THE DIAGNOSTICS SYSTEM FOR THE AGOR SUPERCONDUCTING CYCLOTRON

B. Launé, C. Olivetto*, J. M. Kaplanski, B. Montsanglant, P. Dambre, D. Vincent
Institut de Physique Nucléaire
91406 Orsay Cedex, France†

ABSTRACT

Although the diagnostics needs had been included in the design at an early stage of the project, the compactness and the energy/particle range of AGOR required special care in the design of the different probes: a set of 3 centering probes, an array of 13 phase probes, a straight radial probe (multihead, removable without breaking the machine vacuum), extraction probes (each extraction element has a profile monitor, multiwire or scanning wire, at the entrance and a beamstop at its exit). Full use of the Bitbus interface has been made in the design of the electronics (multiwire BPM, current and phase measurement).

1. INTRODUCTION

The compactness of superconducting cyclotrons requires that the diagnostics needs be included in the design at an early stage of the project: space constraints would forbid further addition of probes. From the beginning it was decided to implement a complete system in order to make tuning as easy as possible and to be able to reach the desired beam quality.[1)] As a matter of fact, this is almost compulsory considering the broad energy/particle range of AGOR (6 MeV/nucleon heavy ions up to 200 MeV protons) and the accordingly complex extraction. In addition, radiation resistant harware had to be used. As will be described in details, automatic tasks are foreseen that make full use of the computer control system and the Bitbus interface. The layout of the internal beam diagnostics systems is shown in Figure 1 and consist in i) three dedicated centering probes ii) an array of 13 phases probes iii) a radial probe with interchangeable heads iv) extraction probes. This system will now be decribed in details, after having recalled the axial injection line diagnostics hardware.

*Present address: Centre de Physique des Particules de Marseille, Luminy, Marseille, France.

†Work jointly supported by the Institut de Physique Nucléaire et de Physique des Particules (IN^2P^3), France and the Stichting voor Fundamenteel Onderzoek der Materie (FOM), the Netherlands.

2. AXIAL INJECTION LINE

The axial injection line has been described elsewhere[2)] and the diagnostics equipment is the following:

- current measurement units (I/V converters) connected to Faraday cups and slits,
- beam Profile Monitor (BPM) : 32-wire harps,

For both systems the same electronics as for the internal probes will be used, but with different ranges. See the electronics section for a complete description.

3. BEAM CENTERING

3.1. Principle

Beam centering is essential for beam quality; measurement and control of centering is highly desirable in order to ensure efficient extraction. The principle of the centering determination is the following:

Assuming that ν_r=1 and that acceleration is continous, one can write the beam radius at azimuth θ_i:

$$R(\theta_i) = R_0 + A\sin\theta_i + B\cos\theta_i + \frac{\theta_i}{2\pi}\Delta r \quad (1)$$

A and B represent the centering error, R_0 a reference radius and Δr the energy gain per turn. At least three different angles θ_i are necessary to find A and B. It was then decided to implement three dedicated probes at 120°. As far as radius is concerned, measurements should occur when the turns are well separated but on the other hand correction has to be accomplished and checked: trim coils 2 and 3 are used to produce a first harmonic such as their combined effects vanish at the measurement location. The selected radial range is therefore 250-300 mm. Beam centering will be made by measuring the effect of one given first harmonic and the same dephased by 90°, enabling the calculation of the correction matrix. Computer simulation has shown that a reasonable precision can be achieved in this way. The radial probe will be used to stop the beam and be sure that one selects the right turns to solve system 1.

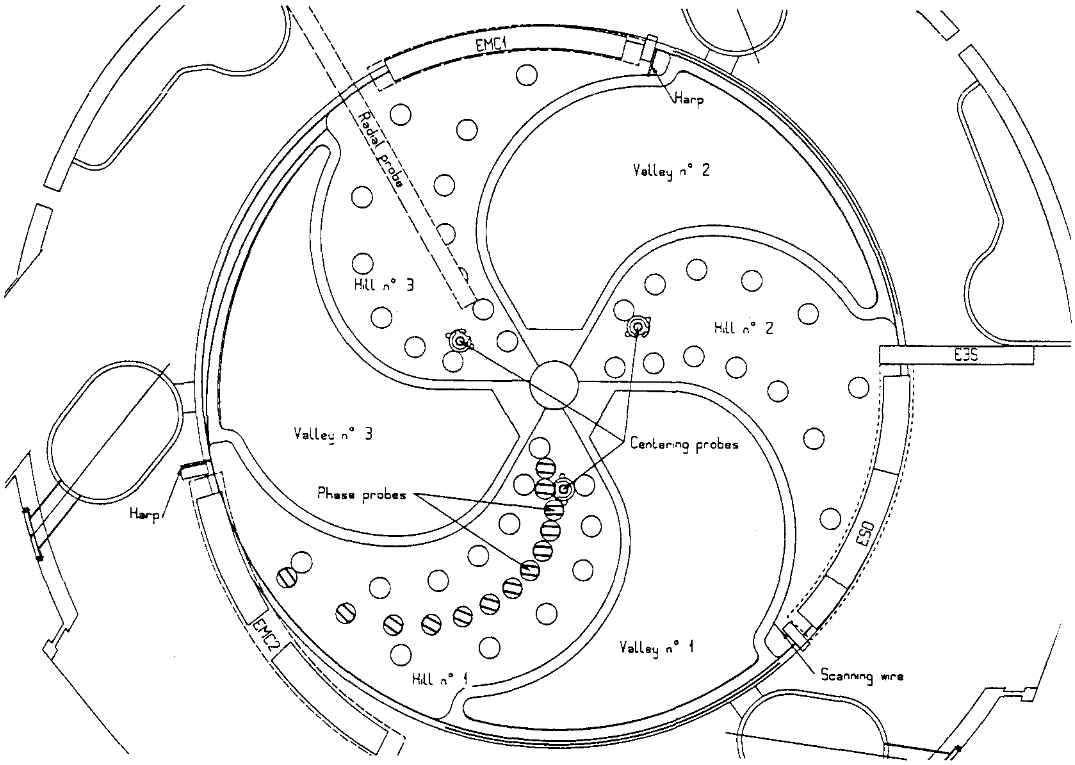

Fig. 1. Layout of the beam diagnostics equipment.

3.2. Centering probes

The lack of space in the center of the cyclotron makes the design of a probe very difficult. A first design was based on a trolley pulled by a string, actuated through a hole in the yoke. A step in the track made the wire flip. A prototype has been built and tested, but failed to sustain a sufficient number of travels. It was then decided to use a different principle: the new one is based on rotation instead of translation and Fig. 2 shows pictures of the probe where the wire is at rest and in a measurement position. The probe is bolted into the vacuum chamber and rotation is accomplished by a tube through the yoke, on top of which a stepping motor is located.

4. PHASE PROBES

A set of 13 non interceptive electrostatic pick-up probes has been implemented in one hill, taking advantage of the "little valley". The probes are bolted into the massive copper vacuum chamber; a 50 Ω coaxial feedtrough and a metallic seal ensure vacuum tightness.

As it is already implemented in others cyclotrons,[3] the data of the phase measurement will be used on-line by a program to calculate the corrections to apply to the main and trim coils in order to obtain the desired phase law; the program has been written and tested using simulated data.

5. RADIAL PROBE

The purpose of the radial probe is to stop and measure the beam from the center up to the extraction radius (see Fig. 3). The low hill spiralisation allowed a straight travel from a radius of 180 mm up to the exit of the extraction elements: electrostatic deflector ESD or first electromagnetic channel EMC1, as the probe has two possible locations. Multihead system was mandatory, considering the functions to be fulfilled and the kind of accelerated beams. The heads are common with the E3S extraction probe (see below); an absolute/differential and a five-finger probe heads have been built (see Fig. 4).

The motion has been divided in two:

- a measurement motion (770 mm), powered by a DC-current motor, the position is given by an absolute encoder and vacuum tightness ensured by bellows.

- a withdrawal motion (1400 mm), powered by a stepping motor, with a sliding seals sytem, that allows the insertion of a valve for head changes.

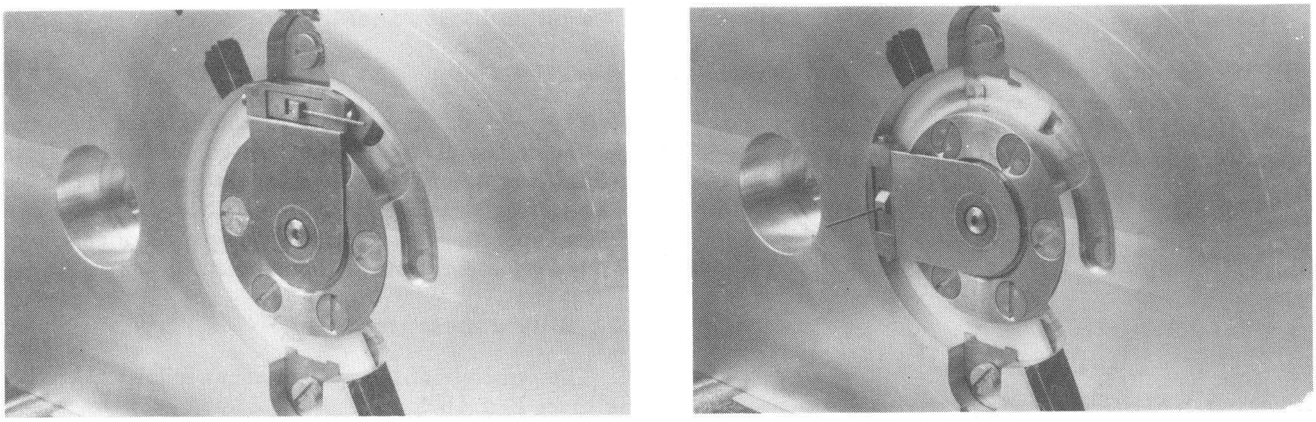

Fig. 2. The centering probe shown at rest (left) and at a measuring position (right).

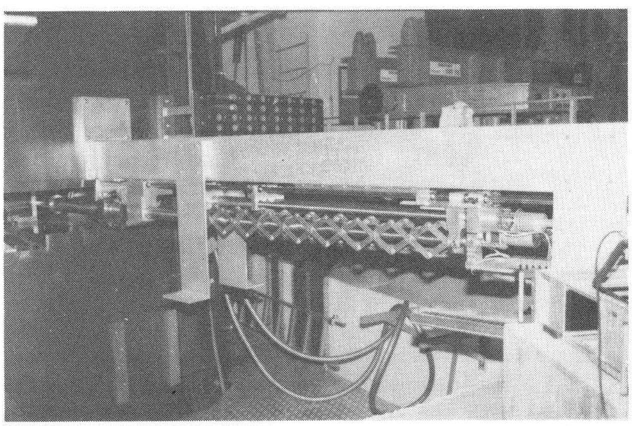

Fig. 3. The radial probe aligned on the cyclotron.

6. EXTRACTION PROBES

Considering the difficulty of the extraction system, a efficient diagnostics system would be particularly helpful. The following guidelines have been followed:

- measurement at entrance and exit of each element,
- beam profile and position at the entrance,
- beam stop at the exit,
- monitoring of losses on each entrance collimator.

We will now review in detail each extraction element:

6.1. ESD

At the entrance, a fast scanning wire allows the control of the beam separation and of the bump tuning, a dedicated probe (E3S) stops and measures the beam at its exit (this probe is compatible with the radial probe, but with a reduced travel: 80 mm); the probe follows the motion of ESD as turn separation between internal and extracted beams is small, it also checks the internal current, allowing efficiency measurement.

6.2. EMC1

The profile and position at the entrance with respect of the channel will be measured by a BPM, based on secondary emission (32-wire harp), that can be withdrawn (see Fig. 5). The compactness of the multiwire board has required construction of a prototype. The beam is mesured and stopped at the exit by the radial probe.

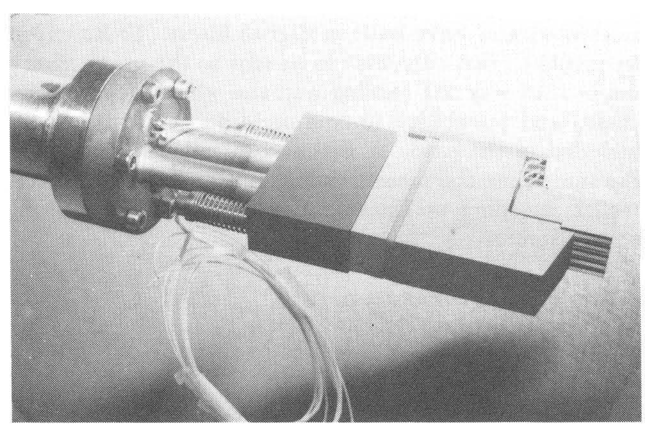

Fig. 4. Five-finger head mounted on the E3S probe.

6.3. EMC2

At the entrance, there is the same sytem as for EMC1, but because of space limitation, no probe could be located at the exit of this superconducting channel.

6.4. QP's

BPM's measure the beam horizontal position and profile at the entrance and exit, while vertical ones are checked at the exit. Beam stopping is accomplished by a Faraday cup located after the second quadrupole.

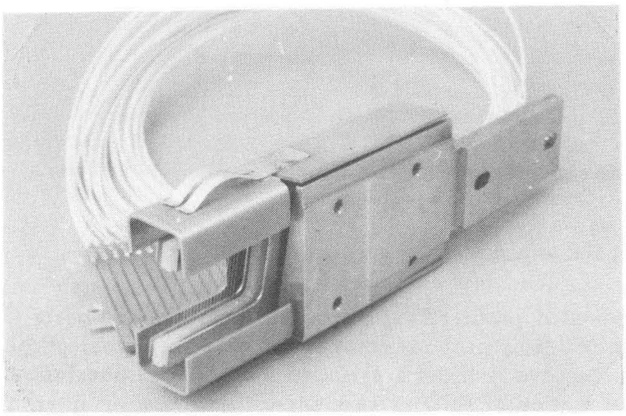

Fig. 5. 32-wire harp located in front of EMC1.

7. ELECTRONICS

7.1. Current measurement

High precision, wide range units are necessary to measure the current on both axial injection and accelerated beam probes. I/V converters have been built to be mounted directly on a Bitbus crate. Commuting the counter-reacted resistor allows the range selection: only three different resistors are necessary by using 16-bit Analog-to-Digital Converters, that are also self-calibrated and have built-in digital filters (10 Hz cut-off frequency). Test currents (to be sent to the probe, checking in that way the cabling and the whole measurement chain) and possibility to command an actuator are also included in the card. A Bitbus controller commands at the same time the measurement unit and the motor controller, speeding up the scanning of a probe for a profile acquisition.

7.2. Profile measurement

A modular set of 5 cards on Europe-size crate is assembled for each BPM:

- an I/V conversion card, with 32 amplifiers, a multiplexer followed by a variable amplifier providing the dynamic range. SMC technology and four-layer, double sided boards are used,
- a second I/V card if both vertical and horizontal profiles are measured,
- an ADC card,
- a Bitbus interface card,
- a power card.

The value of the resistors are 500 kΩ for the axial injection units and 50 MΩ for extracted beam ones. Tests performed on the KVI beam lines showed a noise of 2.5 pA. The local intelligence in the Bitbus controller can perform operations such as averaging or elimination of off-sets by measurement without beam.

7.3. Phase measurement

The principle of the measurement follows GANIL's one[3] (see Fig. 4):

- a multiplexer selects the probe number, signals from top and bottom are then summed,
- due to the position of the probe, a large pick-up at the fondamental of the RF frequency is expected:
  - measurement is made at twice the RF frequency,
  - a front-end filter cancels the fondamental. Its principle is to split the signal in two, delay one way by the amount that corresponds to 180° at the fondamental and recombine: all odd components should be eliminated. In order to avoid the use of an expensive delay line, a system based on a combination of fixed delay and variable phase shifter operating at a fixed frequency (160 MHz) will be tested.
- the phase measurement is made at a fixed frequency: 21.4 MHz (heterodyne method) by multiplying the signal with the resonator reference at 0° and 90°, producing signals proportionnal to the sine and cosine of the dephasing (I/Q detector), values that are converted in digital by the same ADC as used in the I/V's, then delivered to Bitbus,
- doubling of the reference will use a Phase Lock Loop to improve the spectral purity if necessary.

8. REFERENCES

1) AGOR: Cyclotron Design Report, October 1986.
2) M. Malard et al., "AGOR Axial Injection, using a Positive Light Ion Multicusp Source", in **Proceedings of the Twelfth International Conference on Cyclotrons and their Applications**, Berlin, 1989.
3) A. Chabert, F. Loyer, J. Sauret, "Beam Tuning and Stabilization using Beam Phase Measurements at GANIL" in **Proceedings of the Tenth International Conference on Cyclotrons and their Applications**, East Lansing, 1984.