INNOVATIVE DESIGN PRINCIPLES OF SUSI – SUPERCONDUCTING SOURCE FOR IONS AT NSCL/MSU

P. A. Zavodszky, B. Arend, D. Cole, J. DeKamp, G. Machicoane, F. Marti, P. Miller, J. Moskalik, J. Ottarson, J. Vincent and A. Zeller, NSCL/MSU, East Lansing, MI 48824, USA

Abstract

An ECR ion source is being designed to replace the existing 6.4 GHz SC-ECRIS. This ECRIS will operate at 18+14.5 GHz microwave frequencies. The radial magnetic field will be produced by a superconducting hexapole coil, capable of 1.5 T at the aluminum plasma chamber wall (R=50 mm). The axial trapping will be produced with six superconducting solenoids enclosed in an iron yoke. We will present the Flexible Axial Magnetic Field Concept, introduced for the first time in this design, which will allow tuning the distance between the plasma electrode and resonant zone in the plasma. The injection hardware and bias disc will be separately movable allowing great flexibility of tuning the ion source.

INTRODUCTION

The National Superconducting Cyclotron Laboratory at Michigan State University operates two cyclotrons in coupled mode in order to produce radioactive ion beams by projectile fragmentation [1]. The primary beam energy is up to 200 MeV/u, and since October 2000 many different primary beams were accelerated between ^{16}O and ^{209}Bi [2]. The primary ions are produced by two ECR ion sources, one superconducting (SC-ECR) built in the early 90's [3], and the other (ARTEMIS) with room temperature magnets [4] built from a design based on the AECR-U at LBNL [5].

During the commissioning of the coupled cyclotrons, it became evident that the emittance of these ion sources poorly matches the acceptance (about 75 π mm mrad) of the cyclotrons. Besides a planned upgrade of the existing ECR ion sources extraction systems and further studies to improve the transport efficiency of the injection beamline, the other approach is to build an ECR ion source, which is more flexible than the existing ones in order to better match the emittance of the source with the acceptance of the accelerators.

After studying several technical options, we decided that we would design and build in NSCL an ECR ion source capable of operating at 18+14.5 GHz, using fully superconducting magnets.

DESIGN OF THE MAGNETIC TRAP

According to the currently accepted semi-empirical design criteria [6], an ECR ion source optimized to use 18 GHz microwave frequency for plasma heating should have a magnetic confinement characterized by the following field values: an axial magnetic trap with $B_{inj} \approx$ 2.6 T at the injection side, $B_{ext} \approx 1.3$ T at the extraction side, with a minimum magnetic field $B_{min} \approx 0.5$ T. The radial confinement magnetic field value at the plasma chamber walls should be $B_{rad} \approx 1.4$ T.

In order to reach these magnetic field values and a plasma chamber of 100 mm diameter, it is difficult to use room temperature solenoids and permanent magnet hexapole. It is more convenient to construct a fully superconducting magnet system. This has the advantage of a tunable radial magnetic field, lower electric power consumption for the axial solenoids and no risk of demagnetization of the permanent magnets used in a room temperature hexapole system for the radial confinement. With a superconducting solenoid magnet there is no need for an iron plug in the injection side, leaving more room for different devices necessary to produce metallic beams, for multiple waveguides, bias disk and good vacuum pumping.

Considering the existing 2 kW LHe plant at NSCL, it is not necessary to use cryocoolers and high-Tc superconductor current leads to minimize the LHe consumption, simplifying the design and lowering the initial capital investment.

THE FLEXIBLE MAGNETIC FIELD CONCEPT

The RIKEN group reported [7] that the extracted beam intensity for a specific ion type depends on the position of the plasma electrode relative to the plasma. In the design of SuSI, we adopted a different approach to change the position of the plasma electrode relative to the resonant zone in the plasma. We will keep the plasma electrode fixed and we will move the axial magnetic field. This can be accomplished with two solenoids at each end of the ion source, INJ_1 and INJ_2 at the injection end, EXT_1 and EXT_2 at the extraction end as shown in Figure 1. In order to have the magnetic field minimum easily adjustable, there will be a third pair of solenoids between the injection and extraction ends, running electric currents in the opposite direction: MID_1 and MID_2. Each combination of INJ_i, MID_j and EXT_k (i, j, k =1, 2) is capable of producing the required magnetic field profile for optimum operation at 18 GHz. We call this approach the Flexible Magnetic Field Concept and it is described in detail elsewhere [8].

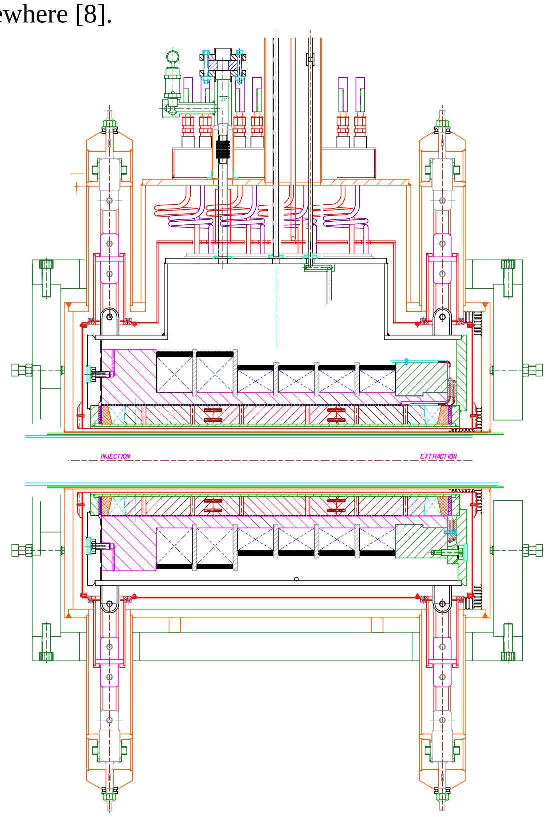

Figure 1. Schematic drawing of the SuSI magnet system.

The advantage of the above solenoid configuration relies in a great flexibility of shaping the axial magnetic field profile. Besides the three cases, a multitude of other situations can be easily obtained by tuning the current values in the solenoids. It is possible, for example to produce a flat-field magnetic configuration necessary for the volume-type ECR ion source [9]. The distance between the magnetic field maxima will be variable in the range of 340 to 460 mm; the whole axial magnetic field profile can be shifted with fixed distance between the two magnetic maxima, equivalent with a plasma electrode movement of about 50 mm.

CONVENTIONAL COMPONENTS

Another important finding of the RIKEN group is the dependence of the ECR ion source output on the bias disc position [10]. It is believed that the length of the plasma chamber is changed by moving the bias disc and by this the coupling between the microwave and the plasma is tuned for better matching.

Figure 2 shows the design of the injection hardware. This hardware will accommodate two rectangular waveguides, two gas inlet lines, a bias disc with electrical feedthrough and a high temperature inductively heated oven (not shown on Figure 2). The whole injection hardware will be movable without breaking the vacuum, with a stepper motor driven bellows-based mechanism, providing possibility to tune the plasma chamber length. The bias disc will be movable also, relative to the traveling flange of the injection hardware, providing maximum flexibility to tune its position relative to the plasma chamber end wall and the axial magnetic field maximum on the injection side. Pumping will be provided on the injection side by a 550 l/s turbomolecular pump. The high voltage DC break in the microwave waveguide will be a specially designed multi-stage unit with a voltage divider and without a dielectric inside the waveguide to prevent microwave absorption, which caused in the past several failures at high microwave power levels and voltages exceeding 25 kV. The gas inlet valves will be stepper motor driven precision needle valves, with stabilized temperature in order to assure a constant gas flow.

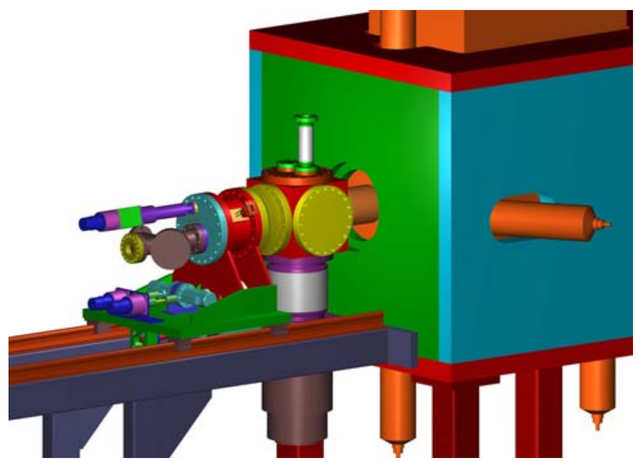

Figure 2. Injection hardware of SuSI.

Because the interest in the production of intense medium charge state ions for the Coupled Cyclotron Facility operation at NSCL, SuSI is designed with a smaller plasma chamber than the other above mentioned superconducting ECR ion sources. The plasma chamber will have a 100 mm diameter, with a 5 mm wall thickness; the material will be aluminum, in order to provide good secondary electron yields. The plasma chamber will have two parts and it will be water-cooled by three independent helicoidal passages machined on the wall of the inner cylinder. The cooling will be capable to remove a total of 4 kW heat injected by the 18 and 14.5 GHz microwave generators.

The electrical isolation between the warm bore of the cryostat (120 mm inner diameter) and the plasma chamber (110 mm outer diameter) will be provided by a plastic tube made of PEEK. This material was specially developed for the nuclear industry to resist in high gamma and X-ray radiation. In order to prevent possible high voltage breakdowns in small air gaps between the plastic and metal, the inner and outer walls of the insulator tube will be metalized. These metal surfaces will be in ohmic contact with the metal parts at different potentials.

For ion extraction we will use an accel-decel electrode system. In order to mach the plasma meniscus with the extraction electrode system at a fixed extraction voltage, it is important to have an adjustable puller electrode. The moving mechanism will allow adjusting the extraction gap, without breaking the vacuum. The maximum injection energy in the K500 cyclotron is 30 kV*q, where q is the charge state of the ion. In order to decrease the effect of the space charge in the emittance growth, presently we are studying the possibility to bias the beamline from SuSI at –30 kV and decelerate the ion back to 30 kV*q after the analyzing magnet, when the unwanted charge states are removed so the effect of the space charge is less important.

An extraction box will host two 550 l/s turbomolecular pumps and the remote drive mechanism for the puller electrode. The box will be slim, in order to decrease the distance between the extraction electrode system and the first focusing element. At this moment we plan to use a superconducting Glaser lens as focusing element, but recent studies in our laboratory [12] show a better transport efficiency and beam quality with an electrostatic quadrupole triplet used in the K500 cyclotron injection beamline in conjunction of the existing SC-ECR. The beam will be analyzed with a 90°, double focusing bending magnet, similar to the magnet built at LBNL for VENUS [13]. This magnet will have a large gap and corrections for aberrations caused by the multipole terms in order to transport large ion beams with good efficiency. Steering magnets, biased Faraday cups, scintillator beam viewers and two Allison-type emittance scanners will complete the beamline associated with SuSI. The floating beamline will be electrically isolated from the magnets and beam diagnostics.

Present Status and Timeline

The first small solenoid winding was completed at NSCL on September 17, 2004. We also did a test winding of a hexapole coil to experiment the technique to be used to wind the real hexapole coils. The coil winding is expected to be finished by the end of March 2005. The design of the cryostat will be completed by the end of 2004. Successful tests were already made with the indium alloy inflatable bladders, this technology being new at NSCL. The design of the plasma chamber, injection box with hardware and the extraction box with a three-element accel-decel extraction electrode system will be presented in [11]. The first plasma is expected in early 2006. After extensive tests and optimization studies, SuSI will replace the SC-ECR.

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