COMPARISON OF OPERATIONS OF THE SERSE ION SOURCE AT 18 AND 28 GHZ

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Abstract

The SERSE source has been efficiently working at the Laboratori Nazionali del Sud in Catania since 1998, by operating at 14 and 18 GHz, with a maximum power of about 2 kW, for the beam injection into the K-800 Superconducting Cyclotron. In 2000 a collaboration was established in order to test the behaviour of SERSE at 28 GHz, so that a new operating domain could be studied, featuring a very dense plasma (up to 10^{13} cm^{-3}) and hopefully a very high current of highly charged ions (1 emA of Pb^{27+} is the goal of CERN and GSI for future heavy ion projects). Tests were carried out with a generator based on a gyrotron tube which was refurbished and made available by CEA and Xenon ions were chosen as a reference, because the ionisation difficulty for Xe^{20+} is similar to Pb^{27+}. The results were excellent and the current of Xe^{20+} exceeded our expectations (more than 0.5 emA in afterglow and more than 0.35 emA in dc mode). These results, obtained with a limited power (4 kW in dc mode and 6.5 kW in pulsed mode), can be considered as a remarkable step, in view of the third generation of ECR ion sources. The details of the experiments will be described, along with the comparison of the results obtained with the injection of 18 GHz microwave.

1 INTRODUCTION

In the frame of a collaboration between CERN, GSI, CEA, ISN and INFN–LNS, a research program was established in order to produce very intense beams with an ECRIS [1] by using a frequency heating higher than the typical 6.4 to 18 GHz commonly used in an ECRIS. The 28 GHz frequency was chosen, which should increase n_e by a factor 2.4 as compared to the 18 GHz operation. However, the maximum "effective" mirror ratio R of SERSE should be, in that case, reduced from 2.4 at 18 GHz down to 1.6 at 28 GHz. The "effective" mirror ratio R is defined as $R = B_{max}/B_{res}$, where B_{max} is the value of the magnetic field at the mirror throat and B_{res} is the magnetic field at the resonance (1 T at 28 GHz). By changing R from 2.4 to 1.6, the electron confinement was lowered, but the tests of SERSE at 28 GHz permitted to obtain the highest currents ever achieved for any Xenon charge state above 20^+ by means of its higher plasma density.

The experiment was carried out by using the SERSE source and its analyzing magnet (fig. 1). Ion currents were at first measured on the Faraday Cup located close to the source exit in order to get the most of the extracted beam. Analyzed beam currents are measured by the Faraday cup located at the image point of the magnet, immediately after the ± 10 mm slits.

No major changes were made to the SERSE source [2]. The source injection flange was modified to include a window for high power 28 GHz microwave injection.

The design of the microwave line was carried out for safe operation and a minimum reflected power. The satisfactory results (reflected power was a few %) are reported in [3,4]. The flange also included a window for 18 GHz microwave injection in order to allow comparison between the two modes of operation. The main difference with respect to the standard flange consisted of a fixed biased probe which was certainly a limiting factor. The extraction gap was shortened in order to get the maximum current from the 12 mm hole, but the extraction optics was not changed. The extraction voltage was limited to 26 kV and the tests were carried out mostly at 20 kV.

Figure 1: A recent photo of the SERSE source and of the first section of its beamline.

2 PRODUCTION OF INTENSE BEAMS

The study for the production of Xenon ions with charge states q≥20 was carried out either in dc mode and in pulsed mode. In both cases the reproducibility of the results was excellent but the long term stability was not, mainly because of technical problems (outgassing, high voltage discharges), especially in the case of a poorer confinement of the plasma. Because of the outgassing the power was limited to 3 kW in dc mode (except for a short test at 4 kW) and to 6.5 kW in afterglow mode. The dependence of Xe^{20+} intensity on the microwave power was about linear up to 3 kW then it saturated and decreased above 3.5 kW; on the other way in pulsed mode there was not an optimum but a continuous beam current increase with the power was observed.

The performance for the highest charge states had a similar trend and for ions like Xe^{30+} and Xe^{33+} the increase of current with the power was steeper between 3 and 4 kW. During a short test devoted to the optimization of the high charge states production in dc mode, a higher power and a very low amount of gas were injected, so that a few charge states were optimized at power level above 4 kW. In spite of the relatively high pressure inside the plasma chamber (~$2\div3\times10^{-7}$ mbar) we observed about 100 eμA of Xe^{30+} , about 8 eμA of Xe^{38+} and 0.5 eμA of Xe^{42+}.

Unfortunately these levels could be maintained only for a few minutes, then they decreased by a factor two or more; anyway they confirmed that a remarkable increase can be obtained by operating an ECR source at 28 GHz.

A large part of the tests was devoted to the study of frequency and magnetic field scaling. It was shown in ref [5] that the increase of current obtained by increasing the frequency is at least proportional to $(f_2/f_1)^2$, once that the magnetic field is scaled by a factor f_2/f_1.

Fig. 2 compares the Xe^{27+} intensities extracted from SERSE at three different frequencies and for an increasing radial field. It is clear that the performance of the source is improving with the increase of radial field and that a net increase of the highly charged ion beam current is obtained by increasing the frequency. The same result was obtained by changing the axial field; it confirmed that even at 28 GHz the higher is the field the better is the performance [4]. A complete report of the study of dependence on the magnetic field and frequency may be found in ref [3,4].

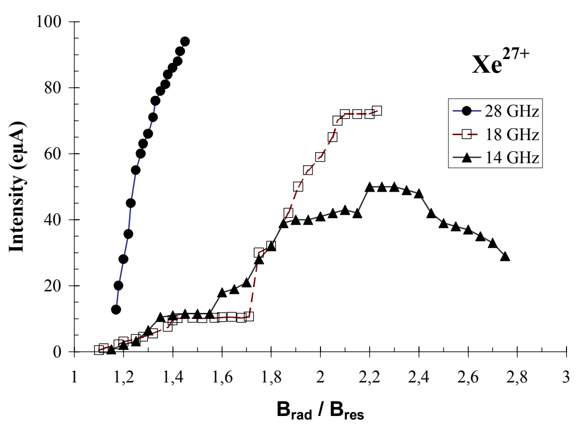

Figure 2: Xe^{27+} currents obtained by operating SERSE at different frequencies versus increasing radial field.

Further tests were devoted to the study of the afterglow mode operations at 28 GHz. The current of Xe^{25+} measured on FC4 is shown in fig. 3. It can be observed that the enhancement factor was about 1.5 or 2 with respect to the yet larger current obtained in dc mode. It must be remarked that it was not possible to extract larger currents because of the limited current available from the high voltage supply (the available drain current was only 15 mA). The performance of the source in dc mode and in afterglow mode were not much different and it was observed that the optimum trap for dc mode production is also the optimum for the afterglow mode. The results concerning the peak stability were less good than at lower frequency, when the source operates in High B mode, but it is still acceptable for most of applications, being about ±10%.

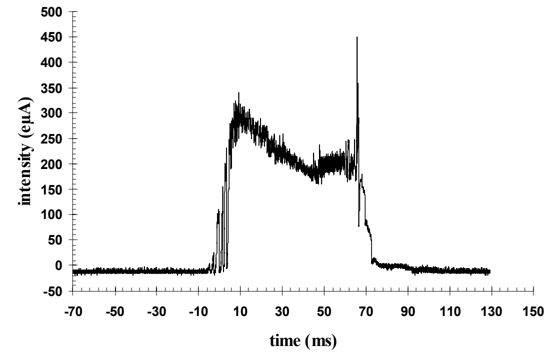

Figure 3: A Xe^{25+} beam pulse in afterglow mode.

3 SOME TECHNICAL PROBLEMS

High voltage sparks often occurred because of the high gas load which was needed to optimize the production of intense beams. A further load derived from the beam divergence: we carried out the tests with the same extraction system which were optimized for the low current, low emittance beams used for the injection into the cyclotron and it was not appropriate. Simulations have shown a very large beam emittance (about 500 to 900π mm.mrad for the typical total current of 4 to 15 mA from the extractor) whereas the acceptance of the analysis beamline is about a factor five smaller and the beam emittance obtained at 18 GHz is about one order of magnitude lower. The large emittance led to relevant beam loss either between the extractor and the first Faraday cup and between the two Faraday cups (we estimated that about 35% of the beam is lost in the analyzing magnet).

More problems came from X-rays and LHe boil-off. The high flux of X-ray which we measured around the source was generated by the electrons lost on the chamber wall, because of the insufficient plasma confinement.

In fig. 4 the X-ray measurements in the radial direction at 18 and 28 GHz are compared (the source setting was similar in the two cases). The energy distribution was not much different but the X-ray level in the radial direction is much higher at 28 GHz; this is a hint of the bad confinement: in fact on the axis, the level of radiation measured during 28 GHz operations was not higher than the one which we measured at 18 GHz.

A further evidence of this intense X-ray bombardment consisted of the higher LHe consumption which was associated with the lower radial magnetic field. The LHe consumption increased from 4.5 to 10 l/h and because of this effect and of the plasma instability, we could not decrease the radial field below 1.17 T in our test of scaling laws [4]. In fact the energy release in the cryostat decreased the safety margin of the magnets and we got a few quenches which were caused by the X-ray bursts, in spite of the magnet setting, which was considered safe.

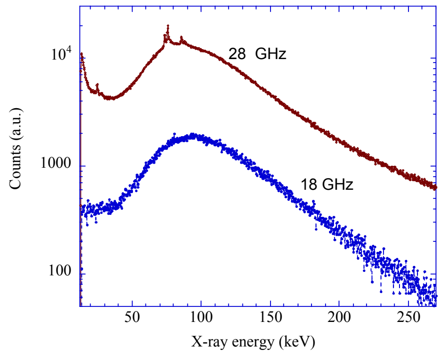

Figure 4: Comparison of the X-ray emission rate.

	SERSE	GyroSERSE
Frequency	14-18 GHz	28-35 GHz
B_{radial}	1.55 T	2.7 T
B_1	2.7 T	4.5 T
B_2	1.6 T	3.5 T
$\phi_{chamber}$	130 mm	180 mm
$L_{chamber}$	550 mm	700 mm
$\phi_{cryostat}$	1000 mm	~1000 mm
$L_{cryostat}$	1310 mm	1540 mm
V_{extr}	20-25 kV	40-50 kV
LHe consumption	~4l/h (100 l/day)	0
O^{8+}	~7 pμA	~50÷100 pμA
Ar^{18+}	>20 pnA	~1 pμA
Xe^{42+}	----	~.02 pμA
Pb^{52+}	----	~.01 pμA

Table 1: Comparison between the design features of SERSE and GyroSERSE.

4 THE GYROSERSE PROJECT

The successful completion of the study of SERSE at 28 GHz reinforced our intention to build the GyroSERSE source [2,6]. This source is designed to operate in high-B mode at a frequency equal or higher than 28 GHz, getting a hot dense plasma (10^{13} cm^{-3}).

The main features of its design are compared with the ones of SERSE in tab. 1. Fig. 5 shows a sketch of the GyroSERSE magnets.

The mechanical constraints have obliged to choose a well larger inner bore than for SERSE, because of the boundary conditions for the hexapole (the stored energy is above 300 kJ). The warm bore thickness corresponds to an internal diameter of the plasma chamber of 180 mm, 50 mm larger than the one of SERSE. The maximum field in the conductor is about 7.5 T. The length of the plasma chamber will be about 700 mm and the volume will be larger than 14 liters. The large diameter will help to get a pressure in the order of 10^{-8} mbar inside the chamber and will make easier the design of the injection flange that will host the ports for 14, 18 and 28 GHz injection, two gas inputs and a 35 mm flange for the oven, the biased disk, the sputtering system or the target for laser ablation. On the outer side a 5 mm double wall watercooled stainless steel chamber will be able to dissipate a maximum power of 10 kW. On the outer a 3 mm thick PEEK tube will insulate the cryostat (at ground) from the chamber (at 40 or 50 kV). The extraction system will be further studied. In conclusion, this source seems to be feasible and not more expensive than SERSE, as many components will be inspired by the design of SERSE. An estimate of the time involved with the completion of such a source has been roughly carried out, and we believe that 3.5 years from the date of funding (expected for the summer 2001) are needed.

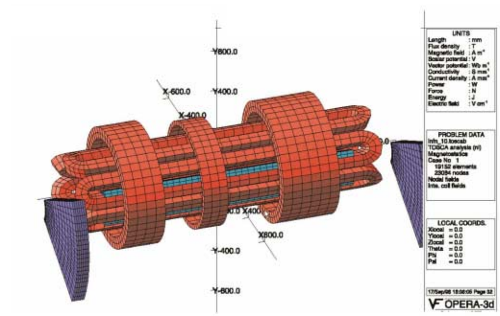

Figure 5: A sketch of the GyroSERSE magnets (courtesy of ACCEL Instr. GmbH).

5 ACKNOWLEDGMENTS

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