STATUS OF CYCLONE44 : A POSTACCELERATOR FOR RADIOACTIVE ION BEAMS

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CYCLONE44 is a compact cyclotron under construction at the University in Louvain-la-Neuve, for the acceleration of radioactive ion beams, in the energy range 0.2 → 0.8 MeV/A, for nuclear astrophysics. The main characteristic is that it combines a large overall efficiency (injection-acceleration-extraction) with a large resolution for similar charge/mass ratio beams : typically, an attenuation of 10^5 for a beam with $\Delta(Q/A)$ of $1*10^{-4}$ is expected. To achieve this goal, acceleration in harmonic modes 8 and 6, large turn numbers (200-265) and a special central region geometry have been chosen. A first beam is expected in the second half of 1996. The magnet is completed and results of numerical calculations with TOSCA, of the magnetic field, are compared with measurements. The status of beam dynamics studies and measurements on the panel-tuned coaxial RF cavity scale model are reported.

1. Introduction

The reasons which led to the decision to build CYCLONE44 have already been presented elsewhere[1,2]. Now that the cyclotron is taking shape we can report on the first results and the more definitive characteristics of CYCLONE44 :

- its energy range : 0.2 to 0.8 MeV/A, covering the astrophysically important region not accessible with CYCLONE (lower limit is 0.56 MeV/A) ;
- its acceleration efficiency : one order of magnitude larger than the efficiency of CYCLONE allowing the study of nuclear reactions with smaller cross sections, e.g. those reactions involving alpha particles and short lived radioactive nuclei ;
- its isobaric resolving power : 10^{-4} to allow the use of pure radioactive ion beams of very low intensity in the presence of large isobaric stable element beams ;
- its availability and flexibility.

The main characteristics of CYCLONE44, have been fixed now and are given in table 1.

Table 1 : Main characteristics of CYCLONE44

Energy Constant K	MeV	44
Energy Range	MeV/amu	0.2 - 0.8
M/Q Range		4 - 14
Max. Average Field	T	1.54
Extraction Radius	m	0.633
RF System	2 Variable Angle Dees	
Frequency Range	MHz	13.3 - 18.7
Max. Dee Voltage	kV	20
Harmonic Modes		6 - 8
Injection	Axial	
Extraction	Electrostatic Deflector Passive Gradient Corrector	

Figure 1 shows the median plane view of CYCLONE44.

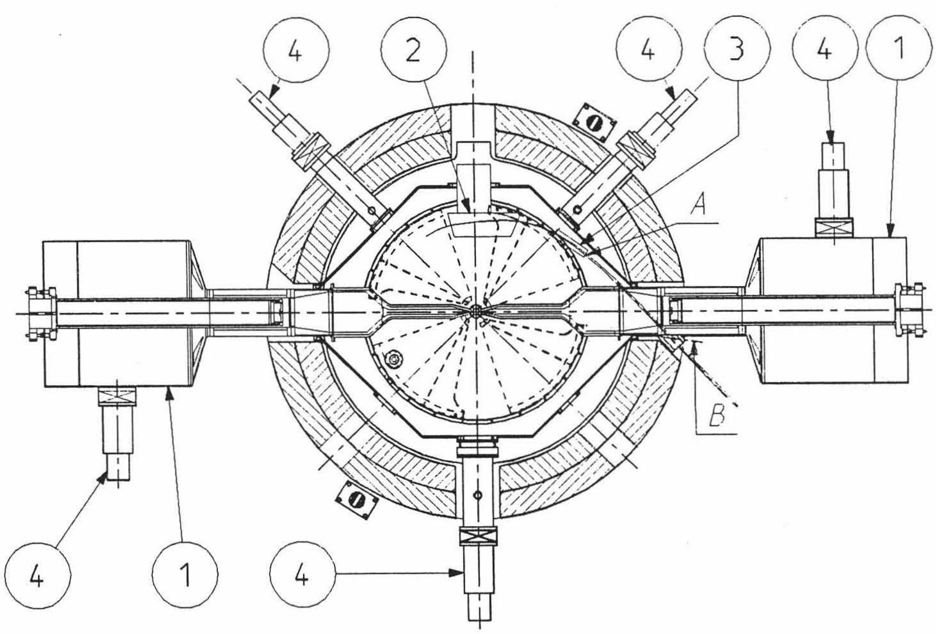

Figure 1 : Median Plane View of CYCLONE44
1 : RF cavities 2 : Electrostatic Deflector
3 : Passive Gradient Corrector 4 : Cryogenic Vacuum Pumps

The status of the project is summarised in table 2.

Table 2 : Status of CYCLONE44

Magnet	Field mapping and shimming completed.
Vacuum Box	Under construction, to be delivered Nov. 1995.
RF System	Scale model measurements completed. Mechanical design full size cavities started Oct. 1995.
Vacuum Pumping System	To be delivered Dec. 1995.
Extraction System	Mechanical Design started Sept. 1995
Injection and Central Region	Design study in progress
Low Energy Beam line : RIB ECR source → CYCLONE44	Design study completed

In the following paragraphs, the main parts of CYCLONE44 are described in somewhat more detail.

2. The Magnet

The parameters of the magnet that is now completely assembled are given in table 3.

Table 3 : Parameters of the CYCLONE44 magnet

Weight of the Iron	tons	56
Height	m	1.5
External Diameter	m	2.86
Pole Diameter	m	1.56
Hill Gap	cm	12
Valley Gap	cm	24
Angle of the Sectors	degrees	33 - 65
Max. Hill Field	T	1.95
Max. Valley Field	T	1.0
Main Coils	Number of Turns	420
	Max. Current (A)	500
	Max. Voltage (V)	105
	Weight (tons)	2
Correction Coils	Circulars, on the sectors	12 pairs
Harmonic Coils	Injection	4 pairs
	Extraction	4 pairs

Field maps of the magnet have been measured and compared with the numerical calculations using TOSCA. The radial profile of the average field at different field levels is very close to the calculated field (see figure 2.) so that no shimming of the sectors was required. The major difference in the field shape appears near the centre. This is probably due to a difference in the B-H curve used for the calculations and the effective B-H curve of the magnet in saturation. Only minor modifications had to be executed on the central ring. The field measurements have been done with a Dubna built mapping system. It comprises essentially one Hall-probe with exceptional stability and precisely calibrated using NMR, mounted on a radial arm that is moved azimuthally, allowing the coverage of the complete pole surface in polar co-ordinates. Both movements are controlled by computer. The Hall-voltage is measured at the dead-time of each azimuthal step and converted to the corresponding magnetic field value.

Measurements of the effect of the correction coils for different field levels have been done and the isochronisation of the field has been tested at all field levels to determine the maximum required trim coil currents.

Measurements of the first harmonic components are in progress. The maximum amplitude is about 4 Gauss. Harmonic coils will be placed in the central- and extraction regions in the valleys.

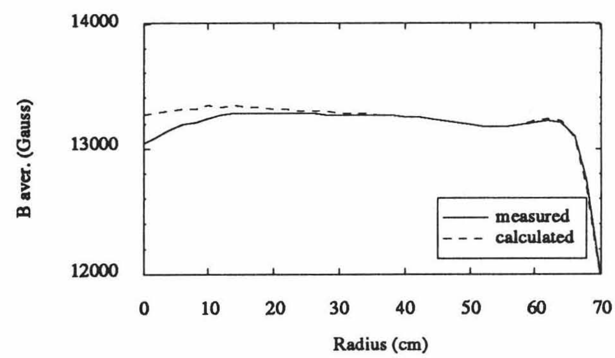

Figure 2a : Average Field versus Radius for an Intermediate Field Level

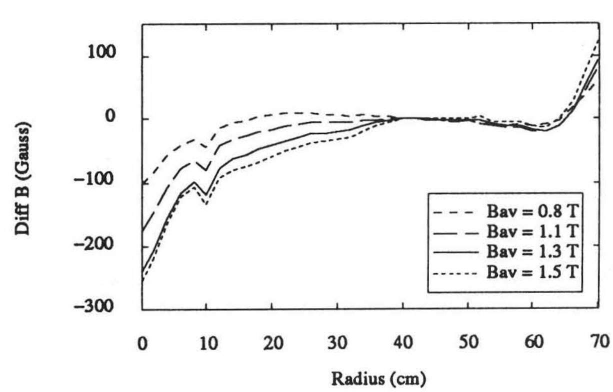

Figure 2b : Difference between Measured and Calculated Field versus Radius for Different Field Levels

3. RF system

The accelerating system consists of two independently driven electrodes of variable azimuthal width. The electrode tips are exchangeable to accommodate the different central region geometries in the 6^{th} and 8^{th} harmonic mode. The free space inside the electrodes is 40 mm (height) by 660 mm (radially) and the gap width varies from 18 to 37 mm. The two resonators consist of a fixed coaxial resonator preceded by two adjustable capacitive panels around the stem. They allow coarse tuning over the whole frequency range (13.25 to 18.75 MHz). A movable plunger in the coaxial resonator is used for fine tuning at the resonance frequency. The accelerating electrode is mounted on a beam that is fixed at the rear of the cavity near the short circuit. This allows for an easy positioning in all directions. Since the short circuit is fixed no movement along the resonator axis is necessary. The power amplifier is coupled to the cavity by means of an inductive loop; estimated maximum power is 2 kW per cavity.

Excellent phase and amplitude stability (0,1° phase / $1*10^{-4}$ amplitude) are required to guarantee good extraction efficiency and beam quality.

A scale model (1/2) was built to determine the final RF and mechanical characteristics.

A series of measurements have been carried out on the scale model and compared to the numerical results obtained with Poisson/Superfish (table 4). The largest difference is in the quality factor. This is probably due to the poor surface condition of the copper and to poor design and assembly of the different parts.

Table 4 : Measurements on the RF scale model

	Numerical Simulation		Scale Model	
frequency	37,5 MHz	26,5 MHz	37,5 MHz	26,5 MHz
unloaded Q	5600	5041	3328	2086
Δf for Δx plunger 5 cm	59 kHz	42 kHz	90 kHz	75 kHz
Δx capacitive panels	30 mm	2.5 mm	33 mm	3 mm
Position of the short circuit	27 cm	27 cm	24 cm	24 cm

4. Central Region Design and M/Q resolving power

One way of separating particles with similar M/Q (stable isobaric contaminants in our case) is to accelerate them in a cyclotron where the total number of RF periods required to accelerate the isochronous particle to full energy is large enough. The non-isochronous particle will then accumulate sufficient phase slip during acceleration so that it never reaches the full energy. This condition can be written as follows, in first approximation[1] : $\Delta(M/Q)*2\pi*N*H > 1$ where $\Delta(M/Q)$ is the mass/charge ratio difference between particles; N is the number of turns and H is the harmonic mode.

To achieve this condition in CYCLONE44, harmonic modes 6 and 8, low accelerating voltage and radially varying accelerating electrode widths have been chosen. Especially with high harmonic modes, the central region must be very carefully designed to maintain good beam quality. In particular, the azimuthal distance between accelerating gaps must be as close as possible to the optimum width for maximum energy gain per turn. For this reason the Dee-tip is kept at this optimum value. This width is different for H6 and H8 and therefore the Dee-tips have been made interchangeable. Posts are added to reduce transit time in the first gaps. After the first few turns the Dee-angle is gradually reduced with increasing radius to attain the required turn number : 265 turns in H6 and 200 in H8. To provide maximum turn separation at extraction, the Dee-angle is allowed to increase again during the last few centimetres before extraction.

Figure 3 represents phase histories of particle beams with slightly different Q/M values obtained with the accelerating system as described.

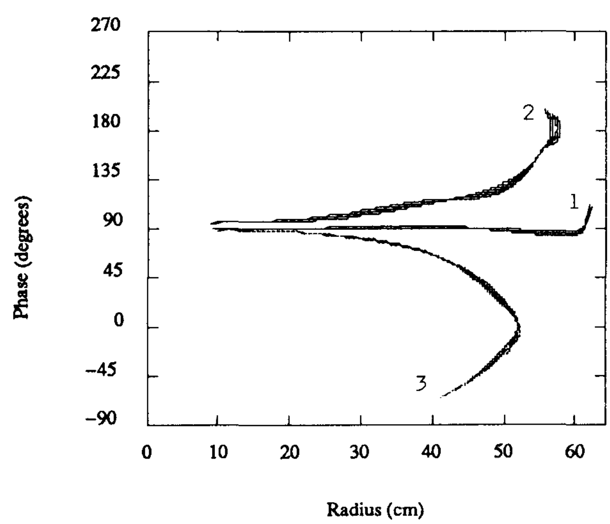

Figure 3 : Mass Separation for 6th Harmonic Mode : Phase history as a function of radius. The extraction radius is 63 cm. The isochronous beam of particles (1) is the radioactive beam. (2) is a contaminant beam with a mass difference ($\delta M/M$) of 1×10^{-4} (V_{DEE} = 11 kV). (3) is the contaminant beam with a mass difference ($\delta M/M$) of 2×10^{-4} (V_{DEE} = 20 kV).

Particles are injected with a magnetic bending radius of 35 mm in the isochronous field and deflected in the median plane on an off-centred orbit with a spiral inflector[3] with the following characteristics : height = 37 mm; K = 0.58; k = 0.051.

To centre the beam, it passes twice through one Dee (microtron-mode), before starting classical cyclotron acceleration. This central region layout is shown in figure 4.

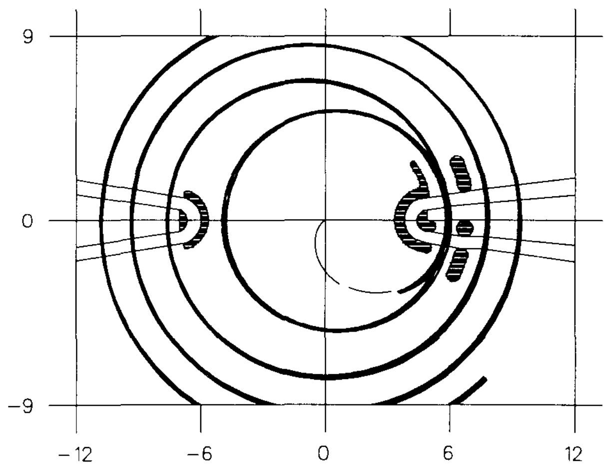

Figure 4 : The Central region for 6th Harmonic Mode (dimensions in cm) : Preliminary Solution. The trajectories represent 10% of the emittance of the source. The acceleration electrodes are represented on the horizontal axes. The trajectory linking the centre of the cyclotron to the beam represents the central ray in the inflector and a short drift.

5. Extraction

Extraction will be performed using an electrostatic deflector. Its radial and azimuthal position as well as its length and the use of a passive gradient correction have been simulated numerically. The acceptance of the extraction system is 90 mm*mrad in the horizontal plane and 50 mm*mrad in the vertical plane.

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