DEVELOPMENT OF COMPACT CYCLOTRON FOR EXPLOSIVES DETECTION BY NUCLEAR RESONANCE ABSORPTION OF GAMMA-RAYS IN NITROGEN

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Abstract

The inspected object is scanned by a beam of 9.17 MeV gamma-rays, which represents on-resonance flux capable of being absorbed by nitrogen nuclei. The resonance gamma-rays are generated in reaction of the proton capturing by C-13 and the following irradiation of gamma-rays by the appeared N-14 nucleus.

To produce the 1.747 MeV protons the compact isochronous cyclotron with external injection of H^- ions is under consideration. Computer simulation of beam dynamics in such a cyclotron confirms a possibility to produce on the target the proton beam with intensity of some milliamp. The paper describes the main cyclotron parts – injection line, magnetic, acceleration and extraction system.

INTRODUCTION

The maximum cross-section of the resonant 9.17 MeV γ-ray production via $^{13}C\ (\rho\gamma)\ ^{14}N$ reaction is equal 2.1 barn. It occurs at the proton energy 1.747 MeV and the thick target. Reaction yield into 4π is calculated to be ~$6 \cdot 10^{-9}$ γ/proton. Since the life time of the 9.17 MeV level ($5 \cdot 10^{-18}$ s) is very short compared to ion stopping time (typically ~$1 \cdot 10^{-12}$ s) the emission of γ-ray occurs during the recoil of the exited ^{14}N nucleus, resulting in Doppler-shifting of the γ-ray. At the resonant angle $\theta_R = 80.66^0$ with respect to the proton beam, the nuclear recoil energy losses that occur during emission and absorption of the γ-ray by the ^{14}N nucleus are precisely compensated by the Doppler-shifted energy component [1]. The resonant photons are emitted with axial symmetry relative to the proton beam forming an angular cone of width $\Delta\theta$ centered around the resonant angle θ_R. The gamma-rays resonant absorption crossection for ^{14}N nuclei near the 9.17 MeV level is equal 2.4 barn with the total energy width of the level 128 eV. Hence we need the proton source with intensity of some milliampers with the as small as possible energy spread and the angular divergence [2]. To produce the proton beam with energy 1.747 MeV and with intensity of some milliampers we consider the compact isochronous cyclotron with an external injection of H^{-35} ions. The full scheme of the γ-rays production is shown in Fig. 1.

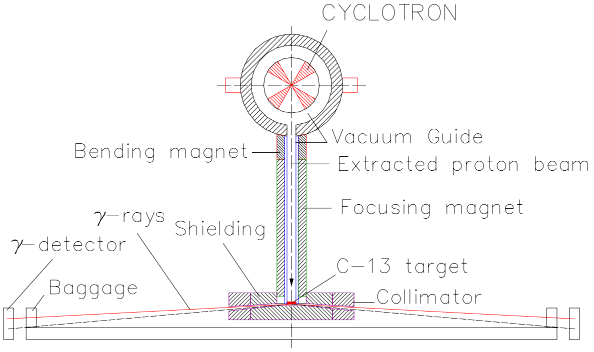

Figure 1: General layout of the explosive detection.

PARAMETERS OF THE CYCLOTRON

Main cyclotron parameters are showed in the following Table 1.

Table 1.

Type of ion		H^-
Injection energy	(keV)	30
Extraction energy	(MeV)	1.8
Average magnetic field	(T)	0.64
Number of sectors		4
Number of dees		2
Betatron frequencies	ν_r, ν_z	1.1, 0.85
Angular span of dees	(°)	45
RF voltage	(kV)	60
Orbital frequency	(MHz)	9.76
Harmonic number		4

The choice of the magnetic field level (0.64 T) is a compromise between the next considerations.

From one side the higher field level has to be chosen to provide the small cyclotron sizes. At the same time the higher field level provides higher space charge limit due to higher axial focusing strength.

From the other side the higher field demands the higher injection energy, hence the higher voltage on the spiral inflector. At the same time the turn separation is smaller at this case and the extraction efficiency goes down.

Main systems of the cyclotron will be described in the papers which will be reported at this conference. Here the short theirs description will be done.

MAGNET

The 4-fold type magnet with all-round yoke is chosen for the cyclotron [3]. The cyclotron vacuum chamber for this design is shaped by the magnet poles and yoke.

Table 2.

Magnet height	89 cm
Magnet outer radius	70 cm
Pole outer radius	35 cm
Final orbit radius	30 cm
Hill field at final radius	1.35 T
Valley field	0.2 T
Number of sectors	4
Hill gap	3 cm
Valley gap	40 cm
Sector angular width	10-30 ^{0}
Power consumption	10 kW

Sketch of the magnet is shown in Fig. 2. The dees and spiral inflector are shown schematically at the same picture.

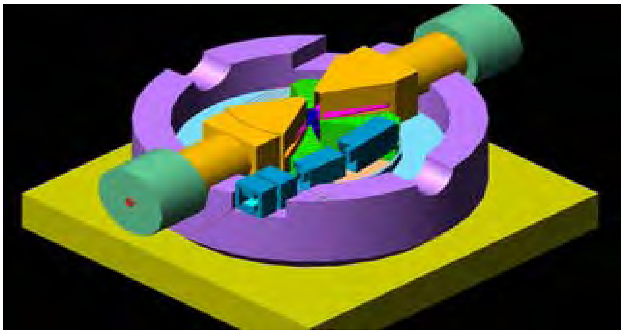

Figure 2: Magnetic structure, inflector, dees, deflector.

In Fig. 3 the plan view of the cyclotron is shown with the particle trajectories [4].

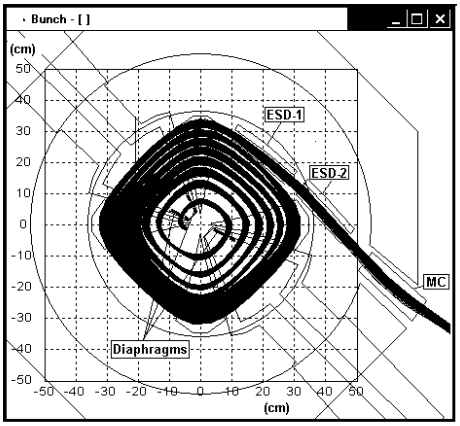

Figure 3: Plan view on cyclotron with extraction system.

ACCELERATION SYSTEM

High frequency system is formed by two resonators, consisting of the two 45-degree dees, which are located in opposite valleys (Fig. 2); of two resonance lines with the systems of feed, the voltage and phase stabilization and control.

The radiofrequency f=39 MHz corresponds to 4th harmonic of the orbit frequency; amplitude of accelerating voltage U=60 kV, peak energy gain per turn $\Delta W=4U$. The dissipated power in each resonator is near 5 kW.

EXTRACTION SYSTEM

The extraction system consists of two electrostatic deflectors (Fig. 3) ESD-1 and ESD-2 with the electric field strength 22 kV/cm in the center of their radial aperture. The voltage on the high-voltage electrode is equal 60 kV. To compensate the beam horizontal defocusing the electrostatic field in deflectors has gradients – 4.6 and – 12.2 kV/cm in ESD-1 and ESD-2, respectively. The electrostatic deflectors are followed by the passive magnet MC (Fig. 3) with the gradient magnetic field. Extraction efficiency calculated to be near 80%.

ION SOURCE

It is supposed to use for the cyclotron the TRIUMF type H^- Volume-Cusp Ion Source produced by DHL (Dehnel Consulting Ltd). This Ion Source will have next parameters: beam energy – 30 keV; beam continuous current – 15 mA. At this beam current the normalized 4 rms emittance is 1.0 mm*mrad. General view of ion source is shown in Fig. 4.

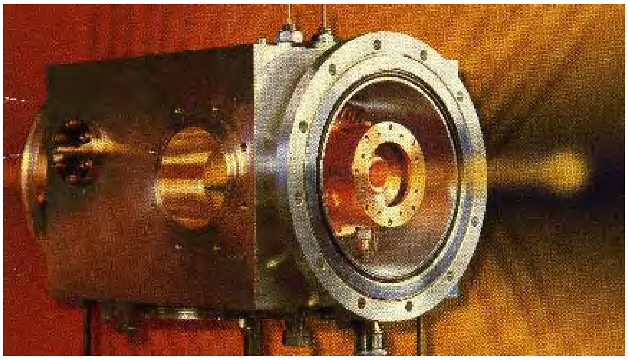

Figure 4: General view of ion source.

INJECTION SYSTEM

The injection system consists of a double-drift beam bunching system, a spiral inflector, beam analysis diagnostics, focusing and adjustment elements [5]. A layout of the injection system is shown schematically in Fig. 5. We plan to use a double-drift buncher design (the buncher gap is 5 mm and the distance between 2 gaps is $3/2\beta\lambda$ (92 mm)) with sinusoidal waveform. The position for the buncher is 0.4 m from the cyclotron median plane.

Quadruple doublet is used for injection line focusing, quadruple field gradient less than 300 Gs/cm, effective length of the quadruples - 10 cm, aperture diameter – 15 cm. The spiral inflector for ion bending from axial to median plane is used. The spiral inflector view is presented in Fig.6. A spiral inflector consists of coaxial, spirally twisted electrostatic deflection plates placed in a magnetic field. The chosen electric field of 24 kV/cm is restricted by breakdown limit. Height of the inflector is limited by cyclotron magnet center design and equal to 25 mm. The 10mm gap between electrodes was chosen to ensure bending of beam with emittance 100 ÷ 150 π mm mrad. The aspect ratio between the width and the spacing of the electrodes is taken equal 2 to avoid the fringe field effect and to tolerate shifts in beam trajectories inside the inflector. Computer modeling confirmed the possibility of high-intensity beam transmission, bunching and bending from axial to median plane with losses less than 10 % at an injection voltage of 30 KeV.

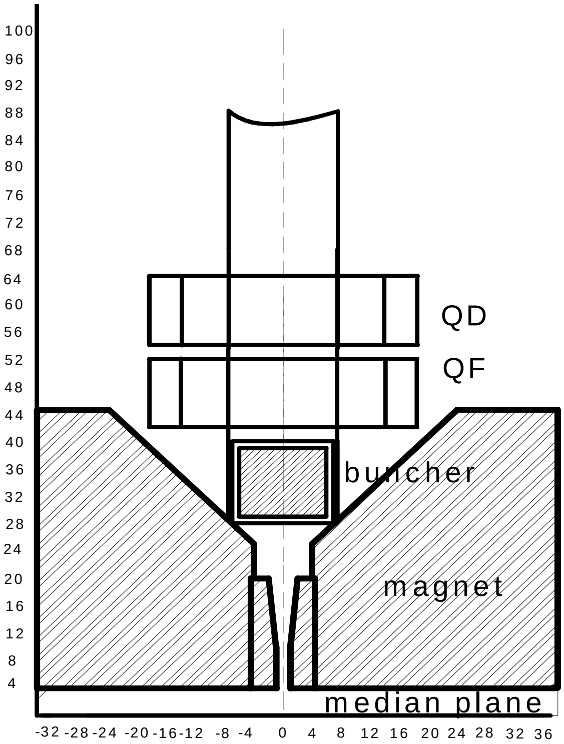

Figure 5: Layout of the injection system.

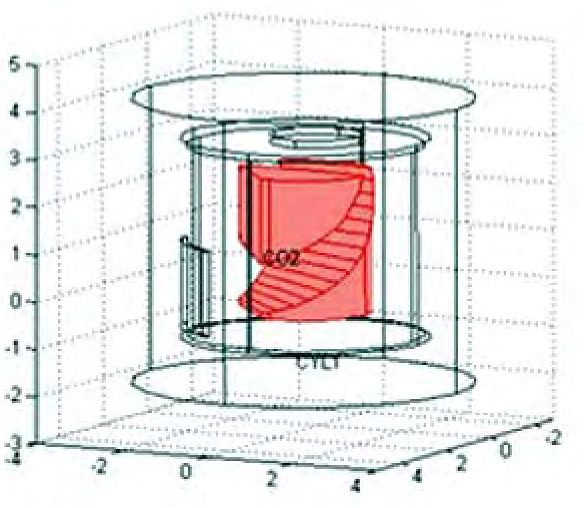

Figure 6: The spiral inflector.

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