FIRST COMMISSIONING RESULTS OF THE SUSI ECRIS*

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Abstract

A fully superconducting ECR ion source (ECRIS), SuSI (Superconducting Source for Ions) was constructed at the National Superconducting Cyclotron Laboratory at Michigan State University (NSCL/MSU) to replace the existing SC-ECRIS. This ECRIS operates at 18+14.5 GHz microwave frequencies. During the initial commissioning of the magnet, the axial field reached 3.6 T and 2.2 T at the injection and extraction, respectively. The radial field reached 2 T at the plasma chamber walls. These magnetic field values will be needed for a planned upgrade to 24-28 GHz in the second phase of commissioning. The first commissioning results of this new ECRIS are presented.

INTRODUCTION

The NSCL/MSU 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 between ^{16}O and ^{238}U were accelerated. The primary ions are produced by two ECR ion sources, one superconducting (SC-ECR) built [2] in the early 90's, and the other (ARTEMIS) with room temperature magnets built in 1999 [3]. In order to increase the primary beam power for heavy ions we decided to replace our SC-ECR with a new ECRIS and associated beamline elements capable of handling total extracted currents up to 10-15 mA. After studying several technical options, we decided that we would design and build SuSI capable of operating at 18+14.5 GHz, using fully superconducting magnets. A fully superconducting magnet system 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. In addition, 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, multiple waveguides, bias disk and good vacuum pumping.

DESIGN GOALS

In order to operate efficiently an ECRIS at a given microwave frequency, the magnetic confinement should have the following field values [4]: an axial magnetic trap with $B_{inj} \approx 4\ B_{ECR}$ at the injection side, $B_{ext} \approx 2\ B_{ECR}$ at the extraction side, with a minimum magnetic field $B_{min} \approx 0.8\ B_{ECR}$. The radial confinement magnetic field value at the plasma chamber walls should be $B_{rad} \approx 2B_{ECR}$. The extraction magnetic field is also correlated to the radial field through the relationship: $B_{ext} \approx 0.9\ B_{rad}$. The resonant magnetic field for 18 GHz operations is B_{ECR} = 0.64 Tesla.

The limited acceptance (75 π mm mrad) of the K500 cyclotron prompted us to adopt solutions, which will allow us to flexibly tune different ion source parameters, to optimize the emittance of the ion beam. The Flexible Magnetic Field Concept and the movable injection and extraction systems were described in two of our previous publications [5-6]. A cross-sectional view of SuSI is shown in Fig. 1.

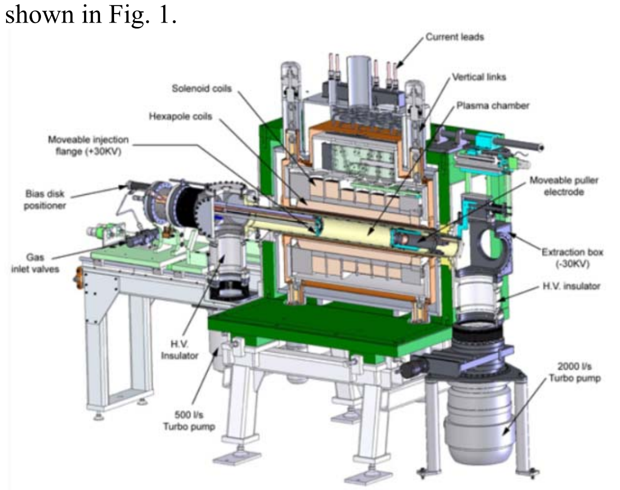

Figure 1: A cross-sectional view of SuSI.

MAGNET FABRICATION

Coil winding

All of the superconducting coils, both solenoids and hexapoles, were wound from 1 mm x 2 mm NbTi rectangular wire with a copper to superconductor ratio of 1.7. The two large solenoids contain 2630 turns each, the four small solenoids 1630 turns each and the hexapole coils contain 581 turns each. The detailed winding process was described in [7].

Magnet assembly

The procedure used to build the magnet system was similar to the Versatile ECR for Nuclear Science (VENUS) ECRIS built for LBNL [8], except for the solenoid bobbin and hexapole radial constraint cylinder being one piece. The other critical difference is that the hexapole coils are not banded to the hexapole bobbin the full length, leaving the first and last 15% of the total length not constrained properly. The hexapole assembly was not vacuum-impregnated with epoxy in the solenoid bore after the bladder inflation, as it was done in the case

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of VENUS construction. The banded hexapole assembly before insertion in the solenoid bobbin is shown in Fig. 2.

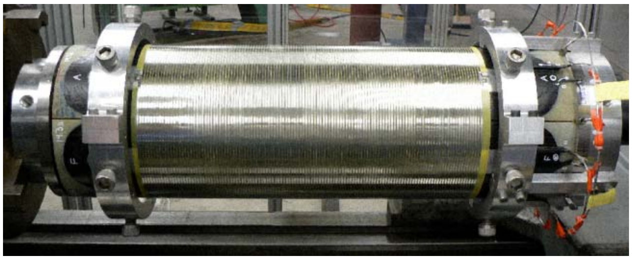

Figure 2: The hexapole coil assembly during the banding process. Coil leads and bladder inflation tubes are at the right end of the assembly.

MAGNET TESTING

Two small solenoids and one large solenoid were tested individually, before the magnet assembly, beyond their 400 A operational design current with no training. The small solenoids were taken to 445 A, and the large solenoid was taken to 485 A without quenching.

Because coil forces are significantly different when the whole hexapole is assembled, only coil quality and information on current at peak field in the coil could be obtained from single hexapole coil tests. The operating current for the coils at 18 GHz is 400 A. The first coil tested was trained to 663 A corresponding to a calculated peak field in the coil of 6.3 T where testing was stopped. The remaining tests were stopped at 700–720 A. The last coil tested was taken to 770 A where training reached a plateau.

The fully assembled coil system was tested vertically suspended from the lid of the test Dewar. After a series of training quenches described in detail in [8], the magnet reached 3.6 T and 2.2 T on the axis and 2 T radially at the plasma chamber radius (50.8 mm). These field values are enough to run the magnet optimally at the strength needed for 24-28 GHz operations.

Lessons Learned During Magnet Testing

Although the solenoids and the hexapole coils could be trained up to field strengths higher than the originally designed values needed for 18 GHz operations, when we tried to ramp up the hexapole in the field of the solenoids, we could not pass some relatively low current values, e.g., when the solenoids were producing the axial field needed for 18 GHz operation, the hexapole coils always quenched around 75-80 A, although the needed value was ~400 A. Because ramping up the solenoids and hexapole together could be accomplished, it was decided to proceed with the magnet assembly.

After the cryostat assembly was completed, the magnet testing was continued. With some re-training, the magnet was able to reach the designed current values needed for 18 GHz and 24 GHz operations. To our big surprise, this steady state operation was proven to be unstable in time. The magnet quenched after some unpredictable interval while running in steady state mode.

Several tests excluded the power supplies, too low current lead flow or heat leaks as possible causes of these quenches. Large electromagnetic perturbations (high voltage sparks produced near the coils and power supplies) did not trigger quenches. When only the solenoids or the hexapole coils were energized they could stay on without quench for days. After such tests, when the full system was energized, we always experienced a few re-training quenches. With half of the solenoids energized with opposite polarity, we could cancel the axial force on the hexapole coils and still experience the same quench behavior. This test excluded the sudden horizontal movement of the hexapole coils inside the solenoid bobbin as a source of heat generation and quench production.

With a multi-channel fast data recorder (model Astro-Med DX18 [9]) we were able to determine the sequence of the quenches. The hexapole coils always quenched first, followed either by the injection side solenoid or the middle solenoid and the extraction side solenoid quenched last. This scenario indirectly excluded a hexapole coil lead movement as a source of the quench, because the hexapole coil leads are located on the extraction side of the coil assembly. A quench sequence is shown on Fig. 3.

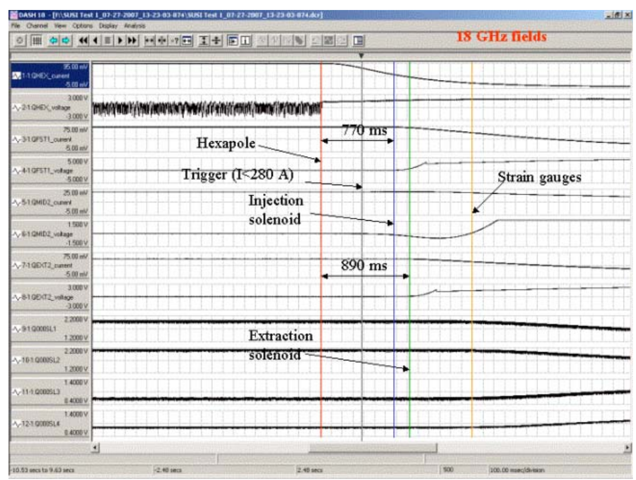

Figure 3: Astro-Med DX18 fast data recorder output. There were monitored the following parameters: the hexapole (QHEX) current and voltage, the injection side solenoid (QFST) current and voltage, one of the middle solenoid (QMID2) current and voltage, the extraction side solenoid (QEXT2) current and voltage and the horizontal strain gauges (Q000SL1-4), measuring the stress in the horizontal links of the cold mass.

The data was captured 1 minute before and after the trigger event (hexapole current drops under 280 A). The strain gauges measuring the stress in the horizontal links between the cold mass and the vacuum vessel of the cryostat begun to change values always after all the coils quenched, excluding the possibility that the quench is triggered by a sudden movement of the whole cold mass.

As the tests proceeded, we observed that the length of time between reaching the desired field strength and the quench gradually increased, resembling to a second type of training, not experienced with any of the several hundreds of superconductor coils built in our laboratory. We ultimately reached the status, when the full magnet was on, without quenching at 18 GHz optimized fields for longer than 7 days. This second type of training is still not fully understood and requires further investigation. The most likely cause of the unpredictable quenching behavior is the improper restrain of the hexapole coil ends inside the solenoid bobbin. We are considering different options to improve the coil system, but fortunately, the ion source development could proceed with the present level of coil training.

FIRST CHARGE STATE DISTRIBUTIONS

After the usual outgassing, characteristic to any newly commissioned ECRIS, the SuSI development proceeded with Argon gas. At the time of the conference, the highest extraction voltage applied is 27 kV; the highest microwave power level injected in the ion source is 1.3 kW (18 GHz) with 300 W (14.5 GHz).

When the tuning was optimized for Ar^{8+}, the highest analyzed beam current in this charge state measured in a Faraday cup equipped with secondary electron suppressor (biased to –200 V) was 1.0 mA. When the tune was optimized for Ar^{11+}, the analyzed current in this charge state was 0.58 mA and 0.37 mA in charge state 12+. Optimizing the tune for Ar^{14+}, the analyzed intensity was 0.1 mA in this charge state.

A preliminary $^{129}Xe^{q+}$ charge state distribution obtained after few hours of tuning is shown in Fig. 4. This tune was optimized for charge state 20+ and resulted an analyzed ion current of 0.325 mA. Typical transmission, calculated from the sum of the analyzed current values divided with the drain current of the high voltage power supply, was 85-90%. The highest total current extracted so far was around 8 mA.

FUTURE PLANS

The next tests will involve the production of heavier ions (Kr^{q+} and Xe^{q+}) as well as biasing the beamline between the ion source and the decelerating section after the 90° -analyzing magnets to a negative high voltage [10]. This will increase the velocity of the extracted ion beam, improving the emittance of the beam, by decreasing the negative effect of the space charge. With higher ion beam velocity, it will be possible to remove the focusing solenoid between SuSI and the analyzing magnet, shortening the distance where all the unwanted charge state ions are traveling with the desired charge state ion.

After the completion of the beamline downstream of the 90°-analyzing magnet, systematic studies are planned to optimize the brightness of the analyzed beam in function of different ion source parameters. The transverse emittance will be measured with a pair of Allison emittance scanners. Testing of metallic ion production hardware will be also an important area of development.

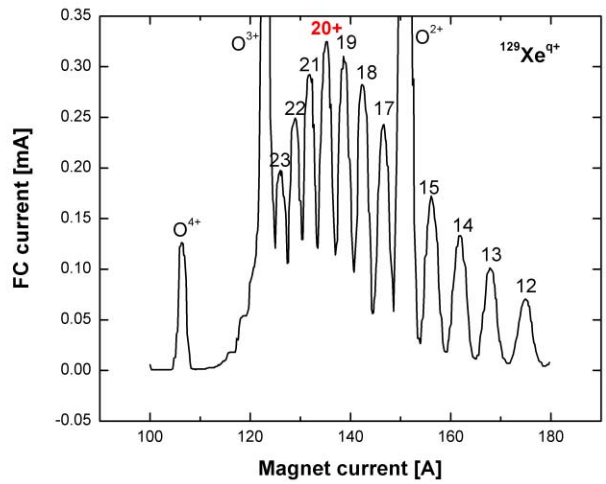

Figure 4: $^{129}Xe^{q+}$ charge state distribution measured in a Faraday cup (FC). The tune was optimized for Xe^{20+}. O_2 was used as a mixing gas. The extraction voltage was 27 kV; the applied microwave power was 780 W 18 GHz and 310 W 14.5 GHz. The bias disc voltage was –100 V, the diameter of the aperture in front of the FC was 25 mm.

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