STATUS OF THE MULTIPURPOSE FULLY SUPERCONDUCTING ECR ION SOURCE *

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Abstract

The MSECRIS source has been designed with the aim to exceed the highest currents of highly charged heavy ions available up to now. It is based on a minimum B trap made of a hexapole and three solenoids. The design magnetic field is 2.7 T for the radial field produced by the hexapole at r=90 mm and 4.5 T for the mirror field, in order to permit operation not only at 28 GHz but also at higher frequency, thus increasing the plasma density and finally the beam current. Such high level of magnetic field is a challenge because of the forces arising on the superconducting coils; it largely exceeds the highest magnetic field available for existing ECRIS. The magnets are now able to operate in stand-alone mode up to 100% of the nominal field but when hexapole and solenoids are energized together they do not reach 50%. An improved containment system is under preparation at ACCEL company, in order to modify before the end of the year the magnetic system and to assembly the source in 2009. All the other components of the source are now ready and available at the EIS testbench of GSI, Darmstadt.

INTRODUCTION

Intense heavy ion beam production is a common requirement for many of the accelerators under construction in Europe and elsewhere. This requirement may be fulfilled by electron cyclotron resonance (ECR) ion sources based on a plasma trap with a B-minimum shape, according to the High B mode concept [1].

Electron density above 10^{13} cm^{-3} and very high current of multiply charged ions are expected with the use of 28 GHz microwave heating and the MS-ECRIS ion source has been designed following this guideline. The project is the result of the cooperation of nine European institutions with the partial funding of EU through the 6th Framework Programme. The contribution of different institutions has permitted to build in 2006-07 all accessory components.

The scheme of the MS-ECRIS source is shown in fig. 1. A relevant update of the drawings of the source and of its ancillary systems has been done during the construction phase with respect to the conceptual design of “GyroSERSE” source [2].

In particular, some new data concerning the microwave injection at high power rate, the X-ray management, the water cooling of the plasma chamber and the development of new oven technology has been relevant for the final design.

A complete description of the MS-ECRIS project is given in [3,4].

Table 1: The design features of MS-ECRIS.

Maximum field at injection mm	4.5 T
Minimum field mm	0.4 T
Maximum field at extraction	3.2 T
Hexapolar field on the plasma chamber wall	2.7 T
Cryostat length	1347 mm
Warm bore diameter	202 mm
Maximum hexapolar coil current	287 A
Maximum solenoids currents	105 A

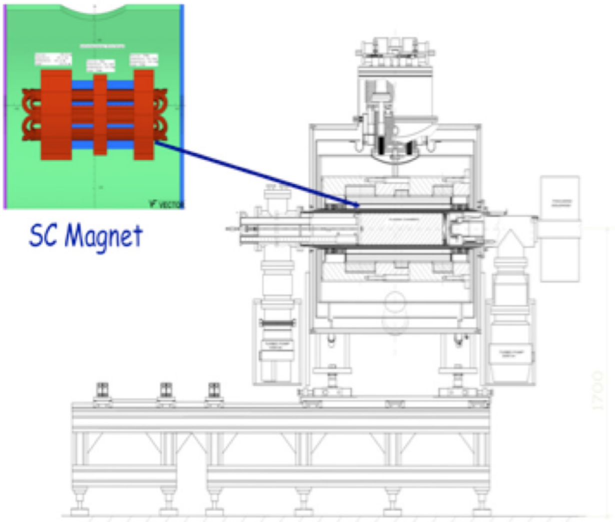

Figure 1: Scheme of the MS-ECRIS source.

The containment of forces and stresses over the coils is in fact one of the most difficult tasks of this project, mainly because of the superposition of axial and radial fields. For NbTi superconductors the requested level of field (tab.1) is close to the technological limits nowadays for minimum B traps. Such a high level of magnetic field is essential to reach the ideal confinement for 28 GHz and 37 GHz resonance, but its leaves also the possibility to run at higher frequency with a modest confinement. This condition is particularly interesting for the production of high intensity beams of moderate charge states, that is relevant for different facilities.

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MAGNETS AND GENERAL DESIGN

The sophisticated technology of cos3θ coils to generate the hexapolar field, surrounded by 3 coaxial solenoidal coils to generate the axial mirror field, was adopted for the MS-ECRIS magnet system (fig. 1). To cope with the high forces the collar technique was adapted to the design of the magnet system.

Prior to the first cold test of the coil system all possible operation modes of the coil structure were investigated and the forces and mechanical stresses have been analysed. It came out that safety issues suggested to add mechanical keys in order to guarantee a reliable operation of the magnet system. The functionality and performance of the coil system were verified during a first short cold test in May 2007, but not before December it was possible to proceed with the complete training.

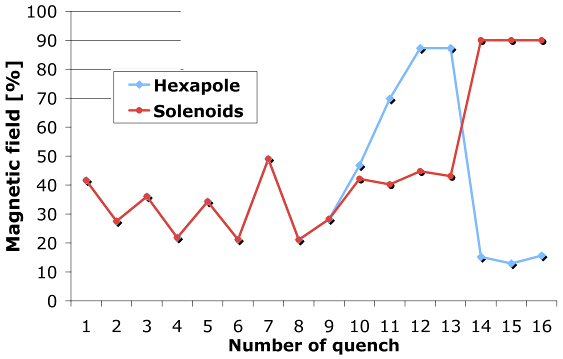

Figure 2 MS-ECRIS magnetic system quench history.

Figure 3: The MS-ECRIS plasma chamber.

The three solenoid coils reached specified performance without quench. The hexapole was also energized up to the nominal current in stand alone mode and it featured a correct value of uniformity. Anyway when the solenoids and the hexapole were energized together they showed a statistic quenching performance which may be explained by a non sufficient prestress of the hexapolar coils after the thermal cycles. Depending on powering the solenoids, the maximum performance of all coils simultaneously is between 40% and 50% (fig. 2).

The analysis of the measurement data showed no significant indication of a special hexapole coil to quench, therefore the magnets are now going to be dismounted to verify any possible modification due to thermal cycles.

Minor problems have also been detected for the LHe consumption that exceeds the estimates. The heat load of the cryostat was evaluated by the company to be about 1.0 W, including all the thermal losses but without the heating contribution coming from X-rays. The cooling capacity provided by two cryocoolers will be 3.0 W that may permit the LHe-free operation even in presence of a X-ray heating contribution of 1.7 W. A 10% cooling power was considered as an expected decrease of efficiency before the maintenance (0.3 W).

MECHANICAL DESIGN AND MICROWAVE EQUIPMENT

All the mechanical parts have been built during the past year. Some changes with respect to the original design described in [3] have been carried out, particularly to the plasma chamber and to the injection plug. The plasma chamber is the most delicate component of each ECRIS with superconducting magnets, as its design has to fulfill the requirements of RF power dissipation, of X-rays shielding and of electrical insulation with respect to the grounded wall of the cryostat warm bore. The plasma chamber is a cylindrical tube, 1162 mm long, made of AISI 316L stainless steel; its inner diameter is 180 mm and the inner wall thickness is 1.7 mm (fig. 3). A dig of 1.8 mm is made at the position of maximum X-rays emission to contain a 1.5 mm thick tantalum tube. Finally a 4 mm thick PEEK tube will be mounted between the plasma chamber and the warm bore, for the insulation up to 60 kV, that should permit to safely operate at 30 to 40 kV. The X-rays shield, tantalum-made, has been limited to 1.5 mm because of the mechanical constraints on the chamber external wall. Such thickness may permit to shield the most of X-rays up to 100 keV and a fraction of the more energetic ones. Some experimental observations and other considerations suggest that X-ray production may be limited by an optimized magnetic field and microwave injection, but additional studies are needed in this sense.

As for the water cooling, a value of 70 to 80 l/min was measured for a pressure of 4 bar, sufficient for the maximum microwave power (10 kW).

Even the injection plug was modified with respect to the design reported in [3] to optimize the position of the oven and of the microwave ports. In the design of the injection plug the priority was given to the position of the two waveguides (for 28 GHz and for 14 or 18 GHz), that was calculated to optimize the coupling of microwave power from the generator to the plasma chamber. A WR62 port and the 28 GHz circular port (1.284” diameter) were placed at about half the radius, at different azimuthal position; both positions are placed outside the area on the flange where the plasma is expected to hit (the so-called ECRIS star). The oven was originally placed in a central position but lower with respect to the beam axis, so that it would have been disturbed by the plasma impact. Now it has been moved to one side (39 mm) with an angle of 60°, to not be influenced by the changes of the plasma itself and to maintain the temperature stable even in presence of changes of gas and microwave input. The flange dimension has been kept as large as reasonably possible, and a DN40CF has been mounted, that is sufficient either for the induction oven and for the resistive oven.

For the gas input it was chosen to adopt 16 mm pipes that can be rapidly evacuated and may give an easy feedback of pressure from the injection side. An additional port DN16CF is available for plasma diagnostics to be used for optical diagnostics mainly, but in perspective may be used also for some RF diagnostics. The biased disk is placed at the center of the plug, i.e. on the source axis, with the possibility to move it along the axis about 20 mm. The disk diameter will be 30 mm, but different dimension, shape and materials will be tested.

The beam axis is placed at a height of 1700 mm. The vacuum chamber at the injection side contains all the services for the biased disk, for the oven and for microwaves and gas input. The injection and extraction vacuum chambers host a 1000 l/s and a 2000 l/s turbomolecular pump, respectively.

The extraction vacuum chamber will also host the first beam diagnostics box and the motion system of the extractor. The puller movement will cover 80 mm.

The microwave generator is based on the same 10 kW 28 GHz tube that was used for the experiments in [4] and even the microwave injection system will follow the same scheme, except for the position of the microwave port. A new power supply and control system for the generator have been built recently. Tests of the power supply were carried out up to 30 kV - 1.3 A, that is the power needed for the maximum microwave power. The system can be controlled either in local and through remote control by Ethernet. Safety issues limited the reflected power to 2%, but the tube in principle can withstand 10%. Rise and fall time of 10 ms with a maximum repetition rate of 25 Hz can be realized, then pulsed mode operations will be possible, but afterglow mode will not be accessible.

BEAM MANAGEMENT AND SOURCE COMMISSIONING

The ECR injector test setup (EIS) at GSI has been revised to host the MS-ECRIS source and now the testbench is ready for the assembly of the cryostat with the mechanical components. A 6 mm Pb shield is provided around the testbench to decrease the radiation level, that may be important especially during operation at high microwave power rates. Additional shielding will be provided after the source commissioning according to the safety regulations. All the needed infrastructure facilities (electric power, water cooling, computer network connections, etc.) are prepared for superconducting magnet power supplies, cryocoolers, gyrotron system and klystron generator. The preliminary version of control software is working and the quench detection system has been tested. The support and movable base plate for cryostat is ready, and cryogenic equipment as e.g. LHe transfer line are available for the first cooldown and possible training quenches.

The beam formation will be made by means of an extraction system consisting of the plasma electrode, fixed inside the plasma chamber and cooled by contact with the wall, and of the movable system made by a screen electrode system and a ground electrode that can be shifted together to optimize the ion extraction. The puller is water-cooled with demineralised water. The distance between the puller and the ground electrode is fixed to 5 mm.

The beamline consists of a solenoid located at 350 mm from the source, followed by a magnetic quadrupole lens and two 67.5° bending magnets for the analysis of the beam [4]. The maximum beam magnetic rigidity allowed by the beamline is 0.088 Tm, suitable for full characterization of any beam at a voltage of 40 kV or lower. A part of the beam diagnostics previously used will be still used for the experiments with MS-ECRIS, as the watercooled Faraday cups, but many changes have been made to the other devices to withstand the higher beam power.

Because of the large delay in getting the magnetic system, the tests of the source will begin only in the course of next year. The priority will be given to the study of intense beam production for highly charged heavy ions of interest for the laboratories involved in the collaborations. In particular for GSI it will be mandatory to get the highest currents as possible for beams with m/q ratio lower or equal to six, while for the INFN-LNS the priority will be given to very high charge states of the heaviest ions, namely above 40+. The first group of experiments should be done in CW mode, with gases. Oxygen and argon are chosen for the startup experiments, Xe with its more complicated spectrum will come later. For all these gases data exist for the EIS testbench with CAPRICE in cw mode and afterglow mode. Before switching to pulsed mode, metal ion beams will be optimized, e.g. by using the GSI standard oven and Zn or Cr for which well known parameters exist. Pulsed mode should also start with gas operation, here xenon is a preferable candidate, as data exist for CAPRICE and SERSE (at 28 GHz). Scaling laws measurements will be carried out, with particular regards to the diagnostics of X-rays which are affected by the electron energy inside the plasma.

REFERENCES

[1] S. Gammino et al., Rev. Sci. Instr. 72 (11), 4090.
[2] G. Ciavola et al., "A new superconducting ECR ion source for the future accelerator facilities", EPAC 2002, Paris, THPRI008.
[3] G. Ciavola et al., Status report of the MS-ECRIS construction, High Energy Physics and Nuclear Physics, Vol. 31, Supp. I, Jul. 2007, 13.
[4] G. Ciavola et al., Rev. Sci. Instr. 79, 02A326 (2008)