FREQUENCY UPGRADING OF THE SUPERCONDUCTING ECR ION SOURCE SERSE

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Abstract

The installation of the superconducting ECR ion source SERSE at LNS and its commissioning have been successfully accomplished during last year. The problems related to LHe supply and high voltage insulation have been solved and the source is now fully operational with currents that are equal or greater than any other already operating ECR ion source.
Recently the upgrading to higher field and frequency (from 14.5 GHz to 18 GHz) has been carried out, in order to increase further the plasma density and then the beam currents. The preliminary results of the study of magnetic field scaling are reported, along with the experimental evidence of the "two frequency heating" (14.5 and 18 GHz), according to the experience of LBNL source.
The source is going to be coupled to the K-800 Superconducting Cyclotron and it will allow a significant increase of the intensity (one to two order of magnitude) and of the energy of the extracted beams, with respect to the injection of beams from 15 MV Tandem, used up to now.

1 INTRODUCTION

The design of the superconducting Electron Cyclotron Resonance (ECR) ion source SERSE is described in previous papers [1,2,3]. Tab. 1 describes its main features.
SERSE was designed on the basis of the concept of High B mode [1,4] that relates the performance of the ECR ion sources to the frequency and to the strength of the magnetic confining trap, with a scheme, which is complementary to the Geller's scaling laws [5].
The source construction has begun in fall 1993 and in 1995 all the components were operational, except the hexapole, which was able to attain only 70% of the nominal field, a value which did not meet our request to operate the source in High B mode (i.e. with a magnetic field exceeding the value of $2 \cdot B_{ECR}$, where B_{ECR} is the resonance magnetic field, corresponding to 0.52 T for the frequency of 14.5 GHz and 0.64 T for the frequency of 18 GHz).
Therefore we could not accept the magnets and we ordered a new set of superconducting magnets, which resulted in a delay of almost two years for the whole project. Finally in spring 1997 the magnets were ready and operating above the specification [2] and in summer 1997 the first beams of highly charged ions were obtained, with already excellent performance [3]. The tests on the bench site of Grenoble were completed in March 1998 and the source was moved to LNS, where it was operated at 14.5 GHz for a few months.

Table 1: The main features of SERSE

Frequency	18 GHz + 14.5 GHz
Type of launching	WR62, off-axis
Axial maxima distance	490 mm
B_{max} (injection side)	2.7 T
B_{min}	0.3 to 0.6 T
B_{max} (extraction side)	1.6 T
Resonance zone length	< 100 mm
Hexapole length	700 mm
B_{rad} (at chamber wall)	1.55 T maximum
ϕ plasma electrode	8 mm
ϕ puller	12 mm
Extraction voltage	30 kV max

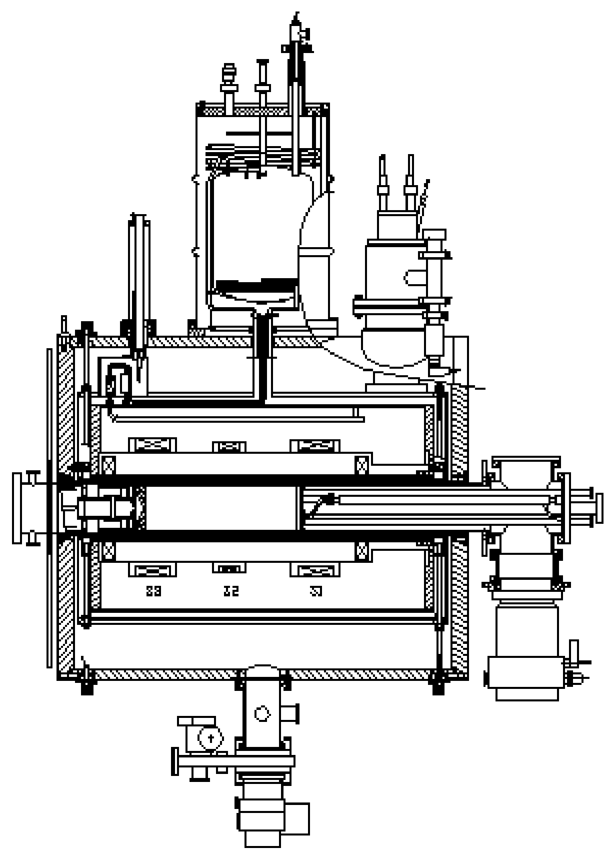

Figure 1 - The source SERSE.

In fig. 1 the source is shown; the stainless steel plasma chamber (ϕ=130 mm) is surrounded by the hexapole, which is enclosed into a structure on which the solenoids are placed. Both the hexapole and the solenoids are made by superconducting wires. On the right there are the microwave and gas inputs and on the left the three-electrode extraction system. A biased disk is placed on-axis at the injection side and can be moved along the same axis. Pumping units at the injection and extraction side provide an operational vacuum of about 2 to $5 \cdot 10^{-8}$ mbar, without plasma (typical values with gas and plasma are 1 to $4 \cdot 10^{-7}$ mbar).

2 FREQUENCY UPGRADING

In a recent paper [6] we estimated that the source SERSE, operated with a 18 GHz generator, should increase its plasma density of about 60% as compared to 14.5 GHz operations and then an increase of current of the same order of magnitude was expected. The condition for the upgrading is that the magnetic field is also scaled by the same factor as the frequency, being B_{ECR} proportional to the frequency.

In fig. 2 the axial magnetic field is shown; the radial confining field was also increased from 1.1 T to 1.45 T.

Except for a few cases, a significant increase of currents was observed, as described in tab. 2.

It needs to be pointed out that the test with increased frequency were carried out with a lower available power (our 18 GHz generator is able to give only 1100 W, in spite of nominal 1500 W). We focused our attention on the production of Xenon high charge states, which beams were at least a factor 1.6 larger with respect to the ones measured at 14.5 GHz. This increase was not only obtained with the higher frequency but even other factors played a role, as the improvement of chamber conditioning and the use of ^{18}O as mixer, according to the experience gained at KVI with the “anomalous isotope effect” [7], which increased the currents of about 20%.

Table 2: Typical currents (in eμA) produced by SERSE

	14.5 GHz	18 GHz
O^{7+}	200	208
O^{8+}	40	55
Ar^{14+}	80	84
Ar^{16+}	17	21
Ar^{17+}	1	2.6
Ar^{18+}	0.05	0.4
Kr^{22+}	46	66
Kr^{25+}	20	35
Kr^{27+}	4.5	7.8
Xe^{27+}	45	78
Xe^{30+}	12	38.5
Xe^{33+}	1.5	9.1
Xe^{34+}	1	5.2
Xe^{36+}	0.4	2

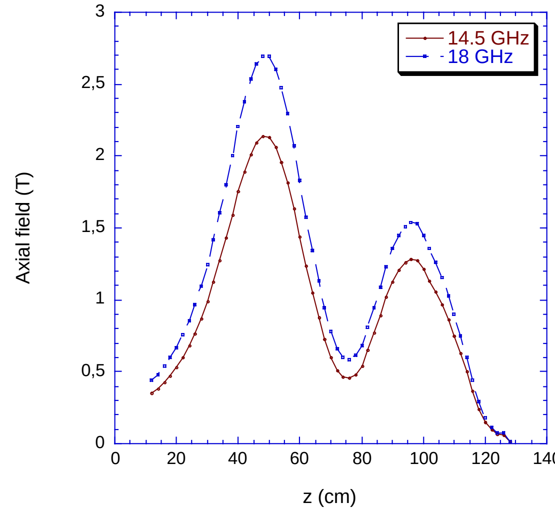

Figure 2 – Axial magnetic field of SERSE.

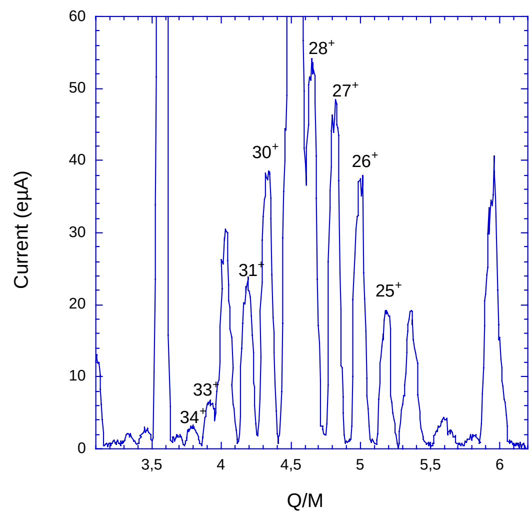

Figure 3 – A charge state distribution for Xenon, optimized for 30^+.

We also operated the source with the “two frequency heating” [8] and the results were not clear, although the currents were higher. The two frequency heating was more effective in the case that the volume of the second resonance was narrow and the amount of power was poor (50 to 90 W). In this case an average increase of 20 to 50% of the xenon currents was measured for the highest charge states, because of the higher plasma density and of the presence of two resonance surfaces.

In fig. 3 a typical charge state distribution for Xe is shown (power was 1040 W at 18 GHz and 60 W at 14.5 GHz). Charge states up to 38^+ were obtained just by decreasing the gas input.

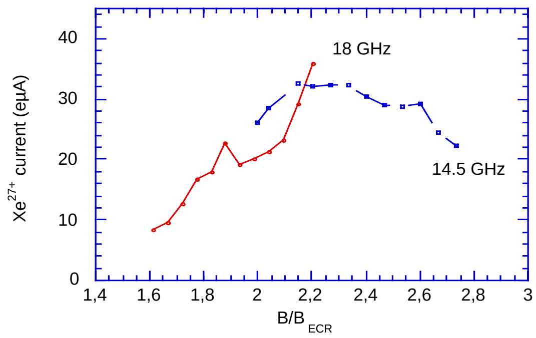

Figure 4 – Xe^{27+} currents for different radial field, with gas mixing and biased disk.

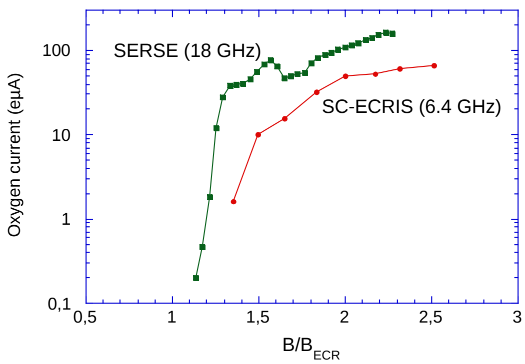

Figure 5 – O^{7+} current for SC-ECRIS (6.4 GHz) and SERSE (18 GHz) for different radial field.

3 MAGNETIC FIELD SCALING

Systematic tests about the magnetic field scaling for the operations at 14.5 GHz and 18 GHz were carried out with the same procedure already used for SC-ECRIS at Michigan State University [9]. The trend that was observed for SERSE was quite similar to the one reported in [9], as it is shown in fig. 4.

The currents increase up to value around $2 \cdot B_{ECR}$ then they remain stable or decrease. Similar results have also been obtained for axial field scaling: a larger axial field than $4 \cdot B_{ECR}$ on the injection side improves the plasma stability, as already observed for SC-ECRIS at Michigan State University [9].

In fig. 5 the comparison between the results of SERSE and the ones of SC-ECRIS is presented for O^{7+}. It can be seen that, except for the absolute values of the current, the shape of the curves is quite similar for the two sources.

The maximum current is not scaled with the square of frequency, as it is foreseen by the Geller's scaling laws, because space charge effects at the extraction play a role (total current is above 4 mA for SERSE, through an extraction hole of 8 mm).

4 CONCLUSIONS

It can be concluded that:

- a radial field above $2 \cdot B_{ECR}$ is necessary to have an optimum confinement and to improve the production of highly charged ions;
- axial field above $4 \cdot B_{ECR}$ for the axial field at injection and $2 \cdot B_{ECR}$ to $3 \cdot B_{ECR}$ are needed too;
- the frequency scaling is effective, provided that the magnetic field is high enough, as we underlined some years ago [4].

The results that we have obtained with SERSE have confirmed the validity of our choice to build an ECR ion source with superconducting magnets, even if the time for the construction has been long and the investments have been relatively high. In fact, the operations of the K-800 Superconducting Cyclotron [10] will benefit of the performance of SERSE, which allows to boost the currents extracted from the cyclotron and also to rise the energy, especially for the heaviest ions.

The former result is particularly important, because the EXCYT project [11] needs high currents of fully stripped light ions (up to 5 pμA) that cannot be provided with the radial injection by means of the Tandem, and that can be provided with the axial injection by means of SERSE.

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