IBA C70 CYCLOTRON DEVELOPMENT

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Abstract

Since the end of 2005, IBA has been working on the development of the 70MeV Cyclone, the ARRONAX Cyclotron for the Region des Pays de la Loire in Nantes, France. First of a kind for IBA, the accelerator is equipped with two external ion sources (a multicusp and an ECR) so as to produce 4 types of particles, in particular high intensity, variable energy H^- (30 - 70MeV, 750µA) and fixed energy $^4He^{2+}$ (70MeV, 35pµA). Moreover, the $^4He^{2+}$ beam can be pulsed. The unique magnet structure is composed of three layers: sector, pole and pole cover. Furthermore, compensation coils are wound around each of the poles in order to obtain the different isochronous fields. The RF system at about 30.4MHz consists of a 100kW RF amplifier coupled to a home made cavity. Extraction is then obtained either by stripping or by electrostatic deflection. Finally, two switching magnets redirect the beam to one or two of the 6 transport lines used for R&D applications or radioisotopes production. The overview of the development of the cyclotron subsystems following a tight schedule will be presented.

INTRODUCTION

The Cyclone® 70 is an ambitious project that occupies a major role in the R&D activities of IBA's Technology Group business unit. This unique cyclotron is a powerful and flexible tool that is the answer to the radiochemistry and oncology needs related to the ARRONAX (Accélérateur Recherche Radiochimie Oncologie Nantes) project [7]. For the development of this prototype, IBA has concentrated its twenty plus years of expertise in cyclotron technology. Indeed, the Cyclone® 70 is a mixture of proven techniques commonly used in models like the Cyclone® 30 and the Cyclone® 230 to which newly developed technology related to the particular specifications of the accelerator, namely the combination of alphas and protons, is added. IBA accepted the challenge of delivering this multi facet cyclotron in an extremely tight schedule of thirty four months. Thus, end of September of 2008, the Cyclone® 70 shall be in the hands of its end users, capable of producing a large spectrum of radio-isotopes (PET, SPECT and Therapeutic).

SCOPE

The deliverables of the Cyclone® 70 project are the following:

- Multi particle cyclotron with the following beam characteristics:

Table 1: Beam Characteristics

Accelerated Beam	Extracted Beam	Extracted Energy (MeV)	Beam Intensity (eµA)	Exit Ports
H^-	H^+	30 - 70	750	dual
D^-	D^+	15 - 35	50	dual
$^4He^{2+}$	$^4He^{2+}$	70	70	single
HH^+	HH^+	35	50	single

The cyclotron is composed of two exit ports allowing for dual beam extraction for protons and deuterons. Alphas and molecular hydrogen are exclusively extracted on the electrostatic extraction port.

- Six beam transport lines (one of the lines divides up into three transport lines)
- Four solid targets
- Alpha pulsing system installed on one of the lines.
- Control system and user interface

PROJECT DEVELOPMENT LIFE CYCLE

The master schedule of the project can be summarized as follows:

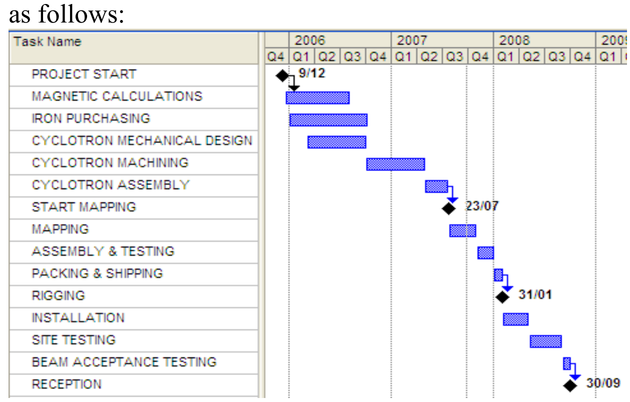

Figure 1: Master schedule.

The schedule presents diverse challenges, technical and logistic.

On the technical side, the magnetic calculations were the first major challenge [5]. At this stage the choice of using correction coils to profile the alpha magnetic field was a turning point for the development of the machine. This choice steered the magnetic design to a unique inner iron configuration composed of three specific layers: a sector, a pole and a cover. The correction coils are wound around the pole. Moreover, the combination of alpha and proton extraction needed particular attention in defining the magnetic configuration for the transition from the hill magnetic field to the outside of the machine.

The mechanical design presented a delicate problem concerning the iron pileup so that the magnetic gap could be precisely guaranteed. The retained solution was the use of carefully machined spacers between each part that ensure the final gap [4].

The machining phase was a major challenge for both IBA and the sub-contractor [4]. To ensure the quality of the results, the collaboration between the two was very intense. During the last two months of the machining, identified as the critical period during which the parts were reaching their final dimensions, a day to day follow-up ensured an almost perfect result. To map the cyclotron, a new measuring system was developed with the constraint of being able to move in a particularly narrow magnetic gap (30mm) [3].

Presently the mapping is on going and the results obtained until now are very promising. First, the correction coils have been validated. Despite the amount of mechanical problems related to the integration of these coils around the pole as well as their fragile design (prototypes), their magnetic characteristics are in line with expectations. This validation allowed us to rework the coils design and purchase the final set of 8 coils. Before expedition to Nantes, a last mapping with the full set of coils has been planned.

Secondly, the main magnetic field measurements also fit with the models. After a first iron correction, physicists are optimist about isochronising the machine for proton particles in just a few iterations before the end of October. The analysis of the magnetic measurements is being interpreted in collaboration with the company AIMA.

The end of the mapping will lead the project to an assembly phase during which the vacuum chamber, RF cavities, central region and eventually the sources will be integrated for preliminary testing.

The central region calculations were equally an important phase driven by the constraint of accelerating protons and alphas with the same design. This compromise led to a particular form of the inflector as well as the use of an electrostatic deflector for beam centring [2].

In parallel to the activities linked to the construction, machining and assembly of the iron parts, an enormous effort is being put into the design of the different sub-systems: double source bench, injection line, RF system, electrostatic deflector, beam transport lines, alpha pulsing system and the control system. Part of these developments were carried out in collaboration with industrial partners namely, Sigmaphi for the magnetic elements (main coils, injection line magnets and beam transport line magnets) and Pantechnik for the final RF amplifier as well as the Supernanogan® source for alphas. Moreover, the extraction study was done in collaboration with Dr. J. Fermé [1].

Being driven by a tight time scale, the project activities were executed as much as possible in parallel mode. Nevertheless, the development imposed a minimum of sequential phases which defined the critical path of the project: magnetic calculations, mechanical design, cyclotron machining and presently the mapping phase.

Before shipping the cyclotron, the goal is to perform as many unit and integration tests as possible to reduce the risk of having to deal with major problems during the 8 months of installation and testing on site.

GENERAL DESCRIPTION

The Cyclone® 70 is an isochronous, fixed magnetic field and RF frequency, cyclotron with a diameter of just under 4m weighing over 120T. Its main sub-systems are here briefly outlined:

Magnet structure

The cyclotron is based on the deep valleys concept, used on the other IBA models but distinguishes itself by its particular magnet structure composed of three layers and specific magnetic extraction channels [5].

Sources

Two sources, a multi-cusp and an ECR source will deliver the different beams. This configuration is a first for IBA. The equipment is mounted on the source bench which includes the injection line. The bench is a sub-system that can be tested independently [2].

Injection and central region

The injection line and the central region are detailed in the [2]. A part from the constraint of accelerating alphas and protons, the configuration of the injection line and central region will also play an important role in achieving the 750µA extracted proton beam.

RF

The RF system is composed of a 100kW amplifier and a 3.5kW pre-driver, controlled by an IBA low level controller. The working frequency is around 30.4MHz. The RF cavity is a home made design based on a CST model. It is composed of two dees and four accelerating gaps. The accelerating voltage is 65kV and around 20kW of power is needed to sustain it. Particles with a q/m = 1 are accelerated in harmonic mode 2 and those with q/m = ½ in harmonic mode 4.

Vacuum

The vacuum system is composed of four cryogenic pumps of 5800l/s. The principle chamber is split in the median plane and two extraction chambers ensure the connection to the two switching magnets.

Extraction systems

The different beams are extracted by two specific extraction systems:

- Electrostatic deflector ($^4He^{2+}$ / HH^+)
- Strippers (H^- / D^-)

The design of the deflector has been adapted and optimised for alpha extraction. It is very similar to the one used in the Cyclone® 230 but incorporates a pre-septum [1].

From a maintenance and radioprotection point of view, the deflector has also been modified to reduce the operator's exposure and facilitate its insertion and removal from the machine. As for the stripping mechanism, modifications to the Cyclone® 30's model were done for cooling reasons. The cyclotron is equipped with two stripping mechanism installed on each beam port. This allows for dual beam operation with the corresponding particles. At its highest capacity, the cyclotron will accelerate more than 50kW of proton beam in dual beam mode.

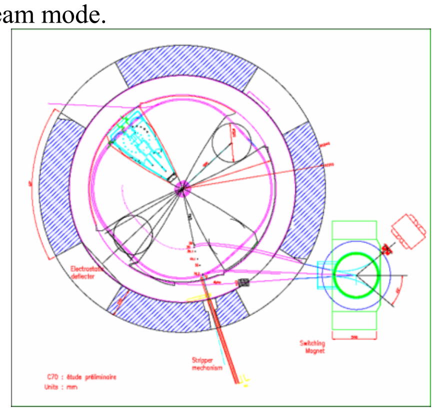

Figure 2: Extraction trajectories

Beam Transport Lines

Through its two ports and by means of two external switching magnets, the cyclotron can deliver beam to six different beam lines. Each beam line has its end point in an independent vault. One of the three beam lines installed on the beam port equipped with the electrostatic deflector divides up into another three lines (much shorter) inside the corresponding vault.

Each line is composed of multiple magnetic elements for focusing and steering as well as diagnostic equipment (faraday cups, viewers, profilers, current measurement).

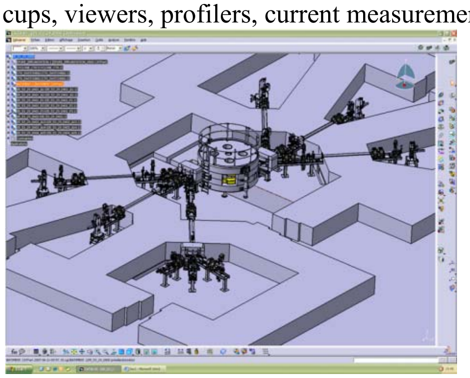

Figure 3: Beam transport lines

Solid targets

Four standard copper solid targets will be delivered for the production of common radioisotopes (^{201}Tl, ^{67}Ga, ^{111}In). Moreover, IBA and SUBATECH are collaborating to develop a universal target support so that the spectrum of radioisotope production is widely increased (^{211}At, ^{82}Rb, ^{67}Cu).

Alpha pulsing system

The configuration of the beam line that splits into three shorter lines includes an alpha pulsing system that IBA is currently developing. The concept is based on a radiofrequency deflector. The scope is to deliver beam pulses with a repetition rate going from 0.66µs to a few seconds with a pulse width of 4ns.

Control system and user interface

The control system is based on a Siemens S7 PLC. The user interface is based on the existing Cyclone® 30 interface developed with InTouch.

BUILDING REQUIREMENTS

The infrastructure required to install the cyclotron and its beam lines is illustrated in figure 4:

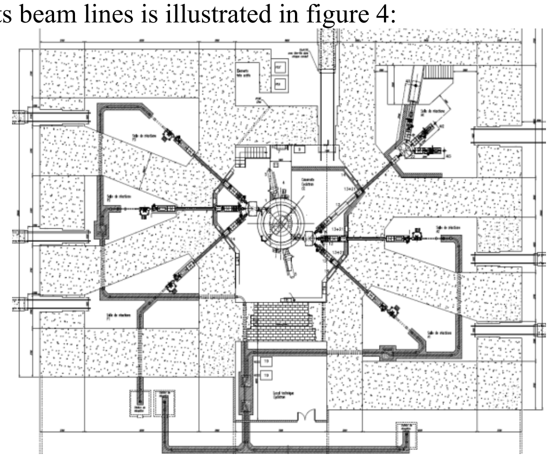

Figure 4: Cyclotron building

The figure illustrates the main cyclotron vault surrounded by six irradiation vaults. The building is 40m long and 28m wide and composed of 10 000m³ of concrete. The insertion of the cyclotron will be done horizontally.

The target transport system (in grey) allows the feeding and the reception of targets from two radiopharmaceutical laboratories.

REFERENCES

[1] D. Vandeplassche et al., Extraction Simulations for the IBA C70 Cyclotron, these Proceedings.

[2] W. Kleeven et al., Injection and Central Region Design for the IBA C70 cyclotron, these Proceedings.

[3] Y. Paradis et al., The Magnetic Field Mapping System for the IBA C70 Cyclotron, these Proceedings.

[4] W. Beeckman et al., Machining and Assembly of the IBA C70 Cyclotron Magnet, these Proceedings.

[5] S. Zaremba et al., Magnetic field design and calculations for the IBA C70 Cyclotron, these Proceedings.

[6] J. Martino, ARRONAX, a 70MeV Cyclotron for Radiochemistry and Nuclear Medicine, these Proceedings.