

A COMPACT MULTIPLY CHARGED ION SOURCE FOR HADRONTHERAPY FACILITY

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Abstract

The ion sources for accelerators devoted to medical applications must provide intense ion beams, with high reproducibility, stability and brightness. AISHa (Advanced Ion Source for Hadrontherapy) is a compact ECRIS whose hybrid magnetic system consists of a permanent Halbach-type hexapole magnet and a set of independently energized superconducting coils. These coils will be enclosed in a compact cryostat with two cryocoolers for LHe-free operation. The microwave injection system has been designed for maximizing the beam quality through a fine frequency tuning within the 17.3-18.4 GHz band which is possible by using an innovative variable frequency klystron. The introduction of an integrated oven will allow the production of metal ions beams with relatively high intensity for light ions. "Accel-decel" extraction system will be used. The LEPT line will consist of a solenoid and a 90° dipole for ions selection. Two diagnostic boxes, made of Faraday cups, beam wires and slits, will allow the characterization the beam. Moreover, a system of scintillating screens and CCD cameras, placed after the solenoid will allow the investigation of the Frequency Tuning Effect (FTE) on the source performances.

INTRODUCTION

The AISHa ion source has been designed by taking into account the typical requirements of hospital-based facilities, where the minimization of the mean time between failures (MTBF) is a key point together with the maintenance operations which should be fast and easy. Therefore, a so called 3rd generation ECR ion source is not suitable, being quite complex for unskilled operators.

The new AISHa source is designed to be an intermediate step between the 2nd generation ECRIS, unable to provide the requested current and/or brightness and the 3rd generation ECRIS, too complex and expensive. It is intended to be a multipurpose device, operating at 18 GHz, in order to achieve higher plasma densities. It should provide enough versatility for future needs of the hadrontherapy, including the ability to run at larger microwave power to produce different species and

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highly charged ion beams and to be upgraded to higher frequency than 18 GHz. These demands implies also the simplification of all ancillary systems including an oven for metallic ion beams, which permits the production of new beam for hadrontherapy and for other applications. The source characteristics are described in Table 1.

The AISHa source is funded within the framework of the program of Sicilian Government named PO FESR 2007-2013 and a pool of Sicilian SME is associated with INFN for this project. The source is potentially interesting for any hadrontherapy center using heavy ions.

Table 1: AISHa Source Characteristics

Parameters	Dimension
Radial Field (max)	1.3 T
Axial Field (INJ/MID/EXTR)	2.6 T / 0.4 T / 1.7 T
Operating Frequency	18 GHz (TFH)
Operating Power	1.5 kW (1.5 kW)
Extraction Voltage (max)	40 kV
Chamber diameter / length	ø= 92 mm / 357 mm
Warm bore diameter / thickness	274.00 mm / 22 mm
Weight	600 Kg

MECHANICAL DESIGN

The plasma chamber will be stainless steel made and it is designed to operate at a maximum power rate of 2 kW by using a multi-channel water-cooling system. The insulation will be adapted to 40 kV operation by means of a 20 mm thick Glass Fiber/Carbon Fiber tube surrounding the hexapole, keeping superconducting magnets and yoke at ground potential. The movable extraction system will permit to adapt the AISHa source to other facilities (e.g. the high voltage platform for INFN-LNL).

A new type of DC-break has been designed to permit reliable operation up to 50 kV.

The layout of the source is shown in Fig. 1.

In the development of this new source some mechanical improvements have been introduced, in particular for the hexapole containment chamber and for the plasma chamber.

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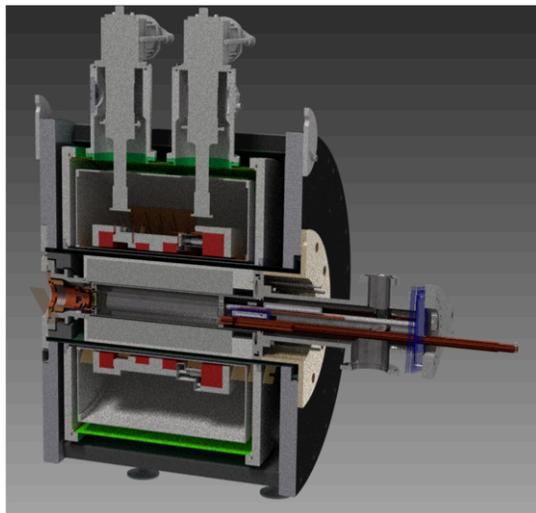


Figure 1: Layout of the AISHa source.

The optimization of these components has focused on two aspects: structural mechanics and fluid dynamics; both of these aspects have been optimized by using the COMSOL simulator.[1] A constant water flow in the plasma chamber is required to not exceed the safe temperature for the permanent magnet hexapole. Therefore, the goal of our study was to optimize the design of the grooves.

The results obtained in the case of aluminum 3003-H18 in terms of temperature are satisfactory, as we are able to keep the maximum temperature on the outer surface of the plasma chamber in the order of almost 30°C, thus avoiding any possible damage to the magnets in contact with it. The flow obtained is proved to be substantially laminar.

MAGNETIC SYSTEM DESIGN

The magnetic system provides a radial field on plasma chamber walls ($\phi=92\text{mm}$) up to 1.3 T by means of a permanent magnet Halbach-type hexapole, while the axial confinement will be given by a set of superconducting solenoids enclosed in a compact cryostat. The latter will include two cryocoolers that will permit to the equipment to run in He-free configuration.

Two different configuration have been evaluated to generate the mirror field, with 3 or 4 solenoids. The latter solution was chosen for its versatility, even if it increases slightly the construction costs. The two middle coils will allow to finely tune the mirror ratio that is deemed to improve the ECR heating process according to recent achievements [2].

The hexapole has been studied and designed with the OPERA 3D code in order to analyze and minimize the permanent magnet demagnetization due to the superconducting solenoidal field. Such calculations allowed to choose the permanent magnet materials and to define the final hexapole structure. The magnetic field values respond to the so-called ECRIS standard model for the operational frequency of 18 GHz [3]. The peak field at the injection side will be around 2.6 T and at the

extraction side it will be about 1.7 T, with a minimum value so low as 0.4 T, about 60% of the ECR resonance field. This design should maximize the plasma density with a moderate microwave power and with a set of magnets that do not present any criticality.

The ECR region may be sufficiently long to facilitate the production of multiply charged ions and is may extend up to 100 mm by changing the current in the two middle coils. The maximum current density in the four NbTi coils is 145, 121, 120 and 121 A/mm² respectively, with the second and third coil current running in opposite direction with respect to the injection and extraction coil. The maximum axial gradients is about 13 T/m, enough to run the plasma in “strong gradient regime” [1,2] even for moderate microwave power (500 W to 1 kW). The tunable magnetic profile allows to improve the heating efficiency, suppressing the production of quasi-collisionless high energy electrons.

The cryostat has quite compact dimensions, its total length being 620 mm and its diameter 550 mm.

The permanent magnet hexapole is made of NdFeB and it has a total length of 440 mm, slightly longer than the plasma chamber which length is 357 mm, roughly corresponding to the distance between the two maxima of the mirror field. A iron yoke with 50 mm thick end plates on both sides surrounds the magnetic system.

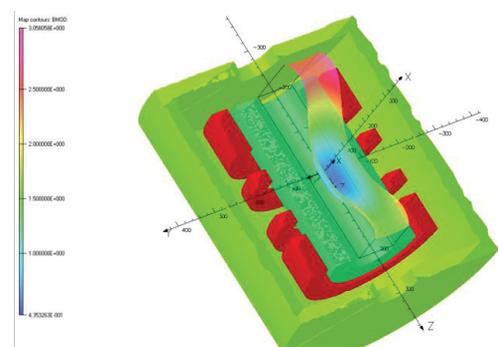


Figure 2: A 3D view of the entire magnetic system.

MICROWAVE INJECTION

The microwave injection system is the key element of the AISHa source design, according to recent studies [1,2].

The source will be equipped with two Klystron High Power Amplifiers (K-HPA) that inject separately microwave at different frequencies in the chamber, one at 18 GHz and other at a higher frequency. The new generation klystron amplifiers allow to finely tune the frequency up to 24 preset channels, through a Fast Digital Tuner System (DFTS), to exploit the mechanisms of Two Frequency Heating (TFH) and Frequency Tuning Effect.

The TFH has been largely used to generate moderate currents of the highest charge states, but it has never been extensively used to optimize the beam brightness. If both the frequencies would be separately tuneable, the electron energy distribution function could be optimized for the ionization of a definite charge state.

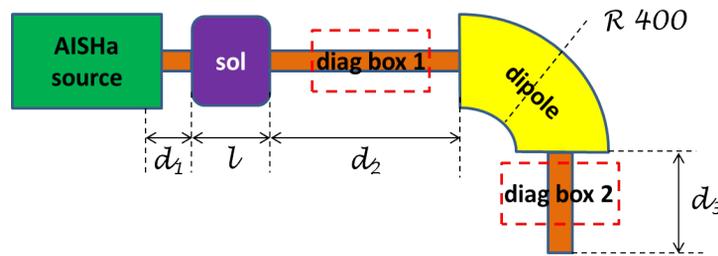


Figure 4: A schematic view of the adopted LEBT line for the AISHa source ($d_1 = 400$ mm, $d_2 = 1008$ mm, $d_3 = 1000$ mm, $l = 300$ mm).

The waveguide position was based on estimation of the maximum intensity of the modal electric fields excited in a vacuum filled cylindrical cavity, representing the plasma chamber.

Figure 3 shows the front side of the injection flange with the different input utilities among which the evaporation oven for metal ion beam production and the biased-disk mounted on axis inside the plasma chamber.

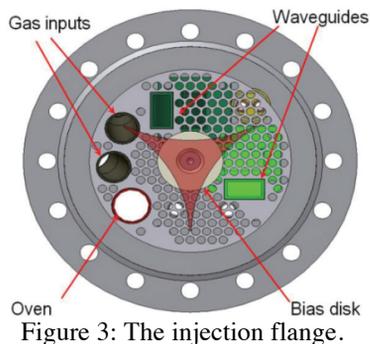


Figure 3: The injection flange.

LEBT LINE

Several different LEBT line configurations have been investigated. The simplest consists of a focusing solenoid, to be placed downstream the source, and a 90° degree bending dipole. A scheme of the adopted LEBT line is shown in Fig. 4.

The solenoid length is 300 mm, while the dipole bending radius is 400 mm. The distances at which the different magnetic elements have to be placed (d_1 and d_2 in Fig. 4) have been evaluated using the TRACEWIN simulation code. The simulations define the distances which minimize the beam losses and emittance growth. The calculations have been optimized for the transport of C, O and Ar ions with different charge states. Two diagnostic boxes will complete the transport line. Faraday cups will be used as current monitors, while beam wires and slits will provide information about the beam shape. A dedicated system, consisting of a CCD camera and a scintillating screen, will be used in order to investigate the source performances through the Frequency Tuning Effect.

CONCLUSION

AISHa source was designed in order to adapt a high performance ECR ion source to hospital facilities needing multiply charged ion production with high reliability and brightness, easy operations and maintenance.

The set of four superconducting coils independently energized will permit to realize a flexible magnetic trap that will allow to shift the position of the minimum B field within the ± 15 mm range.

The use of a broadband microwave generator able to provide signal with complex spectrum content, will permit to efficiently tune the frequency increasing the electron density and therefore the performance in terms of current and average charge state produced.

The chamber dimension and the injection system was designed in order to optimize the microwave coupling to the plasma chamber by taking into account the need of space to house the oven for metallic ion beam production.

Finally the extraction system is designed to take into account the production of high current medium and high charge states without major modification.

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