diagnostics measurements in order to evaluate the impact of the mirror-ratios, of the magnetic field gradients and the interplays with the RF power and frequency on the main plasma parameters such as density and temperature.

The "tool-box" of diagnostics already developed at LNS [5] such as optical spectrometers, X-ray pin-hole cameras [6] and interferopolarimeters [7], will be mechanically adapted to be matched to AISHa setup, thus making this source the first one – among the new generation ECRISs – to be deeply characterized in terms of impact of plasma heating on the plasma properties.

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