MEASUREMENT OF THE SIXTY GHZ ECR ION SOURCE USING MEGAWATT MAGNETS - SEISM MAGNETIC FIELD MAP*

M. Marie-Jeanne#, J. Jacob, T. Lamy, L. Latrasse, LPSC UJF CNRS/IN2P3 INPG, Grenoble, France
F. Debray, J. Matera, R. Pfister, C. Trophime, LNCMI CNRS UJF INSA UPS, Grenoble, France.

Abstract

LPSC has developed a 60 GHz Electron Cyclotron Resonance (ECR) Ion Source prototype called SEISM. The magnetic structure uses resistive polyhelix coils designed in collaboration with the French National High Magnetic Fields Facility (LNCMI) to produce a CUSP magnetic configuration. A dedicated test bench and appropriate electrical and water cooling environments were built to study the validity of the mechanics, the thermal behaviour and magnetic field characteristics obtained at various current intensities. During the last months, measurements were performed for several magnetic configurations, with up to 7000 A applied on the injection and extraction coils sets. The magnetic field achieved at 13000 A is expected to allow 28 GHz ECR condition, so by extrapolation 60 GHz should be possible at about 28000 A. However, cavitation issues that appeared around 7000 A are to be solved before carrying on with the tests. This contribution will recall some of the crucial steps in the prototype fabrication, and show preliminary results from the measurements at 7000 A. Possible explanations for the differences observed between the results and the simulation will be given.

SCIENTIFIC CONTEXT

LPSC Grenoble has initiated an ambitious research and development program for high frequency ECRIS, i.e. with a resonance frequency above 28 GHz. Such a program benefits greatly from LNCMI research on split magnets described in reference [1]. The use of LNCMI radially cooled polyhelix technology allows investigating several magnetic configurations with low fabrication costs and short delays in comparison to classical and superconducting ECR ion sources.

As a first step, the SEISM prototype was designed to produce a CUSP magnetic structure with a closed 60 GHz resonance zone at 2.14 T for a 30000 A current in the helices. Reference [2] recalls the main steps for the design of the prototype, including the results from magnetic, mechanical, hydraulic and thermal calculations.

Due to many uncertainties concerning hydraulic and thermal behaviour of such an innovative helix design, a dedicated test stand was built at LNCMI to study the coils characteristics obtained for various current intensities. The goal of such tests is to validate the magnetic field map at half-current using 2 of the 4 available power supplies of LNCMI, thus creating a closed 28 GHz resonance zone at 1 T for 15000 A in the coils.

PROTOTYPE FABRICATION AND TESTS

Helices

Each helix was first machined with its final diameter, then rigidified by the insulators glued between its windings and finally adjusted to its final height. Helices fabrication process is shown on Fig. 1. According to thermal calculations, insulators had to be as narrow as possible (i.e. 2 mm wide) in order to limit local temperature rise in their centre. Thickness was calibrated to maintain a constant space between two windings (i.e. 0.32 mm thick) in order to avoid constraints on the helix. The difference of potential between two windings was expected not to exceed 10 V at 30000 A. Therefore, composite fibres already "pre-impregnated" (hence the name “pre-preg”) with the resin that would bond them to the windings surface have been chosen. Such pre-pregs can hold a maximum voltage of 35 kV/mm, and are easily cut to their final shape with an automatic cloth cutting machine. As calculated, 24 pre-pregs per winding were glued on internal helices H1 and H2, and 32 pre-pregs on external helices H3 and H4, in order to avoid windings distortion and contact under the magnetic field forces.

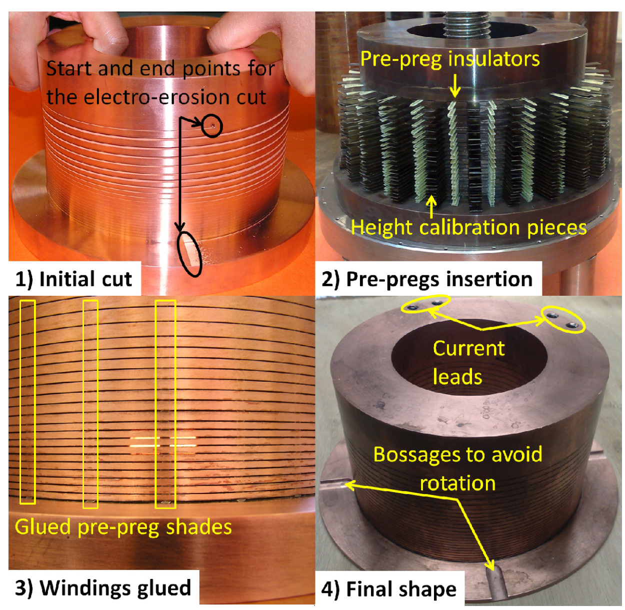

Figure 1: Inner injection helix H1 fabrication process from initial electro-erosion machining (1), through pre-preg insulators gluing (2, 3), to final adjustments in height and shape (4).

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#melanie.marie-jeanne@lpsc.in2p3.fr

After forty hours of run at a 7000 A applied current, thermal and mechanical resistances of the outer coil insulators were checked by inserting an endoscopic camera. Mechanical resistance was validated, as pre-pregs were not displaced and still aligned vertically. Pictures were compared to samples of heated pre-pregs to estimate the temperature reached locally, which seemed to already exceed the temperature expected in the pre-preg centre. The maximum operating temperature being of 165 °C for the pre-pregs, other solutions will have to be investigated for magnetic field tests at full current intensity, where higher temperatures are expected.

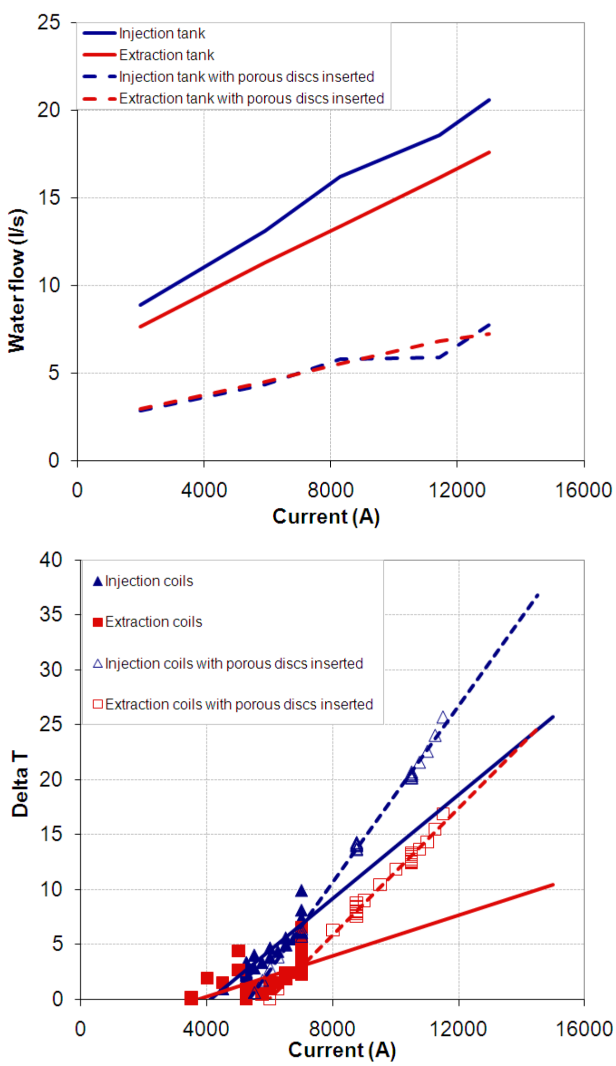

Figure 2: Water flow evolution with and without porous disks inserted (top) and consequences on the coils temperature (bottom)

Tanks

Water circulation in the tanks was first tested up to 18 bars and 18 l/s in each tank, with fake aluminium parts drilled with holes to simulate the water flux. Due to the inaccurate geometry of the water holes, loud cavitation noises could be heard and small damages could be observed on the aluminium. When applying 7000 A on the real copper helices, i.e. 10 bars and 12 l/s in each tank, with the water speed up to 14 m/s in the radial helices slit, cavitation noises could be heard too. In order to increase the pressure in the water outlet of SEISM without modifying the cooling of M5 magnet running in parallel, stainless steel porous discs soldered in flanges were installed on the water outlets of both tanks. The water flow through the prototype went down to half, but helices were still sufficiently cooled down, as can be seen on the graphs from Fig. 2.

Cavitation effects were successfully suppressed, and measurements could go on up to 10500 A current applied. However, because of the pressure difference between the two sides of the porous discs, one of them broke at 10500 A (19.5 bars – 7 l/s). An alternative to the porous discs will be needed to pursue the tests at higher current.

Setup for magnetic measurements

The magnetic field was measured on three horizontal axes along z, and on one radial axis (see Fig. 3), with two gaussmeters equipped with single-axis axial and radial Hall probes calibrated inside the M5 magnet. Two 300 mm-course jacks with a stepper motor allowed moving the Hall probe inside the prototype chamber. A LabView interface was developed to move the jacks to a given position and automatically acquire data.

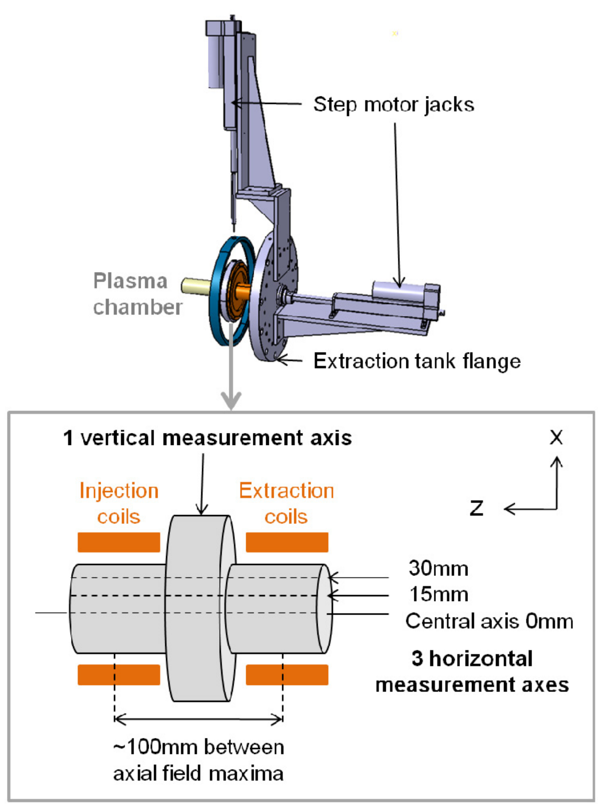

Figure 3: Scheme of the magnetic field measurement setup (top) and of the axes of measurement (bottom).

MEASUREMENTS RESULTS

As a first approximation, the magnetic structure can be considered as axi-symmetric. This is verified experimentally, as one measures a constant field at any angle for given x and z (see Fig. 4).

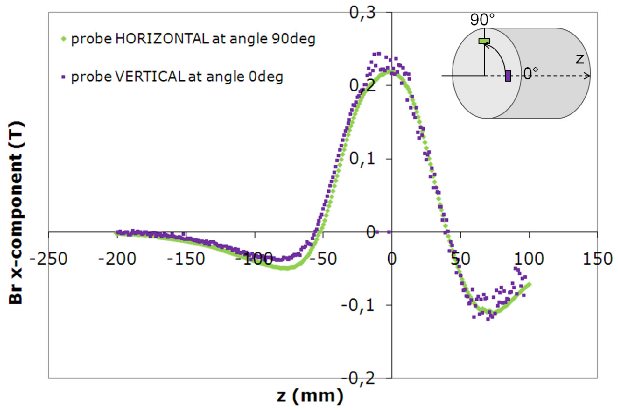

Figure 4: Radial field x-component measured on 15 mm-axis at different angles for 3500 A current applied.

By summing the axial and radial components of the field, one obtains the total magnetic field on three axes of the chamber (see Fig. 5).

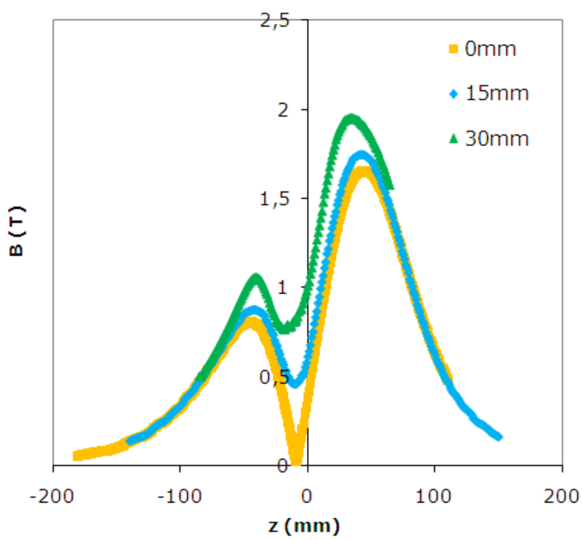

Figure 5: Total magnetic field measured at 7000 A on axes parallel to the coils axis at various distances from the centre.

One can deduce an approximate magnetic field map at 7000 A, shown on Fig. 6. Magnetic field zones at 0.5 T and at 0.64 T are closed within the chamber walls, respectively allowing ECR at 14 GHz and 18 GHz. The first iso-B touching the walls is at 0.76 T. Given the field linear scaling with intensity, one expects to measure a closed 1 T resonance zone at 14000 A.

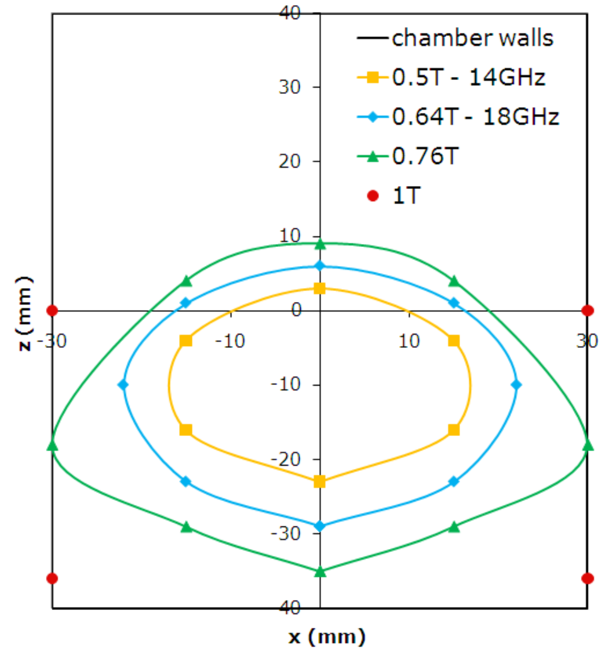

Figure 6: Approximate magnetic field map at 7000 A.

When comparing the measurements with the simulations, one finds a similar structure for the iso-B lines, with lower gradients close to the chamber walls and towards the extraction.

However, the resonance zone centre is displaced of about 5 mm towards the extraction. By measuring the magnetic field produced independently by the injection and extraction sets of helices, one finds that injection and extraction maxima are closer; the summed amplitude is thus lower, especially on the extraction side (see Fig. 7).

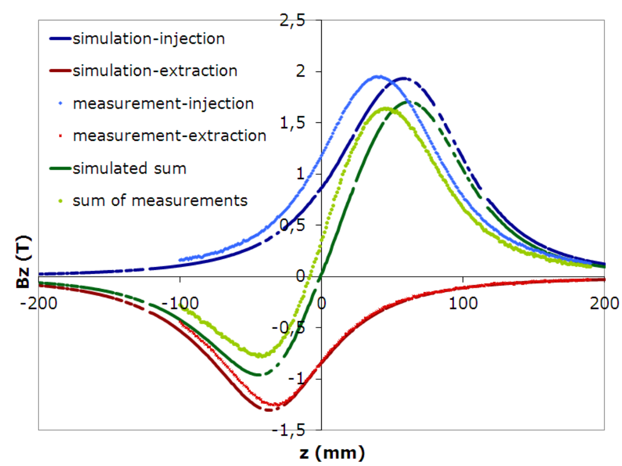

Figure 7: Comparison between measured and simulated (2D model) axial fields at 7000 A on the central axis.

Possible reasons for such discrepancies are being investigated. A mechanical error in the tank or in the helices positioning pieces would induce less than 1 mm displacement, as dimensions were measured within tolerances. The helix shape itself may be wrong, due to a difference between the real helix split (0.37 mm) and the expected one (0.32 mm), causing less than 2 mm total displacement. Each helix magnetic centre should be carefully checked after dismounting. Finally, the comparison with the 2D calculation model may be inaccurate. Simulations are being run again within the 3D model. Temperature gradients in the windings (due to the presence of insulators) and in the cooling water (due to heat exchanges) induce non-linear effects that will be introduced in the calculation.

PERSPECTIVES

In order to carry on with the half-magnetic field tests, the stainless steel porous discs are currently being replaced. A proposal for two extra weeks of magnetic field was accepted and the run is to be scheduled during autumn 2010.

Given the first results presented here, one expects the magnetic structure to be valid for a 28 GHz resonance. Therefore, the design for the components of the source (plasma chamber, gas and microwave injection...) will be possible in 2011. A permanent room at LNCMI is under funding request for the first 28 GHz tests.

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