STATUS REPORT ON THE AGOR SUPERCONDUCTING CYCLOTRON

B. Launé for the AGOR group[++]

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Introduction

Construction of the K600 superconducting cyclotron AGOR, a joint undertaking of the KVI (Groningen, Netherlands) and IPN (Orsay, France), is underway. Details of the design have been published elsewhere[1] and will be briefly recalled : AGOR is a compact, 3-dee, 3-sector cyclotron, the main field is produced by a set of two superconducting coils and the beam is injected axially from external sources. The main parameters are summarized in table 1. Acceleration of both light and heavy ions will be possible, from 6 MeV/nucleon for heavy ions with charge to mass ratio of 0.1 up to 200 MeV for protons. It will be assembled and tested at Orsay before its final installation at Groningen. The status of the major subsystems will now be described.

Table 1 : cyclotron main parameters

Bending limit : Kb = 600 Focusing limit : Kf = 220
Pole diameter : 1.18 m
Main coil #1 max current density : 4271 A/cm^2
Main coil #2 max current density : 3270 A/cm^2
Central field range : 1.75 - 4.07 T
RF frequency range : 24 - 62 MHz
Operating harmonics : 2, 3, 4
Peak RF voltage in the center : 85 kV

Building

The building is ready at Orsay to house and assemble the cyclotron. That includes : i) a 6 x 8 m^2 and 5 m deep pit, digged in the experimental hall of the previous CEV cyclotron, that was dismantled; ii) a 50 t crane; iii) power and fluids distribution to main substations; iv) service areas for testing and assembling of subsystems.

Magnet

1) magnet steel : machining of the 320 t steel structure is on its final stage, delivery is expected in the beginning of April 89, that includes the six rings of the cylindrical yoke, the two main plugs with lifting and upsetting mechanisms, the two central plugs, the six hills and the twelve half-hills.

2) trimcoils : the construction of the 15 room temperature trimcoils has started and is progressing on schedule, with delivery expected in september 89. They are wound around each bloc of two half-hills; coils #2 and #3, #14 and #15 are used to produce a first harmonic of the magnetic field for beam centering and extraction respectively. Each branch is then powered independently so that a total of 23 power supplies is necessary. The manufacturer has been selected and ordering should occur in March 89 with delivery a year later.

3) field measurement : the mapping method developed for the NSCL K800 cyclotron[2] and also used for the Texas A&M K500 superconducting cyclotron has been selected. An absolute measurement is made at the center of the machine by a NMR probe and a search coil moving along a radial arm reads the field variation elsewhere on the median plane. Detailed design of the system is underway.

Superconducting coils

The two pairs of superconducting coils are housed in a "split" cryostat that provides free access in the median plane with the exception of six feedthroughs for support, power and fluid communication. The coils will be fully vacuum impregnated and thermal stability is improved by direct contact of liquid helium at all sides of the winding package. Ansaldo (Genova, Italy) has been selected and will deliver at Orsay at mid-1990 the complete system, after testing at 4 °K at the manufacturer site. The 30 km of the superconducting wire have already been ordered.

Helium liquifier

The external cryogenic system consists in :
- a liquifier/refrigerator with two compressors
- a 1000 l liquid helium dewar
- an intermediate 20 m^3/15 bar helium storage
- 80 and 4°K transfer lines.

The characteristics are given in table 2.
Sulzer (Switzerland) has been selected to produce the complete external cryogenic system. Delivery is expected at Orsay at the beginning of 1990.

Table 2 : External cryogenic system characteristics

Power 80°K	: 600 W	(required : 290 W)
Power 4°K	: 50 W	(required : 25 W)
liquid helium	: 15 l/h	(consumption : 11.5 l/h)

(in pure liquifier mode : 50 l/h)

RF system and vacuum chamber

A wooden full scale model of the resonator has been built and measurements performed on it : measured RF frequencies agree with calculation within 3 % in terms of short circuit position and voltage distribution along the gaps is also in the expected range. They also show that 32 kW of RF power are sufficient and current density in the short circuit will be limited to 35 A/cm. The liner acts as the vacuum chamber, it will be made of copper. Detailed studies of this piece, including 3D structure calculations, are underway, as well as for the resonator and their moving mechanisms, so that bids for the construction will be sent out in May 1989.

The delivery of the first RF amplifier will occur in April 1989 at Orsay by Herfurth (Hamburg, FRG). Prototypes of the low-level electronics modules have been tested and construction of the series has started.

Vacuum system

To reach the required vacuum quality, there will be two turbopumps located outside the machine and three cryogenic pumps located in the upper resonators. The scheme for cooling the cryopanels is original (see figure 1) : a commercial cryogenerator and condensers at the top, then a double heat pipe (nitrogen/hydrogen): the refrigeration power is transfered by gravity to the cryopump head. A prototype has been built and tested, in which charcoal is used for hydrogen pumping. Performances are above specifications for the pumping speeds.

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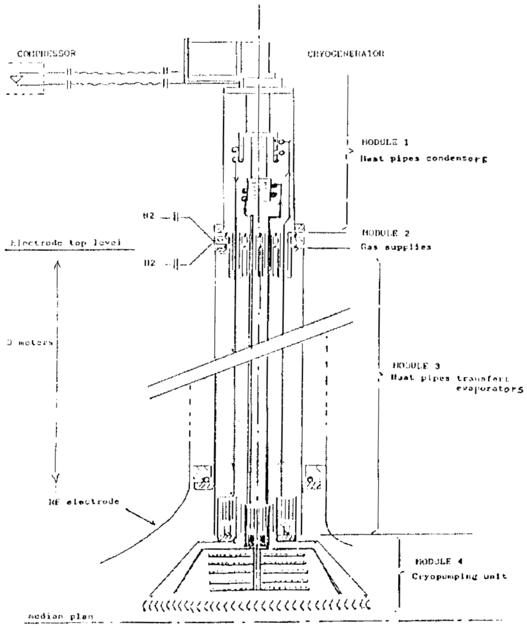

Figure 1 - AGOR Cryopumping System

Axial injection

The first part of the axial injection line (part "A" : source, Einzel lens, defining slits, analyzing magnet, faraday cup) has been built and allowed the testing of the light ion source that will be used for the tests at Orsay. The source is a multicusp type, built by IBA (Louvain, Belgium). Extensive tests were performed including emittance measurements (figure 2);

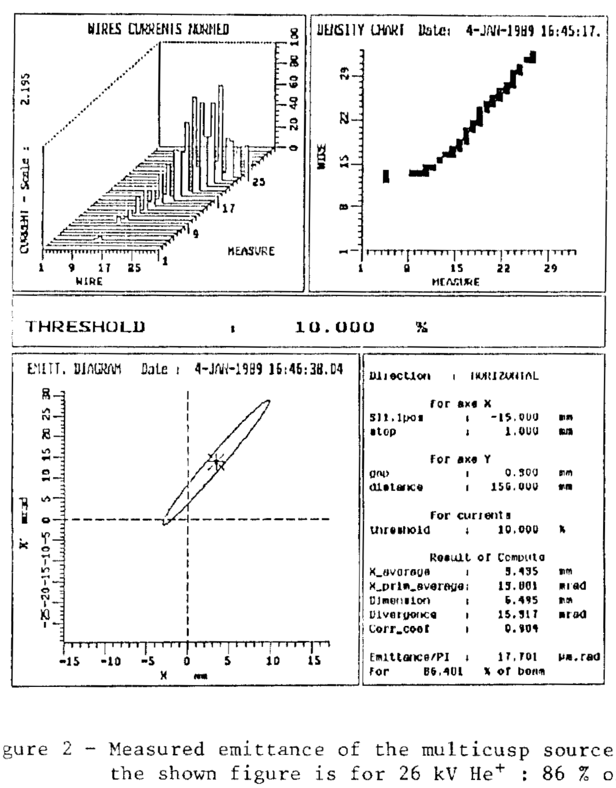

Figure 2 - Measured emittance of the multicusp source : the shown figure is for 26 kV He^+ : 86 % of a total current of 800 μA are within 17.7 πmm.mrad (normalized : 0.066 πmm.mrad).

they show that the source easily met the specifications. For the tests the control system was operational and performed in a very satisfactory way. Calculations of the rest of the injection line are underway and construction of the following section ("B" : from the analyzing magnet up to the vertical part) has started.

Extraction

1) Extraction calculations : new computer codes have been developed to study the acceleration and extraction in detail. First, an acceleration code takes into account the real spiral and radial voltage distribution of the gaps, uses cubic spline functions to interpolate the magnetic field and performs development of the magnetic field outside the median plane up to the fourth order in z. A beam is composed of 100 randomized particles starting at a radius of 0.1 m and accelerated up to the extraction radius where the harmonic coils excite the nur = 1 resonance in order to obtain a reasonable turn separation at the entrance of the electrostatic deflector. The beam is then tracked along the extraction path where one electrostatic deflector is followed by two magnetic channels (EMC1 and EMC2) which provide deflection and focussing (see figure 3).

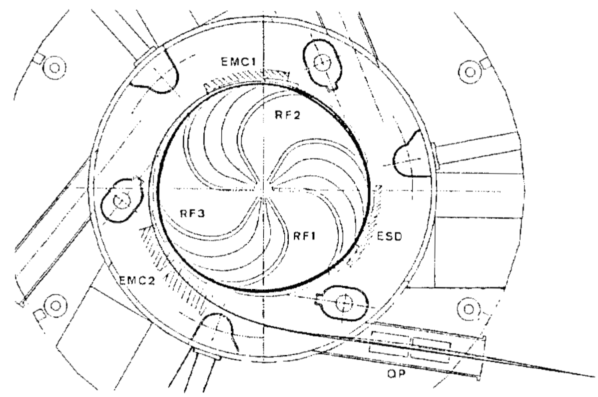

Figure 3 - Median plane section of the AGOR cyclotron showing the reference trajectories of the set of representative beams. The location of the extraction elements is indicated.

They are followed by two quadrupoles in the yoke and finally the beam reaches a common point outside the yoke. In a first step, gradients and fields of the channels are assumed uniform, and optimal form of the channel is then calculated after tracking of a set of representative beams. Realistic field maps of the channels are obtained and final calculations performed through "real" channels. An extensive study is underway. Single and multiturn extraction can be studied in this way and a good insight of the beam properties can be obtained.

2) Technical studies of the extraction elements :

a) ESD : The electrostatic deflector will be made in three parts to match the different beam trajectories. As the transverse electric field is reasonable (105 kV/cm), no prototype will be built.

b) EMC1 : a room temperature version has been selected as studies have shown that a superconducting one could not be built with a sufficient safety margin. The energy deposition of the beam in the thin septum is too large for the cooling that can be provided in order to avoid quenching. A model of the channel will be built in order to test the technical solutions.

c) EMC2 : More room is available and a superconducting version is foreseen. Scenarios of energy deposition of the beam are studied with a code that takes into account the multiple scattering in the materials. First insights show that it could be possible, but the final decision will be taken later.

d) Quadrupoles : superconducting versions are also planned but the studies remain to be done.

Diagnostics

A conplete diagnostics system is planned and includes :
i) a set of three centering probes in the center, one prototype of which is under construction;
ii) a radial probe that measures the beam current from 0.15 m up to the extraction radius, the probe head will be easily interchangeable, the detailed study has started;
iii) different probes along the extraction path (beam profile monitors : harps, and beam stops);
iv) a set of 13 phase probes for isochronization control, a prototype has been built and tested.

Control system

The selected system is based on an array of microVaxes using VAXELN linked by a Ethernet network, each one in charge of a subsystem. A central station can control any element and local consoles are foreseen at each subsystem for maintenance and diagnostics. The Intel Bitbus interfacing has been chosen and is used as much as possible (power supplies, PLC, motor control) while CAMAC is also supported. As mentioned earlier, this system is operational and performed in a satisfactory way for the control of the first part of the injection line.

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References

1) AGOR a superconducting cyclotron for light and heavy ions, S. Galès, Proceedings of the 11 th International Conference on Cyclotrons, Tokyo, 1986.

2) Plans for magnetic mapping of the MSU K800 cyclotron magnet, Proceedings of the 10 th International Conference on Cyclotrons, East Lansing, 1984.