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Production of Heavy Ion Beams by Operating Serse in DC Mode and Afterglow Mode

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Abstract

The superconducting ECR ion source SERSE is going to be coupled to a 28 GHz generator, in order to achieve higher current of intermediate and high charge states of heavy ions. Some preliminary tests have been carried out to demonstrate the capability to produce currents of heavy ion beams in the order of hundreds eμA in dc mode and afterglow mode.

In particular, the latter tests in afterglow mode ùay play a relevant role in the design of the new source for the LHC heavy ion injector.

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1 INTRODUCTION

The superconducting ECR ion source SERSE has been operating at INFN-LNS for two years in dc mode, according to the request of the Superconducting Cyclotron, and a large number of species have been obtained for gaseous and solid elements, with the highest currents of highly charged ions ever produced by ECR ion sources1). The outstanding results and the availability of a larger magnetic field than the one currently used, have suggested to use SERSE as the test-bench of the "gyroSERSE" source, which will be a scaled version of SERSE, able to operate in High B mode (HBM) at a higher frequency, between 28 and 37 GHz2). This new source should be able to produce very high charge states, according to the extrapolations of existing models and of the results of magnetic field and frequency scaling tests in ECR sources3),4),5).
The test to be done in the coming months will consist of the coupling between SERSE (set to the highest magnetic field which can be safely achieved) and a 28 GHz – 10 kW gyrotron oscillator, to be used in dc or in afterglow mode. However, even if the highest available magnetic configuration is used, SERSE cannot provide the High-B Mode (HBM) condition suited to a 28 GHz- excited plasma and we cannot expect to increase the very high charges as it could be done by a scaled version of SERSE; however working at a high frequency may permit to reach a high density, sufficient to increase significantly the currents for intermediate charge states (20^+ to 30^+ for the heaviest ions), whose production is important for two project of paramount importance in the coming years, i.e. the LHC heavy ion injector (1 emA of Pb^{27+} within a 1 ms is required, with a 10 Hz repetition rate6)) and the U.S. Radioactive ion beams factory (RIA project), which requires 300 eμA of U^{30+} in dc mode7)).

On the other hand, in order to to add a new reference frame for the future tests in afterglow mode at 28 GHz, we have decided to study the operations of the source in afterglow mode at 18 GHz.
Tests have begun with the production intermediate charge states (Kr^{17+}) in order to set the ability of the SERSE source to produce intense beams of intermediate charges. The first tests were performed in dc mode, and later in afterglow mode (however these tests should be continued). Then highly charged gold ions were produced, optimized in the typical best configuration of magnetic field.

2 PRODUCTION OF Kr^{17+}

In dc mode a high current of Kr^{17+} was produced; the value reached is 150 eμA, with an extraction aperture of 8 mm in diameter. This small extraction hole is adapted to the extraction of highly charged ions (which are usually close to the axis). Despite this disadvantage this value is already the higher value ever reached for this intermediate charge state. It is highly probable that, with a larger aperture (12 or 15 mm in diameter), this current can be doubled (350 eμA). This experiment clearly demonstrates that the SERSE source is able to produce large values of intermediate charges. In a near future the conditions for extraction of higher currents will be better fulfilled.
In pulsed mode preliminary experiments were started; the conditions were however less adapted to the production of large currents since no bias voltage was available, as the oven (which was installed at that time) cannot yet be biased. However a first estimate of the optimization of the

afterglow can be drawn from these experiments. The optimized values for Kr^{17+} decreased from 78 eμA in dc mode to 57 eμA in afterglow mode, for Kr^{22+} increased from 15 eμA in dc mode to 30 eμA in afterglow mode (fig. 1) and for Kr^{27+} the increase was even more relevant, from 0.5 eμA in dc mode to 2 eμA in afterglow mode.

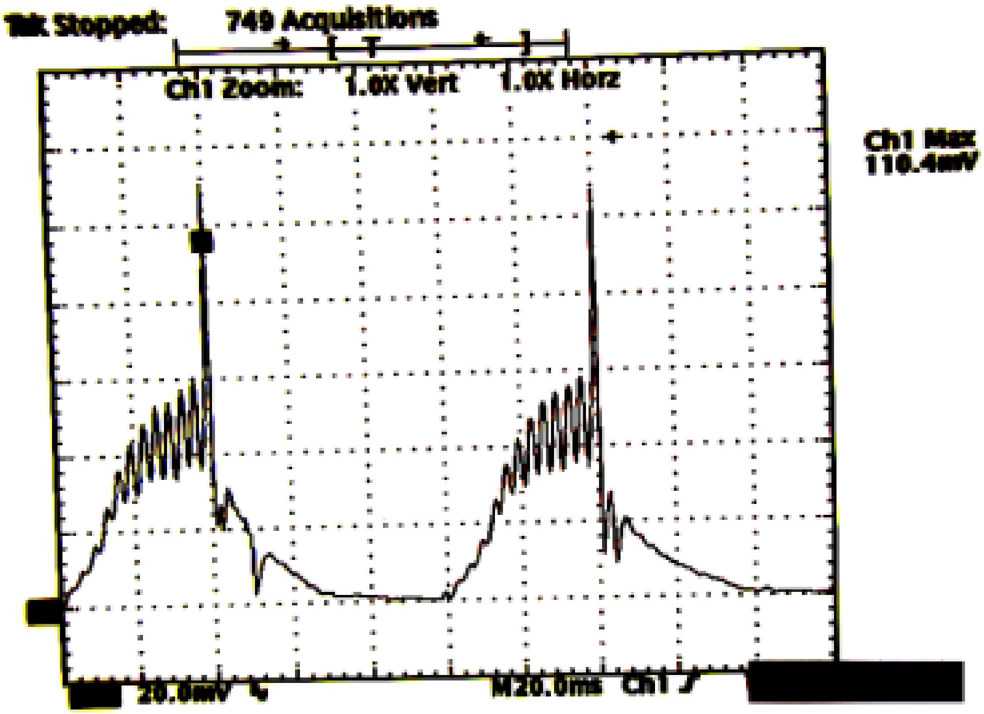

FIG. 1 – A typical afterglow peak for Kr^{22+} (peak height is twice the dc current).

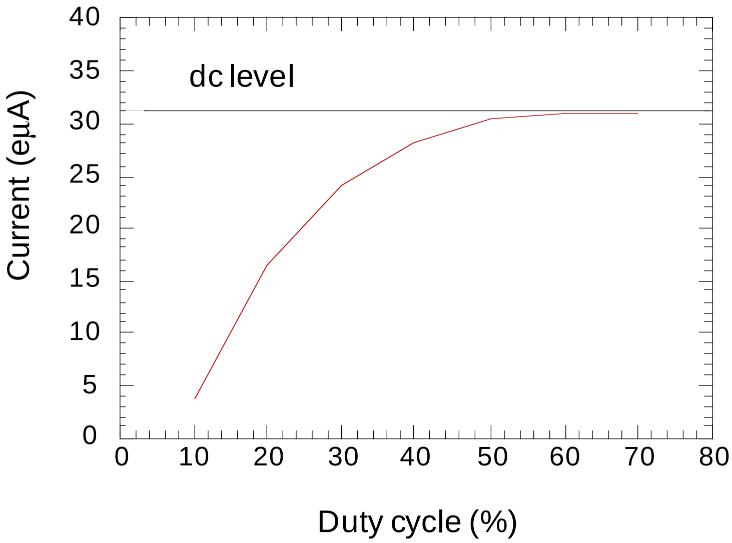

FIG. 2: Afterglow peak current versus duty cycle.

3 PRODUCTION OF GOLD IONS

The next step was the study of operation in afterglow mode for the production of Au^{29+} beams. We changed gas, magnetic field and oven conditions, by leaving unchanged the rf level (1400 W), but changing the duty cycle. No afterglow peaks were put in evidence, but a steady increase of the maximum occurred, saturating around the dc value, as shown in fig. 2. This is due to the finite time necessary to produce high charges.

Afterglow peaks were obtained by reducing the source pressure from $2*10^{-7}$ mbar to $1.5*10^{-7}$ mbar and increasing the rf power at the same time (1650 W). We also observed that the optimization of the peak was possible just by changing the magnetic field profile (fig. 3), with a higher field at the extraction side (about 1.8 T). The duty cycle was 50 to 60% and the peak value was above 37 eμA, with a FWHM above 1 ms.

Tab. 1 summarizes the operating conditions, and the dc currents are given in tab. 2.

The results presented here should be improved in the future, when the oven prototype will be made polarizable.

TAB. 1: The operating conditions of the source (high voltage was set to 20 kV)

Charge state	B_{hex} (T)	B_1 (T)	B_{min} (T)	B_2 (T)	P_{inj} (mbar)	P_{RF} (W)	I_{HV} (mA)
29, dc	1.32	2.62	0.45	1.51	$4.2*10^{-4}$	1400	1.0
29, afterglow	1.23	2.42	0.42	1.53	$1.6*10^{-4}$	1400	0.5
38, dc	1.46	2.68	0.51	1.54	$4.7*10^{-5}$	1720	0.4

TAB. 2: Some results for gold ions

Charge state	dc current (eμA)	Afterglow peak current (eμA)
27	46	48
28	36	Not measured
29	31	37
35	8	Not measured
38	3.4	8
41	0.8	2.4

The current for the different charge states was optimized by changing the amount of gas (any change of rf power and magnetic field decreased the peak value), being the pressure lower for 38^+ and 41^+ and higher for 27^+. In the case of optimization of 38^+ and 41^+ the gain is a factor two or more, but in general it seems that afterglow mode is not very efficient for intermediate charge states, at least to the extent that the power is not high and the pressure low, and even in this case is not so pronounced as it is for sources which have less confinement properties.

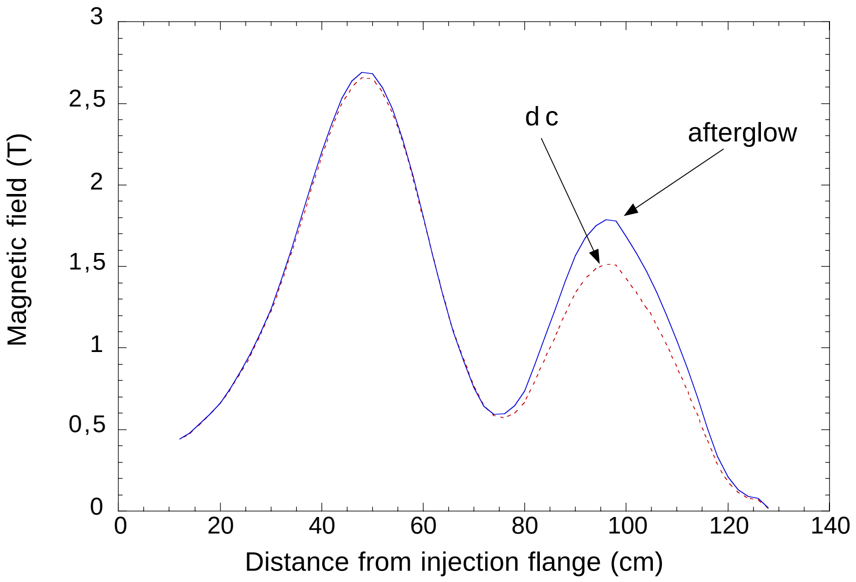

FIG. 3 - Magnetic configuration for dc and afterglow optimization.

In order to verify this assumption we also observed that operating SERSE differently (with radial field below 1 T, and with axial field lower than 1.7 T at the injection: see tab. 3) the enhancement factor was about a factor 2 for Au^{29+}, but the absolute value was largely lower than the ones obtained in HBM operations. This test suggests that maybe some advantage will be obtained by operating SERSE at 28 GHz, in which case the source has not enough confining field to operate in HBM.

TAB. 3: The operating conditions during tests at a much lower magnetic configuration.

Charge state	B_{hex} (T)	B_1 (T)	B_{min} (T)	B_2 (T)	P_{inj} (mbar)	P_{RF} (W)	I_{HV} (mA)
29, afterglow	1.0	1.76	0.3	1.06	$6.6*10^{-5}$	1500	0.5

If a simple scaling is considered, SERSE should not attain the same results at 28 GHz as the ones at 18 GHz in HBM, but it should be considered that the available power is higher (up to 10 kW from 28 GHz generator), enhancing the afterglow effect (to get the current increase needed for LHC heavy ion injector, it seems mandatory to build a scaled version of SERSE, the so-called "gyroSERSE").

4 NEXT IMPROVEMENTS

The SERSE source is already able to produce the largest currents of intermediate charges of gaseous elements; however these currents can be probably doubled as soon as a larger extraction hole is installed. Concerning the production of metallic elements, the oven will be modified to be made polarizable. This is expected to double the currents of intermediate charges. The gain should be still higher for very high charges. It is not yet clear, whether an afterglow mode will be found once a first stage is added to the SERSE source.

5 CONCLUSIONS

This study shows that the afterglow mode does not always lead to an improvement as compared to the dc mode, this effect depending on the charge state:

(i) low and intermediate charges (Au^{27+}): it is possible to tune the source so that an afterglow peak is observed; however the value reached is not substantially higher than the value obtained for an optimized dc mode.

(ii) high charge states: an afterglow peak is always observed, and the optimized dc value (obtained in conditions very similar to the conditions in afterglow mode) can be increased by a factor of 3 and even 4.

These results should be compared with the results obtained at CERN and GSI: the sources Caprice and ECR4, working at 14 GHz, with extraction holes of 12 and 15 mm in diameter, are able to produce respectively 100 and even 175 eμA in afterglow mode; this corresponds to an increase of a factor of 2 as compared to the dc mode, since Pb^{27+} is already a high charge state for these moderate confinement ECR sources.

In the SERSE source, working at 18 GHz, in a non-optimized configuration, comparable current densities are obtained, but no afterglow effect is obtained. Different explanations can be proposed:

(i) perhaps the SERSE source has so good confining properties that no improvement can be obtained through a better confinement;

(ii) this result might also be connected with the absence of biased probe at the first stage: other experiments should be performed to verify these assumptions;

(iii) a very large amount of power is needed to trigger the afterglow mode in a high confinement ECR source.

Concerning the tests at 28 GHz, the SERSE source has lower confinement characteristics at 28 GHz than at 18 GHz (since the relevant factor for confinement is B_{max}/B_{ECR}). Next tests will show if a transient increase of the dc current can be obtained. Therefore it is necessary to have a biased 1st stage in order to get the best and most significant results.

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