

# BEAM DIAGNOSTICS DESIGN FOR A COMPACT SUPERCONDUCTING CYCLOTRON FOR RADIOISOTOPE PRODUCTION\*

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## Abstract

The aim of the AMIT cyclotron is to deliver an 8.5 MeV, 10  $\mu$ A CW proton beam to a target to produce radioisotopes for PET diagnostics. Such a small cyclotron poses some challenges to the diagnostics design for commissioning and normal operation due to its small size, so miniaturized devices should be built in order to fit in the available space. Two sets of diagnostics have been designed, each one aiming at a different phase of the machine lifecycle. During normal operation the stripping foil and the target will be used to measure the current, a dual transverse profile monitor based on a scintillating screen will be used for interceptive measurements and a Fluorescence Profile Monitor will measure the beam position and the horizontal profile without intercepting the beam. During first stages of commissioning the dual transverse profile monitor and the target will be substituted by an emittance monitor based on a pepperpot to characterize the beam at the cyclotron exit. Also a movable interceptive Beam Probe will be located inside the cyclotron to give information about the beam during acceleration. Additionally, a test bench for the characterization of the beam right after the exit of the ion source has been built with different instruments to measure the beam current and the transverse profile. In this paper the present status of the design, simulation and tests of the diagnostics for the AMIT cyclotron are described.

## INTRODUCTION

The use of PET as a diagnostic tool in the cancer diagnostic field has risen the demand of suitable radionuclides. Some of the most used radioactive atoms have relatively short lifetimes (few hours at max), which constrains the distance of the medical diagnoses centers to the radioisotope producing facilities. To overcome this limitation a compact cyclotron provides a good solution to this problem, because its small size makes it easy to allocate in small medical centers, allowing the distribution of the radioisotopes to cover as much area as possible.

The AMIT cyclotron (Fig. 1) tries to improve the size and cost efficiency limitations by a careful study of the beam dynamics [1] and the electromagnetic design [2]. It uses two superconducting coils to provide the 4 T magnetic field and a 180° Dee attached to the RF cavity to accelerate H-ions produced by a cold cathode Penning Ion Source. The machine aims to deliver a 10  $\mu$ A beam of 8.5 MeV protons

to irradiate two different targets (one at a time) in order to produce the required amount of  $^{11}\text{C}$  and  $^{18}\text{F}$ .

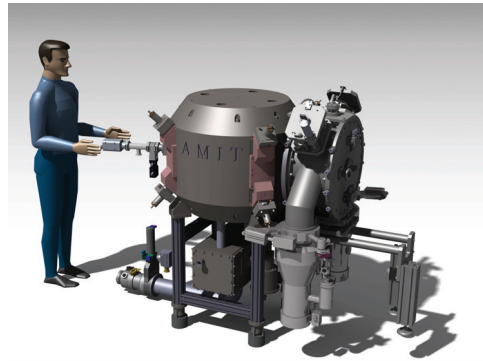


Figure 1: CAD design of AMIT cyclotron.

## MACHINE OPERATION

The main challenge of this cyclotron with respect to the beam diagnostics is compactness. At 4 T and 8.5 MeV the proton bending radius is about 10 cm, limiting enormously the beam diagnostics which can fit inside the cyclotron. Different sets of diagnostics were proposed for the cyclotron's different phases [3]:

1. **Phase 1: Ion Source Characterization.** In this first stage a special test bench (Fig. 2) has been constructed to measure different beam parameters right after the exit of the ion source. This will help to verify and optimize the ion source prior to the assembly in the cyclotron.
2. **Phase 2: Beam Commissioning.** This phase consists of a few subphases, corresponding each one of them at different energy ranges:
  - (a) Low energy: In this phase the proper operation of the ion source and the correct alignment between puller and source and first turns is checked.
  - (b) Intermediate energy: Optimization of the acceleration from the injection up to the stripping foil.
  - (c) Beam delivery at target: Commissioning of the stripping foil and beam transport up to the target and its commissioning.
3. **Phase 3: Operation.** Normal run of the machine with the continuous production of the required radioisotopes.

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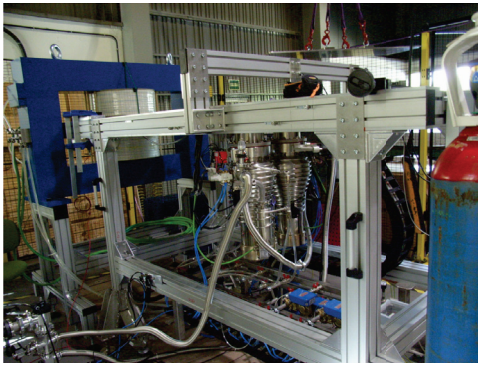


Figure 2: Test bench built for Phase 1 in order to characterize the Ion Source.

### DIAGNOSTIC LAYOUT

The diagnostic layout of **Phase 1** consists of an intercepting beam probe (Fig. 3) to measure the total beam current and a wire scanner to measure both the vertical and horizontal profiles of the beam. The current readings are performed simultaneously by a Keithley 6485 Picoammeter and with the measure of the voltage drop in a shunt resistor. Due to the low beam power (less than 1 W) no special thermomechanical requirements are needed, hence a simple stainless steel probe and copper wires are used. During this phase we have been steadily increasing the voltage extraction and the beam current. So far more than 100  $\mu\text{A}$  have been extracted at 1.8 kV and continuous progress is being made.

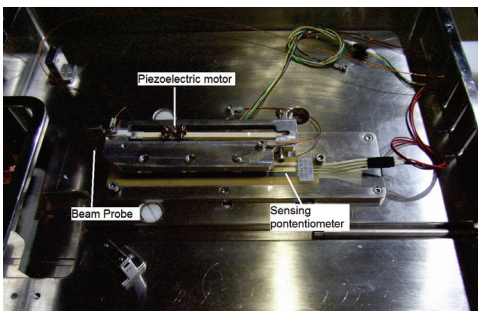


Figure 3: First mechanical test of the beam probe in Phase 1. The final design of the system for the cyclotron improves accuracy and reduces the size.

During **Phase 2** the only possible diagnostic to employ is the moveable beam probe inside the cyclotron. The mechanical design of the probe is similar to the one shown in Fig. 3, albeit with a few changes to improve the design tested in Phase 1. Graphite has been chosen for the probe in order to withstand the 85 W continuous beam power in an area of few square millimeters and keep its activation as low as possible for easy maintenance. Simulations of the maximum temperature over time performed with ANSYS show that the probe should withstand CW operation mode although the RF system is capable of pulsed mode. Results are shown in Fig. 4.

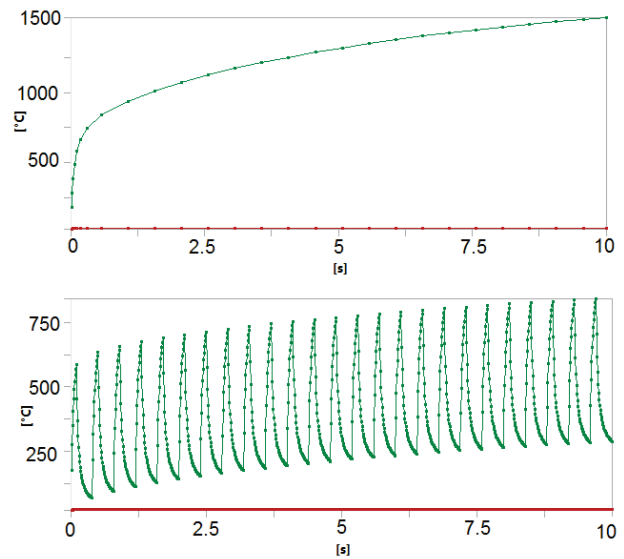


Figure 4: Max temperature with a step pulse at nominal power (top) and maximum temperature evolution with a pulsed beam of 400 ms period and 25% DC (bottom).

After the H- complete acceleration, it is stripped of its two electrons by means of a carbon foil. Another current measurement is integrated in this stripping foil to measure the beam current deposited in the foil. Just after the exit of the cyclotron is located the Compact Diagnostic Line (CDL). This short beamline (Fig. 5) will be installed in both **Phase 2 and Phase 3**, being interchanged with the energy monitor during the former and left alone during the later phase.

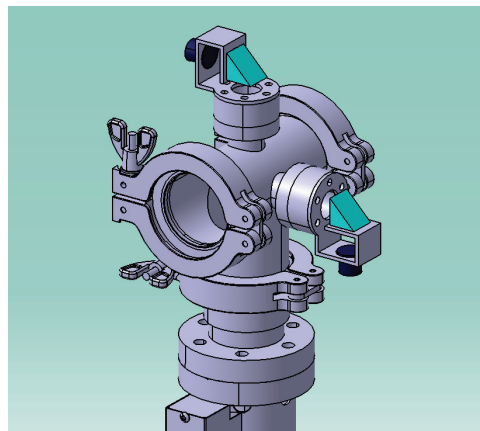


Figure 5: CAD design of the CDL. The prisms (in turquoise) reflect the fluorescence light to the micro video lenses (black) which are attached to the image fibers (not shown) and will be covered to avoid stray light getting into the system. The device in the bottom is the pneumatic actuator which moves the  $\text{Al}_2\text{O}_3$  screen.

The current and energy measurements will come from a dedicated energy monitor. With this information we will be able to evaluate the beam losses in the transport from the stripping foil to the target and the position.

A pepperpot based emittance measurement device has been chosen to characterize the beam during commissioning. In its design the same considerations of the Beam Probe were taken into account, albeit it is expected to activate less the the BP due to its use only during commissioning.

The transverse profile is given by two independent methods, an  $\text{Al}_2\text{O}_3$  fluorescent screen and a Fluorescent Profile Monitor. Both of them share the same optical system, although they are intended for different uses. The screen is dedicated to the commissioning phase and initial tuning during normal operation and the FPM intended to monitor the beam during the irradiation. Due to the small available space for diagnostics the compactness of the diagnostics was a very strong requirement that influenced all the design process, for this reason we choose an approach based on image fiber bundles and micro video lenses, which are capable of delivering the images where camera lies down. Because of the small light output of the residual gas fluorescence [4] a detector based on an image intensifier and a CID camera was chosen, with the possibility to install a gas leak valve to use different gases to enhance both the light output and profile accuracy [4]. It has been also foreseen the possibility to install an optical filter wheel to select different transitions. In our case a rough estimation of the signal strength interpolating the results obtained in [5] gives a cross section about  $10^{-18} \text{ cm}^2$ , which results in a photon yield in our nominal conditions about  $10^9$  photons generated per second in one meter length. It is not a very high number after taking into account the transmittance losses and the aperture of our optical system, which justifies our decision of using a gas leak valve to enhance the S/N ratio of our detector.

Additionally, two beam loss monitors are going to be installed during commissioning and normal operations to

check the radiation levels, one of them for gamma rays detection and the other aiming at the neutrons.

## CONCLUSIONS

A set of diagnostics has been designed and constructed to be installed in the AMIT cyclotron. It includes interceptive devices which are very reliable and are well established in the field with non-interceptive ones which can provide information without affecting the beam. Although the size requirements are very strict the designed instruments fit into the specifications and provide measurements of the beam parameters during commissioning and normal operation.

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