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ECREVIS CONSTRUCTION PROGRESS REPORT

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Summary

Ecrevis is a large external heavy ion source using the Electron Cyclotron Resonance, presently under construction at the L.L.N. Cyclotron Laboratory. Magnetic confining structure includes a superconducting hexapole and solenoids. Some design aspects of the superconducting system and of the microwave coupling system are discussed. A prototype mechanically cooled cryopump able to operate in high magnetic fields has been realized and has shown pumping speed of 8.500 l/s for air. The 16 m long low energy beam injection line has been realized and tested with beams produced by the first stage of the ECR source. The axial injection system in the cyclotron is described and is now almost completed.

1. Introduction

In 1977, it was decided to improve the heavy ions characteristics of the Louvain-la-Neuve isochronous cyclotron (CYCLONE) by the construction of an external heavy ion source. The type of source chosen was the E.C.R. source, as developed in Grenoble by Geller et al.[1,2,3].

At that time, the only operating prototype of this kind of source was the Geller "Supermafios". As the physics underlying this kind of devices were, to say the least, poorly understood, it was decided to keep the design very close to the successful prototype.

The only main modifications are

- *an improvement of the neutral pressure, by the use of two large cryopumps*
- *a reduction of the prohibitive energy consumption of the prototype (4 MW).*

To reach this second goal, two alternative technologies were considered for the realization of the magnetic bottle :

- *To realize the hexapolar part of the field with Sm-Co permanent magnets, the axial field being still obtained from conventional water cooled copper coils.*
- *To realize the whole second stage magnetic structure (solenoids + hexapole) from supraconductors.*

This second solution was chosen. It offers also the advantage to allow, in a further future step, to go to twice the field, i.e. to reach finally four times Geller's electron density.

The whole superconducting system for the main magnetic bottle was ordered in May 79 to Cryogenic Consultants Incorporated, in London.

At the same time, Geller developed a much smaller device : "Micromafios", which did produce also high charge states [4,5]*. Also some theoretical efforts were made by Chan-Tung* [6] *and later by Jongen* [7] *to get a better understanding of the physics involved in the source. From the Micromafios experimental data and these theoretical predictions, it is however clear that the ECREVIS design parameters are quite favourable to get a high production of high charge states.*

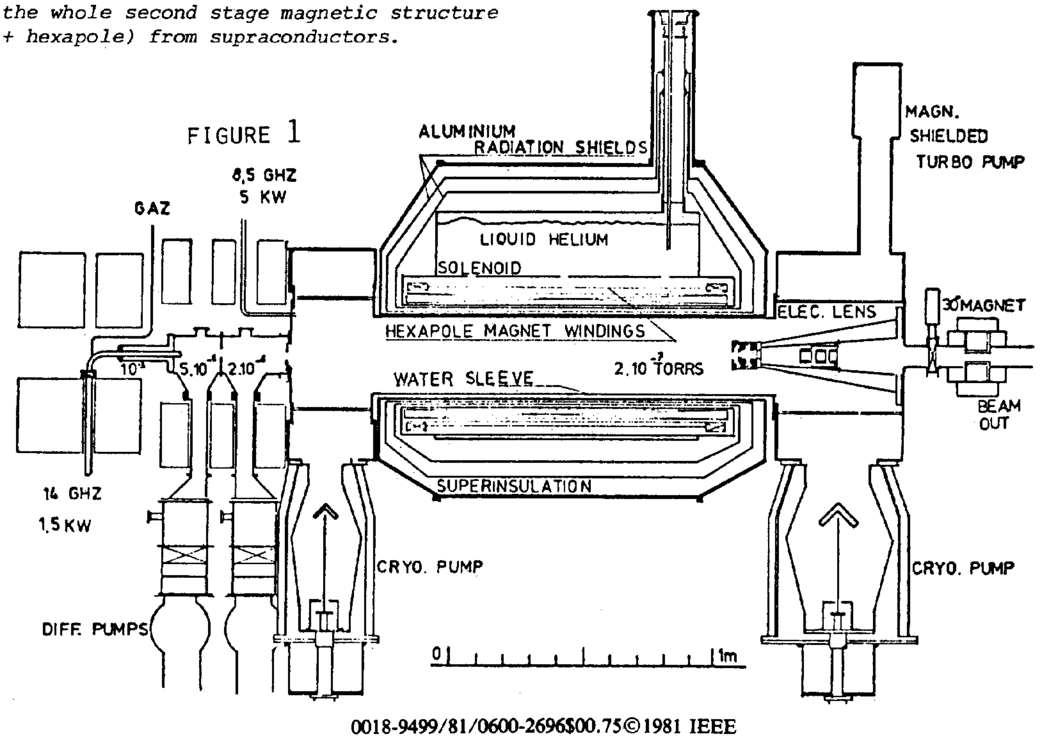
2. Source design

The present design of the source is shown on fig. 1. The superconducting coils making the main magnetic bottle are located in a liquid helium bath. The cryostat, specially insulated to reduce the L.He consumption to less than 0,3 l/hour has a room temperature bore. The cryostat is at ground potential.

The bore is insulated, to hold the source acceleration voltage. In this insulated bore, the water - jacket vacuum chamber is fitted. At the ends of the vacuum chamber tube are located two square vacuum chambers, equipped with large, custom designed cryopumps. In the vacuum chambers, water cooled dumps for high energy electrons will be provided on the computed loss lines.

Microwaves are fed directly from a 8,5 Ghz, 5 kW transmitter from Varian ass. (Palo Alto). The WR 112 waveguide is brought directly into the vacuum chamber, without special coupling device. An aluminium oxyde pressure window is located between the first stage solenoids, at the point of maximum field, to avoid plasma hitting the window.

FIGURE 1



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The cool plasma is produced by ECR in an other, separate stage (the so-called first stage). The ECR field and frequency are respectively 0,53 Tesla and 14,3 Ghz. The ECR occurs in a circular waveguide, diam. 17 mm, where neutral gas is admitted at a pressure of 10^{-3} Torr. The cold plasma diffuses along the magnetic field lines to the main magnetic bottle. Differential pumping is provided by two 1200 l/s oil diffusion pumps to drop gradually the neutral pressure.

The magnetic field for the first stage is provided by watercooled copper coils, optimised to reduce energy consumption.

The total energy consumption of the complete device including peripherical equipment, is around 150 kW.

Some source parameters are shown in table I.

TABLE I : Typical parameters

	Stage 1 (plasma injector)	Stage 2 (main confinement)
E.C.R. field	0,53 T	0,31 T
E.C.R. frequency	14,3 Ghz	8,5 Ghz
Available RF power	1,5 kW	5 kW
Neutral pressure	$\approx 10^{-3}$	$3\ 10^{-7}$ Torr
Electron density	$\approx 8\ 10^{12}$	$3\ 10^{11} cm^{-3}$
Plasma length	75 cm	120 cm
Delivered ionic flux	$3\ 10^{16}\ s^{-1}$	$1,5\ 10^{15}\ s^{-1}$
Electron lifetime	$\approx 10^{-5}$	$3,5\ 10^{-4}$ s
Electron temperature	$\approx$ 7 eV	$\approx$ 5000 eV
Ion temperature	$\approx$ 7 eV	$\approx$ 7 eV
Mean charge stage (Argon)	1,1 +	6,2 +

3. The main superconducting magnetic bottle

The superconducting magnetic system is unusual in the sense that the field levels required are relatively modest, at least for a superconducting magnet. This allows to use a low current density in the coils, with a conductor having a high copper-to-superconductor ratio. The conductor properties are summarized in Table II

TABLE II : Superconducting wire data

Type : Intrinsically stabilised filamentary NbTi alloy in copper matrix	
Diameter before insulation	1.88 mm
Copper-to-superconductor ratio	5 : 1
Number of filaments	672
Diameter of filaments	30 microns
Average minimum filament length	100 meters
Critical current guaranteed at 3 Tesla, 4.2 K	1000 amps
Critical current expected at 3 Tesla	1150 amps
Critical current expected at 4 Tesla, 4.2 K	990 amps
Maximum voltage/meter length at 3 Tesla, 4.2 K, 800 amp. op.	5 microvolts/meter
Insulation	heavy formvar enamel
Diameter after insulation	1.97 mm ± 20 micron

An hexapole being generally a more complicated structure to support mechanically than simple solenoids, large safety margins are included to avoid premature quenching of the system.

A special attention was paid in the cryostat design to reduce the liquid helium boil-off as much as possible. Among the design features selected to reach that goal, let us mention :

- Two thermal shields, respectively at 80° K and 20° K, separately cooled by a closed loop mechanical refrigerator (Cryomech Inc. type GB07).
- A fiberglass inner neck tube, thermally connected to the shields to distort the temperature gradients.
- Support of the axial efforts by special long titanium rods, going through bores in the helium vessel, thermally connected to the shields to reduce heat flow.

Cryostat data are summarized in Table III.

TABLE III : Cryostat specification

Liquid helium capacity	680 litres
Useful reservoir	280 litres
Design helium consumption (zero current, persistent mode)	233 cc/hour
Guaranteed (zero current, persistent mode)	450 cc/hour
Additional consumption at 225 amps (non persistent mode)	1950 cc/hour
Liquid nitrogen required for cooldown	250 litres (nominal)
Liquid helium required for cooldown (with cryogenerator cooling)	150 litres (nominal)
Weight of complete cryostat	approx. 950 kg

4. A reduced scale superconducting magnetic bottle

The large superconducting magnet system, ordered in May 79, was originally scheduled for delivery in July 80. However, various problems did affect the planning, and the delivery is now scheduled not earlier than July 81. This fact, and also the wish to get, in our institute some practical experience of superconducting coils construction, led us to the decision to build a 1/3 scale model of the large system.

Extra advantage of this decision will be the possibility to study scaling laws on very comparable models, and the availability of a very flexible model, to study further improvements (like for instance an octopolar versus hexapolar radial field profile).

5. The cryopumps

Custom design cryopumps were required to accomodate a large pumping speed into the small axial length left by the general source design.

The design of cryopumps for gases condensed at 20° K is easy, using a low power cryogenerator to cool the pumping plate and liquid nitrogen to cool a thermal baffle.

However, we decided to try to avoid the servitude and cost of liquid nitrogen transfers, and to realize a pump entirely cooled by a larger cryogenerator. It can easily be demonstrated that, for a cryogenerator cooled cryopump :

- The pumping speed is entirely determined by the power available at the 80° K stage of the generator.
- The optimum pumping speed for a given first stage power is obtained for an "open hole" configuration, i. e. a configuration without chevron or "venetian blind" baffle.

Those considerations led us to use as cryogenerator the GB04 model from Cryomech Inc. with a power of 50 W at 80° K and 4 W at 15° K. The resulting design is shown in fig. 2.

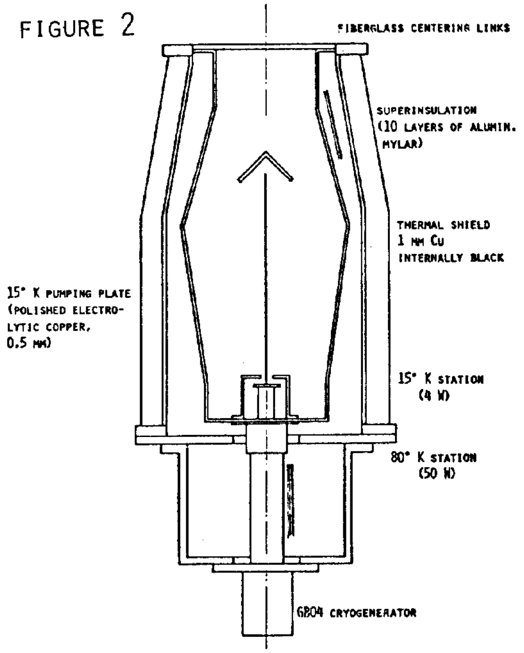

FIGURE 2

The pump has been built in the institute workshop, and tested in a geometry very close to the Pneurop standard for high vacuum pumps testing.

The pumping speed we found was in perfect agreement with the calculations. The speed is 8500 l/s for nitrogen, and looks constant for a troughput varied from 0 to 80 stcc/min (1 Torr l/s). No saturation effect was perceptible after four days of continuous operation at maximum flow, corresponding to 0,5 kg of air ice frozen on the 15° K panel.

The possibility of pumping neon is also foreseen by buriing it under a larger flow of Argon, injected directly into the baffle. The pumping speed at that place is larger than 35.000 l/s, so vacuum degradation by the Argon flow is unlikely. However, neon pumping tests have not yet been done.

Another characteristic still to be tested is the sensitivity of the pump to leaking microwaves. Such tests are foreseen in the next future.

6. *Axial injection system*

The axial injection system (fig. 3) consists of four cylindrical magnetic lenses of the Glaser type[8] *located in the axial hole in the upper magnet yoke followed by an electrostatic inflector of the pseudo-cylindrical type* [9,10,11].

Inflector characteristics and center region geometries have been determined for N = 1, 2 and 3 modes by means of numerical calculations of particle trajectories using electrostatic potential distributions obtained from electrolytic tank measurements.

The beam transmission through the axial line and inflector is being checked in a test set up reproducing the cyclotron field at reduced field level with an HH^+ *beam from a gas source and emittance measurements are under way. A fully automatic system for positioning and removing the inflector through the lower yoke is under construction.*

The entire system will be tested on the cyclotron this spring.

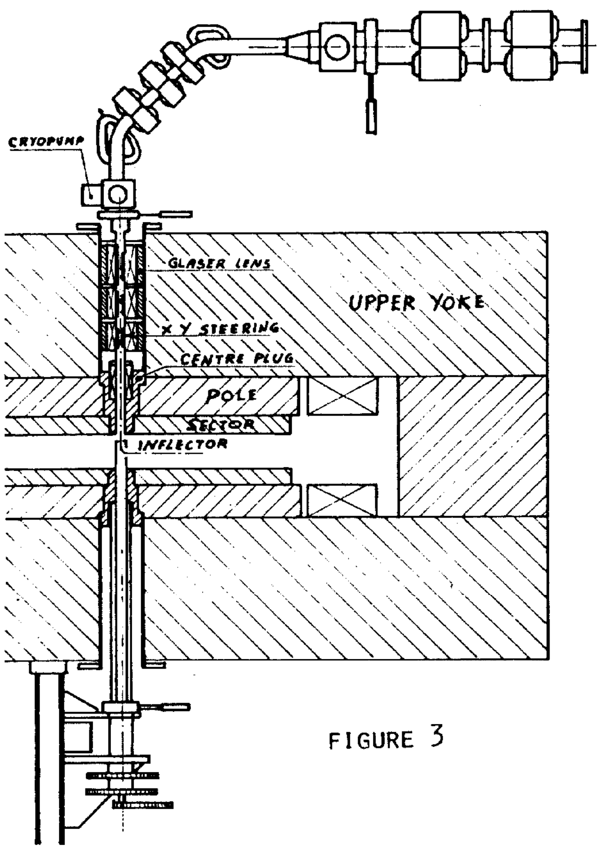

FIGURE 3

7. *Acknowledgements*

A project like ECREVIS is, evidently, the result of the efforts of a large team. The cyclotron operation and development crews did assemble the whole device. The institute workshop realized skillfully the numerous mechanical parts. The logistic staff brought to successful achievement all the orders and contracts with external companies requested by the project. Without their efforts and their experience, the project would never have come to life.

The whole project has been conducted under the direction of Professor P. Macq. His constant attention, the frequent meetings and countless fruitful discussions were the key of success.

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★ *Work supported by the Institut Interuniversitaire des Sciences Nucléaires, Belgium*

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