ISBN: 978-3-95450-226-4 ISSN: 2222-5692 doi:10.18429/JACoW-ECRIS2020-TUZZO04

STATUS OF THE 60 GHZ ECR ION SOURCE RESEARCH

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Abstract

SEISM (**S**ixty gigah**E**rtz **I**on **S**ource using **M**egawatt magnets) is a compact ECR ion source operating at 60 GHz. The prototype uses a magnetic CUSP to confine the plasma. This simple magnetic geometry was chosen to allow the use of polyhelix coils (developed at LNCMI, Grenoble) to generate a strong magnetic confinement featuring a closed ECR surface at 2.14 T. The plasma is sustained by a 300 kW microwave pulse of 1 ms duration and with a 2 Hz repetition rate. Previous experiments at LNCMI have successfully demonstrated the establishment of the nominal magnetic field and the extraction of ion beams with a current density up to ~1 A cm^{-2}. The presence of "afterglow" peaks was also observed, proving the existence of ion confinement in a CUSP ECR ion source. The last run was prematurely stopped due to an incident but the project restarted in 2018 and new experiments are planned in 2021. A new transport beam line has been designed to improve ion beam transport towards the beam detectors. Short and long-term research plans are presented, including numerical simulations of the beam transport line and future upgrades of the ion source with the main goal to transform the high current density measured into a useable high intensity ion beam.

MOTIVATION

In 2014, the experimental 60 GHz ECR ion source, SEISM, produced ion beams with a current density up to $J \approx 1$ A cm^{-2} [1] using a CUSP magnetic configuration [2] with a closed ECR surface. These results were obtained with a 1 mm diameter plasma electrode to manage the beam in a low acceptance beam line. Such a high current density in a CUSP configuration is so far unique in the field of the ECR ion source and it opens new potential applications for next generation particle accelerators. The experiment was incidentally stopped in 2014 by the presence of a stainless steel wire in the water cooling system which created a short cut between two of the four ion source coils and destroy them. At the restart of the project in 2018, an analysis was launched to improve the implantation and the performances of the experiment installed in one of the LNCMI experimental hall.

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SHORT TERMS PLANS

Experiment upgrade

First, the two coils that were damaged during the previous experimental campaign have to be reconstructed. Second, the analysis beam line originally solely composed of a bending magnet has beam revised in order to improve the transmission of the beam line. To do so, numerical simulations were performed with the Tracewin code [3], and a new design using existing available equipements was decided. Figure1 shows the new implantation of the experiment. In this configuration, the transport line is composed of a quadrupole triplet with 150 mm gap to ensure focusing of the ion beam and the original dipole with a 60 mm gap was replaced by an existing dipole with a larger gap of 90 mm and a horizontal aperture of 300 mm. Transport simulations indicate that the theoretical transmission could reach 90 % for a 1 mm plasma electrode diameter.

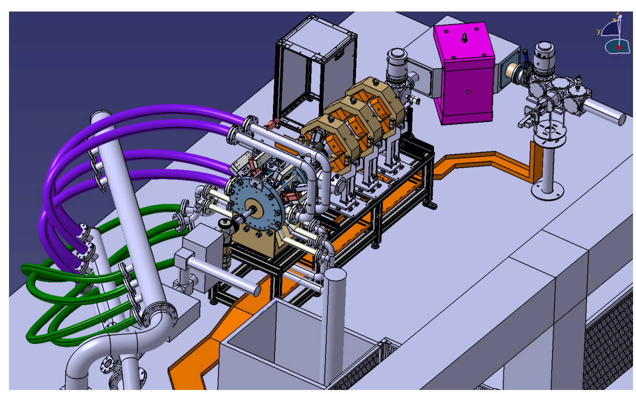

Figure 1: 3D view of the new implantation of the SEISM ion source at LNCMI laboratory.

Another upgrade concerns the range of pressure available in the source. Indeed the existing plasma chamber had a vacuum leak limitating its base pressure to 10^{-5} mbar. A new plasma chamber design was done to solve the issue and reach 10^{-7} mbar. This improvement will also allow to increase the voltage applied on the extraction of the source from 25 up to 40 kV to improve the beam line transport.

Objectives of future experimental sessions

A new experimental campaign is scheduled in 2021 on the SEISM source. Thanks to the upgrade of the beam line, one should be able to reliably reproduce the data obtained in 2014. One experimental goal is to characterize the high

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density plasma as a function of the source parameters such as, magnetic field, gas pressure, HF power and the radial biased ring voltage, located between the the two CUSP coils (see Fig. 2).

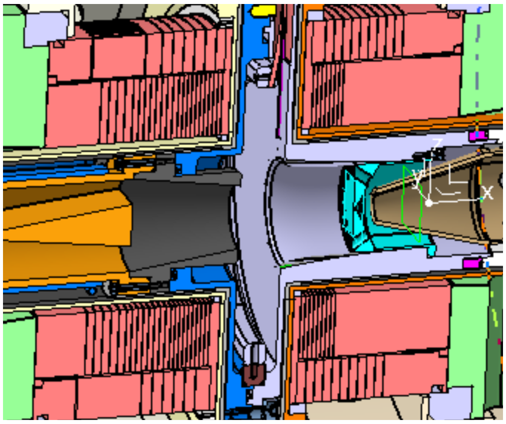

Figure 2: 3D cut view of the SEISM source. Polyhelix (pink), plasma chamber (light grey and blue).

A concomitant monitoring of the plasma stability will be done during the experiments using the technique described in reference [4] . Another point of interest for measurements will be to measure lost electron energy distribution (LEED) which is unknown from a CUSP. Finally, a complete characterisation of the ion beam will be performed. The beam current will be measured in different location, giving information on the transport of very intense beam, and the emittance will be measured by a pepperpot device [5].

LONG TERM PLANS

PACIFICS is a joint project carried by IN2P3 and CEA dedicated to perform high level research and development in the field of particle accelerators. The collaboration answered in 2020 to the EQUIPEX call by the French Agence Nationale de la Recherche. The answer to the call is pending at the time of writting of this document. PACIFICS includes a work package dedicated to the enhancement of high intensity beams for the next generation accelerators. It includes a significant budget for equipements and the priority is first to relocate the SEISM source from LNCMI to LPSC. This action requires to replace the existing resistive coils by a set of superconducting ones [6] . Indeed, experiments at LNCMI are limited to roughly two weeks per year which slows down the research (magnetic field time at LNCMI is shared among several users and must be approved by the European European Magnetic Field Laboratory through calls for experiment). A second priority is to upgrade the 60 GHz gyrotron high voltage power supply from pulsed to 20 kW continuous working (CW) operation. Next, the main goal is to enlarge the plasma electrode extraction hole of SEISM to investigate the production of high intensity beams of medium charge state ions in pulsed and CW operation. It is planned to install an extraction system identical to the SILHI ion source and study the beam emittance and beam neutralisation in a simple LEBT equiped with a diagnostic box and a beam dump. A study was done to investigate the possible geometry of the superconductive coils of the ion source, the goal being to produce a closed 2.14 T ECR surface with two coils arranged in a single cryostat. The parameter varied in the study is the diameter of the plasma chamber taken as 150 mm, 200 mm and 250 mm. The cable used for these simulations has a rectangular section of 1.08 × 0.68 mm with a Cu:NbTi ratio of 1.35:1 from Oxford Instruments [7]. For each configuration, one considers two coils of rectangular section with opposite current applied to reproduce the CUSP configuration. Dimensions of the coils were adjusted to obtain the closed ECR surface at 2.14 T with an added criteria to have a 10 mm minimum distance between the ECR zone and the plasma chamber wall . Table 1 summarizes the coils main parameters for the 250 mm case.

Table 1: Coils Parameters for a 250 mm Plasma Chamber Diameter

	Solenoid 1	Solenoid 2
Axial position [mm]	-60	+60
Inner Diameter [mm]	165	165
Depth [mm]	40	40
Width [mm]	200	200
Turn/layer	185	185
Number of layer	59	59
Turn /coil	10915	10915
Design current [A]	272	272
Length of cable [km]	9.6	9.6
B_{max} at coil (at design current) [T]	5.9	5.9

Figure 3 shows the fieldmap in the case of the 250 mm diameter for the plasma chamber. In this figure, the white rectangle represents the coils, and the blue line represents the plasma chamber wall. In this example, one can see that a closed surface at 2.14 T, corresponding to the magnetic field needed to achieved resonance at 60 GHz, is present. The closed surface is here located 1.6 cm (see Fig. 5) away from the plasma chamber wall, value well above the minimum target design value of 1 cm.

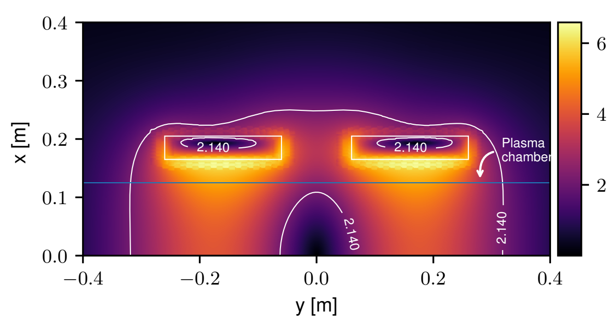

Figure 3: Field map for 250 mm diameter plasma chamber . Plasma chamber (blue). Surface of 2.14 T

To verify the feasibility of the magnetic configuration, one of the important criteria is to verify if the coil loadline

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is not too close of the critical curve of the superconducting cable at 4.2 K. Figure 4 shows the loadlines for the three cases studied . For every case, the coil loadline are always under 85 % of the critical current.

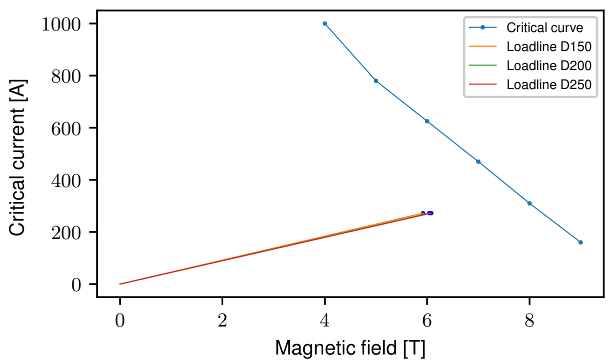

Figure 4: Load lines for the different plasma chamber diameter.

Figure 5 presents the evolution of the distance between the ECR zone and the chamber wall as a function of the diameter of the plasma chamber. One can see that, for all cases, the distance is always above 1 cm, the minimum distance wanted.

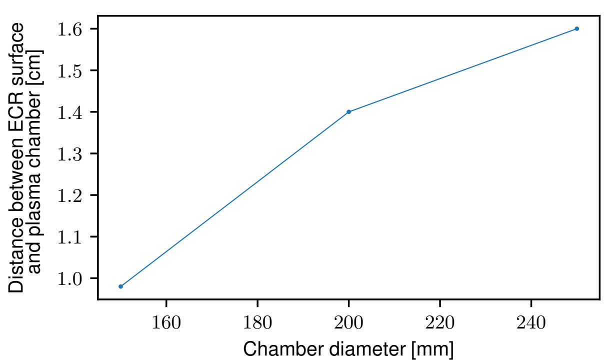

Figure 5: Evolution of the distance between the plasma chamber and the ECR surface for different plasma chamber diameter.

The stored energy in the system is display in Fig. 6 as a function of the chamber diameter.

Figures 7 and 8 respectively present the axial ($r = 0$) and radial ($z = 0$) magnetic field for the three configurations corresponding to the three diameter of the plasma chamber. Table 2 summarizes the magnetic fields properties for each configuration.

Table 2: Magnetic Field Properties

Plasma chamber diameter [mm]	150	200	250
B_{z-max} [T]	4.07	4.08	4.02
B_{r-max}[T]	2.45	2.54	2.47

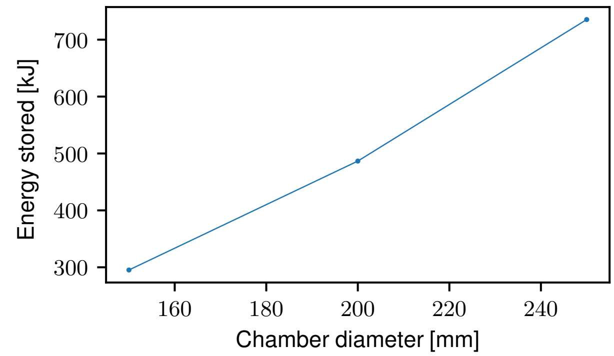

Figure 6: Magnetic energy stored in the system for different plasma chamber diameter .

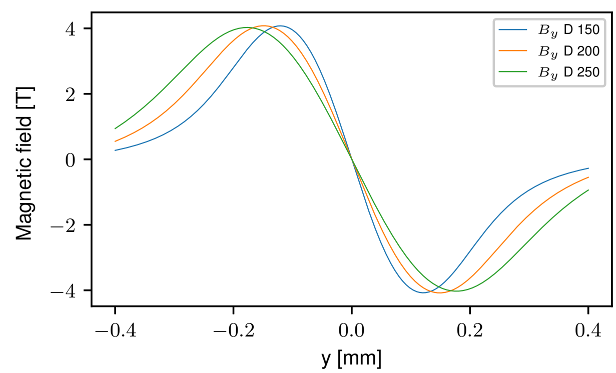

Figure 7: Axial magnetic field on axis (r=0) for the different configuration corresponding to the different plasma chamber diameter.

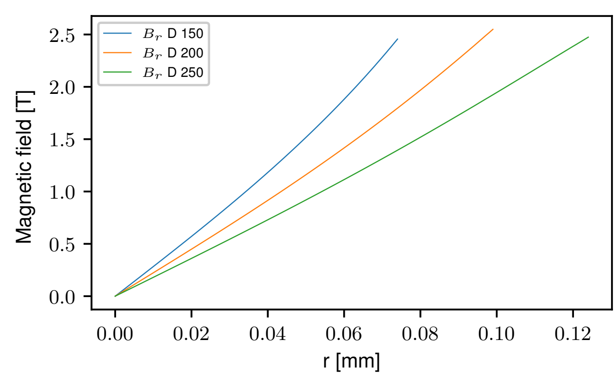

Figure 8: Radial magnetic field at the center of the chamber different configuration corresponding to the different plasma chamber diameter.

CONCLUSION

SEISM ion source R&D will resume in 2021 when a new experimental campaign will happen. Long term plan aims to relocate the ECRIS at LPSC to ease the research and demonstrate the production of very intense CW beam of medium charge state ions.

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