Recent improvements of the SERSE project

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Abstract

A high performance superconducting electron cyclotron resonance (ECR) ion source working at 14.5 GHz is under construction. The source is devoted to the production of highly charged heavy ions to be injected into the K-800 superconducting cyclotron at Laboratorio Nazionale del Sud in Catania. With respect to the first design the source magnetic system has been recently upgraded, permitting to achieve mirror fields in the order of 2.7 Tesla and hexapole fields up to 1.4 Tesla, to allow the source to operate with higher electron density than in the conventional ECR sources, whose fields are remarkably lower. The high magnetic field will also make possible to upgrade the operating frequency in the gyrotrons domain (28-35 GHz). The source is expected to be operational in August 1995 and by the summer 1996 it will be coupled to the cyclotron. The characteristics of the source, the expected performances and the main features of the installation at LNS will be described.

1. INTRODUCTION

The choice of a superconducting ECR ion source for the axial injection of the K-800 superconducting cyclotron now under completion at Laboratorio Nazionale del Sud [1] was carried out because of the high charge states ion beams which in line of principle can be delivered by this kind of source. The availability at LNS of a LHe liquefier which is used to feed the superconducting cyclotron and is able to provide the LHe for other equipment also pushed in this direction.

The project of the superconducting source SERSE has been carried out at LNS [2] and now the source is under construction at ANSALDO GIE and at CEA/DRFMC [3].

The design of the B minimum trap of SERSE was based on the statement that the performance of the ECR sources improve with the increase of the confining field. The high field produced by the superconducting magnets will make possible to operate routinely the ECR source with a 14.5 GHz generator or with a 28-35 GHz gyrotron, when CW gyrotrons will be available.

The idea that increasing the field the ECR source works better found its formulation in the so-called "High B mode" concept [2,3] which provided the main ideas for the design of high confinement ECR ion sources.

This concept has been partially proved by a series of experiments performed at Michigan State University (MSU) on the SC-ECR ion source working at 6.4 GHz [4,5]. The proof on a higher frequency domain may be obtained in next future with the source SERSE.

The increase of the performance with the increase of the field obtained by SC-ECRIS, especially for the axial confining field on the injection side, seems to prove the statement that "the higher the field, the better the performance".

2. THE "HIGH B MODE" CONCEPT

A well known rule of plasma physics says that higher is the "mirror ratio" of a magnetic trap, smaller is the loss cone and the number of lost particles from a confined plasma.

In an ECR source the confining trap is given by the superposition of the mirror field and the hexapolar field, then we will have different loss cones from the plasma in the different directions, depending on the "mirror ratio" B_{max}/B_{min}. The value of the ratio B_{max}/B_{ECR} is also important for the ECR heating process. Since $B_{ECR}>B_{min}$ sometimes the mirror ratio is approximated by the ratio B_{max}/B_{ECR} (it is useful because B_{min} changes with the magnets current, where B_{ECR} is fixed by the rf frequency). The value of B_{ECR} defines the length L_{plasma} of the plasma volume.

The most performant ECRIS are the ones which have both radial and axial mirror ratios high, but in order to have a significant amount of extracted current, the field on the extraction side is usually smaller than the field on the injection side, whereas for the radial direction the rule of thumb is that the field should be as high as possible.

This comes from the "High B mode" concept which states that the increase of the magnetic field affects not only the mean electron temperature and the ion confinement time, but also the electron density, according to the formula:

$$n_e \, k \, T_e << B^2/2\mu_0 \qquad (1).$$

It may be concluded that the magnetic field increase is very beneficial for the ionization of the highest charge states. Another consequence of this concept is that the increase of frequency is not useful if the magnetic field is not sufficient to support the higher cutoff electron density.

The original design of SERSE [2,3] was based on the assumption that the maximum axial field should be of the same order of the radial confining field. Then the radial field was pushed up to the maximum level achievable with the present technology for the required size of the plasma chamber (length=480 mm., diameter=130 mm.), well above the level of other existing sources, and the field maxima of the axial profile were kept close to that level.

The results of the experiments performed on the SC-ECRIS at MSU showed that the chosen topology was not the best one, leading to modify the SERSE magnetic system with respect to the original design [6]. Different loss cones from the ECR plasma for different directions may be envisaged. This new concept, based on the experimental evidence, links the source performance to the capability to vary widely the magnetic field. The magnetic topology of the original SERSE design works in the correct range, but the absolute level of the two axial field maxima must be raised.

The best solution for the optimization of the source towards the high charge states production is then the increase of the magnetic field maxima, mainly on the injection side.

3. THE NEW MAGNETIC SYSTEM

The magnetic field topology of SERSE was originally defined by the capability to reach at least 1.4 T on the plasma chamber wall, with a maximum for the mirror in the order of 2.2 T for the axial field, to be reached when working at 30 GHz; for the frequency of 14.5 GHz the axial field maximum was reqested to be in the same order of the radial field (1.35 T). This is achieved by an hexapole surronding the plasma chamber and a system of three solenoid, with the central solenoid fed with reverse current.

The criterion used to maintain safe and reliable operation of the magnets was to operate each coil at current values well below the critical value. All coils were designed with a temperature safety margin not lower than 1°K in the worst case, i.e. in the windings position where the magnetic field is the highest [6].

The sketch of the whole source was carried out, taking into account the requirement of an easy dismounting and handling of some components like extraction system or plasma chamber and the constraints coming from the magnetic system and from the cryostat.

After the results obtained by SC-ECRIS at MSU the upgrading of the magnetic system was studied to get the same magnetic field profile realized on the MSU device but scaled with the ratio f_{SERSE}/f_{MSU}.

In fig. 1 the best field profile is compared with the old one for 14.5 GHz.

The role of the second coil, which works with reverse field, in the achievement of the best "High B mode" configuration, is fundamental and it is the main difference with respect to the old configuration.

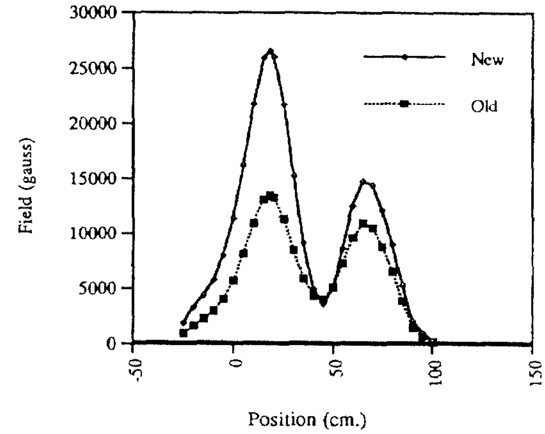

Fig. 1 - Field profiles for the old and new design

Fig. 1 shows that the magnet system should get a mirror ratio higher than 5 on the injection side and higher than 3 on the extraction side, maintaining the ECR surface position more or less unchanged when changing the solenoids current and finally the mirror ratios. An artistic view of the magnet system is shown in fig. 2.

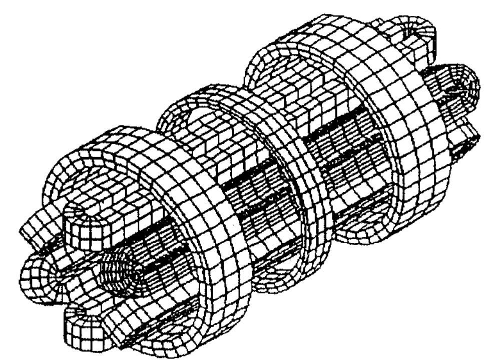

Fig.2 - Tridimensional view of the magnet system

With respect to the old design, the major enhancement performed on the magnetic system has been carried out on the central coil, which was increased from few thousands Ampertums to 210000 Ampertums, whereas the other coils have been slightly changed and hexapole has not been changed because already fulfils our requirements and however it represents the maximum field allowed by this source geometry with a reasonable safety.

The new configuration has the big advantage of keeping the same number of solenoids as the old one, modifying their position only slightly. The operating currents of all three solenoids have not been largely modified and however remain below 120 A.

The temperature safety margin for the superconducting wires is 1°K in the worst case, which is in agreement with the adopted safety criterion, but the external discharge across the biggest solenoid reaches a value of 600 V, thereby nearly doubling the value of the initial design. This value comes closer to the limiting dielectric strength of the cryostat current leads which is about 800 V, but it is within the specifications. The maximum total force acting on the coil system will be about 29 KN.

The maximum ramp rate will be 0.13 A/s, which means a total charge time not lower than 15 minutes.

In conclusion, there is no need to change the specifications of magnet power supplies and cryostat current leads with respect to the old design. The choice of a new configuration, as for calculation and larger winding time, have postponed the time schedule by about half year with respect to the old design.

3.1. The expected performance

The small volume high maxima configuration shown in fig.2 should give the best charge state distribution because of the high magnetic pressure which can be reached (mirror ratios higher than 2.8 in any direction).

Otherwise a low total current should result because of the small plasma volume (which is roughly proportional to the length of the plasma volume, L_{plasma}=71 mm.). The highest charge states transport would take benefit of this fact, taking rid of the most of the space charge effects, at least at the extraction and in the preanalysis section. The extraction of low current high charge states ion beams is a convenient operating condition for the injection of slow heavy ions into the cyclotron.

By scaling the results obtained at MSU-NSCL [4,5], SERSE 14.5 GHz should be able to get $n_e\tau_i$ of about 10^{10} cm^{-3}sec. and T_e in the order of 4-5 KeV and finally to produce 1 eμA of Si^{14+}, Ar^{17+}, Kr^{29+}, Xe^{40+}, etc.

In fig. 3 the energies obtainable after the acceleration in the K-800 superconducting cyclotron [1] are compared with the ones obtainable by using the 15 MV Tandem as injector or a standard room temperature ECR source.

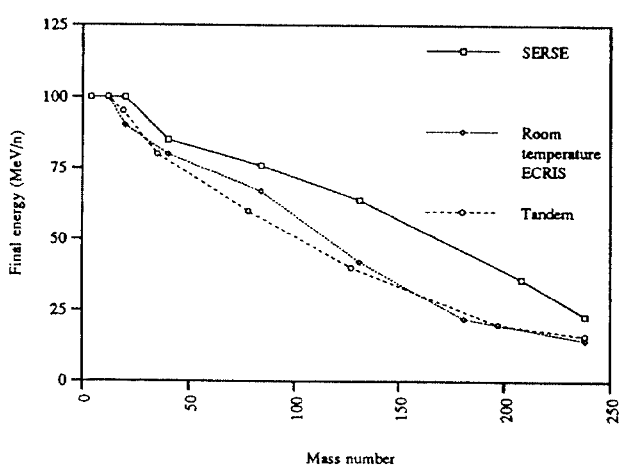

Fig.3 - Cyclotron energy for different injectors.

Other configurations may be also obtained with this magnetic system. Lower mirror ratios but larger plasma volumes are obtainable and medium charge states high intensity beams may be produced. The ECR zone may be extended over a length of 200 mm. with mirror ratios of 3.3 for the injection side and 1.9 for the extraction side. The lower magnetic pressure should limit the buildup of high charge states, but the increase of extracted beam currents should be provided by the increase of plasma volume as recently discussed [7] and demonstrated.

The tests to be carried out with the different axial and radial field which can be obtained by SERSE in a continuous way may give relevant results not only in terms of high charge states and currents, but also in terms of knowledge of the phenomena which arise during the ECR ionization process. Particular emphasis will be devoted to the use of biased disk and wall coating to build up the electron density in the trap.

3.2. The status of the project

The cryostat and the magnetic system are under construction. The main mechanical part are designed and the construction will begin next summer. The vacuum system components, the power supplies and the microwave generators have been ordered. The plans for the installation at LNS are almost defined. The LN_2 and LHe dewar for continuous supply of the cryostat have been yet purchased.

The analysis line has already been ordered and will be mounted on the test bench in Grenoble next winter.

4. CONCLUSION

The extrapolation from recent experimental results have suggested to carry out an enhancement of the SERSE magnetic trap.

The feasibility study has shown that a reasonable compromise can be reached between the improvement of the axial mirrors and the requirement of a safely operating magnet system.

The source will be mounted and tested at CEA/DRFMC, Grenoble on summer 1995 and the delivery of the source to LNS is now scheduled for June 1996.

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