A NEW DESIGN OF TRULY SELFSHIELDING BABY-CYCLOTRONS FOR POSITRON EMITTER PRODUCTION

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ABSTRACT

The very successful design of the CYCLONE 30, a 30 MeV H⁻ cyclotron gave birth to an original design of truly selfshielding baby-cyclotron dedicated to positron emitter production. This new negative ion cyclotron will deliver 10 MeV protons and 5 MeV deuterons. Up to eight targets are located inside the circular return yoke of the magnet which serves as a primary neutron and gamma ray shield. The cyclotron is embedded in an additional neutron shield made of borated-hydrogenated material. One of the main goals of the design is the ease of access to the targets and to the cyclotron inner parts without compromising the shielding efficiency. Any combination of two opposed targets can be irradiated simultaneously. Finally, the size and weight of the proposed system are considerably reduced compared to those of existing cyclotrons.

INTRODUCTION

Positron Emission Tomography is now a rapidly developing imaging technique for in-vivo studies. Recent advances in target technology allow production of up to one Curie batches of the four most commonly used positron emitters (^{11}C, ^{13}N, ^{15}O, ^{18}F) using only low energy protons. However, the possibility of accelerating low energy deuterons offers some advantages: it removes the need for expensive ^{15}N enriched gas as target material for the production of ^{15}O and also enables the production of moderate amounts of $^{18}F_2$ by the $^{20}Ne(d,\alpha)^{18}F$ reaction. The self-shielded baby-cyclotron, CYCLONE 10/5, similar in design to CYCLONE 30 [1], [2], [3] is specially designed for this purpose.

GENERAL DESIGN FEATURES

The choice of the optimum energy for a baby cyclotron is a compromise between conflicting goals: optimizing production yields requires energies as high as possible, whilst the amount of material required to shield the cyclotron is strongly dependant on the energy of the neutron emitters, thus on the energy of the primary beam. Developments at IBA have shown that appropriate amounts of the four classical positron emitters could be obtained with 10 MeV protons and 5 MeV deuterons only.

The new cyclotron uses the same general design as CYCLONE 30 with four straight sectors and deep, essentially field free valleys with the rf resonators installed in two opposite valleys. The negative ion technology used ensures 100% extraction efficiency, ease of tuning and enables targets directly connected to the vacuum chamber to be irradiated. But, unlike CYCLONE 30, CYCLONE 10 is a truly self-shielding cyclotron, the external shielding, the cyclotron body, as well as the eight targets, are designed as complementary units. This feature optimizes the total shielding since the cyclotron yoke serves as primary shielding. This design also reduces significantly the size and weight of the system compared to existing cyclotrons.

MAGNETIC STRUCTURE

The unusual magnet structure of CYCLONE 30 combines the advantages of both separated sector cyclotrons and solid pole cyclotrons and reduces considerably the electrical power consumption [4]. Therefore the same magnetic structure was chosen for CYCLONE 10.

The hill angle is selected to maximize both the vertical focusing and the average field. The hill angle is proportional to the radius to provide an isochronous field up to the maximum radius.

The slight field profile change between proton and deuteron operation is achieved by an appropriate use of the magnet steel saturation, induced by a change in the magnetizing current.

RF SYSTEM

H^- and D^- ions are accelerated by two dees on the 2nd and 4th harmonic mode of the orbital frequency respectively. Although CYCLONE 10 is an almost fixed frequency machine, the difference in relativistic mass increase between 10 MeV H^- and 5 MeV D^- and also the small difference in magnetic field needed to change the field profile calls for two slightly different frequencies (table 1). Either of two reference crystal oscillators is automatically selected as a result of beam choice.

The dee angle varies from 60° at the centre to 36° at the extraction radius. As in CYCLONE 30, the resonators are entirely located in the valleys [2]. The dees are connected at the centre in the median plane.

The rf power needed to maintain 30 kV of dee voltage is approximately 3 kW. In addition, 1 kW of rf power is required to accelerate the beam.

The rf system uses a power triode oscillator with a maximum power output of 5 kW. The rf power is fed to the resonators by a coaxial cable and inductively coupled to the resonators. Fine tuning of the resonators is performed by a variable capacitor controlled by a DC servo motor through a hydraulic piston. A phase locked loop stabilizes the frequency of the system by comparing it to the selected crystal oscillator.

The rf tube selected for this application is a water-cooled industrial power triode operating in class C mode with good effiency and reliability.

CENTRAL REGION - SOURCES

The central region of CYCLONE 10 is equipped with two internal P.I.G. ion sources; one for each type of ion. The sources are the now classical hot cathode P.I.G. sources as developed in Berkeley by K.W. Ehlers *et al.* [5].

The two sources are installed 180° apart, each one injects into a separate puller electrode. Therefore changing beam requires nothing more than switching the power supplies and the gas valves from one source to the other.

EXTRACTION

The ion extraction is performed by stripping the beam with a thin graphite foil (40 $\mu g/cm^2$). Experiments have shown that stripping foil lifetime exceeds $2*10^4$ mAh. This represents over one year of operation under normal conditions.

Eight stripping foil positions are distributed around the cyclotron, feeding the beam into one of the eight targets.

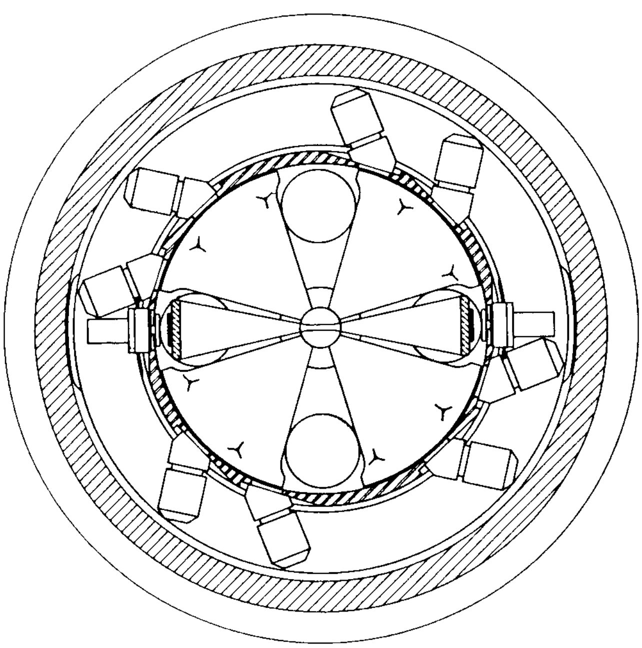

Figure 1
Median plane view showing the 8 target stations.

At each position, a holder carries three foils located 120° apart. According to the rotation angle of the holder, the beam is either extracted or allowed pass to the next station.

The stripping foil holder positioning shafts are located in grooves at the outer radius of the sectors, and pass through the cyclotron yoke via rotary vacuum seals. Each shaft is rotated by a motor unit located under the cyclotron.

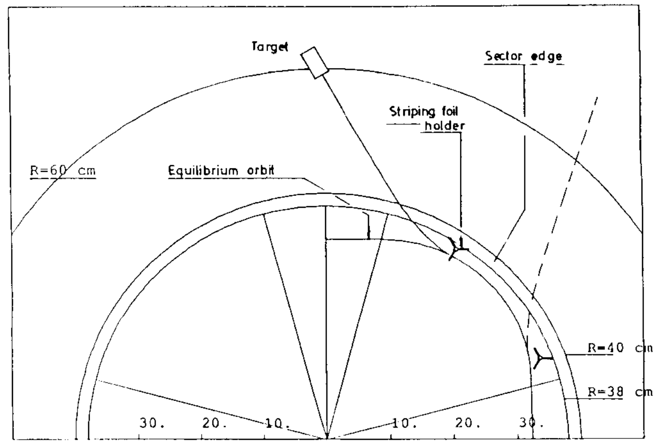

Figure 2
Stripping foil positions and particle trajectories.

VACUUM

To ensure a very low operating pressure, the cyclotron is equipped with two large oil diffusion pumps (2000 l/s), directly pumping the valleys without rf cavities. With such pumping speed, the machine can be brought from atmospheric to operating pressure in less than 15 minutes. This feature combined with the easy-to-use yoke lifting mechanism reduces downtime to a minimum.

TARGETRY

To complement the cyclotron, a set of special targets for the production of the four classical positron emitters is being developed in Louvain-La-Neuve.

- $^{18}F^-$ is produced by the $^{18}O(p,n)^{18}F$ reaction using enriched $H_2{}^{18}O$ as a target material.
- $^{18}F_2$ is produced in limited amounts by the $^{20}Ne(d,\alpha)^{18}F$ reaction, using natural Neon with added $^{19}F_2$ carrier as a target material
- A target for the higher yield production of $^{18}F_2$ by the first reaction, using ^{18}O gas as a target material is under development.
- ^{15}O is produced by the $^{14}N\ (d,n)^{15}O$ reaction on natural nitrogen without the need of enriched target material.
- ^{13}N is produced by the $^{13}C(p,n)^{13}N$ reaction on a new high performance ^{13}C target that avoids the limitations of the current carbon/water slurry method.
- ^{11}C is produced by the classical $^{14}N\ (p,\alpha)^{11}C$ reaction on natural nitrogen.

SELFSHIELDING

In addition to the initial shielding already provided by the cyclotron magnet yoke, CYCLONE 10 is equipped with an optimal integral neutron shield, removing the need for a shielded room.

The upper part of this shield lifts together with the upper part of the yoke. A removable plug in the shielding gives access to the hardware located under the cyclotron.

CONTROL SYSTEM

The operation of CYCLONE 10 and its associated chemical processing are fully automatic, requiring no specialised operator during routine operation. The control system uses an industrial programmable logic controller.

PLANNING

At the time of this conference (May 1989), the prototype CYCLONE 10 is under construction. The first extracted beams are scheduled for November 1989. The first units will be ready for dispatch in the second half of 1990.

Table 1: Main parameters

Beam			
Type of ions	-extracted:	H^+	D^+
	-accelerated:	H^-	D^-
Energy (fixed) <MeV>:		10	5
Maximum intensity			
	-guaranteed <μA>	50	
	-expected <μA>	100	
Targets:		8	
Simultaneously extracted beams:		2	
Power consumption			
Stand-by condition <kW>:		< 5	
Beam on target <kW>:		< 35	
Magnetic structure			
Sectors:		4	
Sector angle (R_{min} - R_{max}) <degree>:		54-58	
Hill field <T>:		2.0	2.02
Valley field <T>:		0.35	0.354
D.C. power consumed by the coils <kW>:		13	
Iron weight <tonne>:		8.8	
Copper weight <tonne>:		1.34	
R.F system			
Number of dees:			2
(connected at the centre)			
Effective dee angle <degree>:		30	
Harmonic mode:		2	4
Fixed Frequency <MHz>:		37.8	38.6
Peak dee voltage <kV>:		30.0	
RF power <kW>:			
	-per dee	2.4	
	-beam acceleration	1	
Ion sources			
Type of source			
(two internal sources):		P.I.G.	P.I.G
Arc power <kW>:		2.0	
Cyclotron dimensions <m>			
Magnet external diameter:		1.54	
Magnet external height:		1.00	
Median plane height:		1.30	
Total height (without shielding):		1.80	
Overall dimensions (with shielding)			
Outside diameter <m>:		2.80	
Total height (inclusive of base 0.15 m)		2.40	
Total footprint <m^2>:		3 * 5	
Weight <tonne>			
Unshielded:		10.5	
Shielded:		20.0	

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