SIX-SECTOR FFAG RING TO DEMONSTRATE BUNCH ROTATION FOR PRISM

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Abstract

An Fixed Field Alternating Gradient (FFAG) ring which consists of six PRISM-FFAG magnets has been constructed at RCNP, Osaka University. The technique of phase rotation to make a mono-energetic beam will be studied by using this ring and alpha particles. Closed orbits have been determined from measurements using the ring, and the results were compared with tracking simulation results.

INTRODUCTION

A mono-energetic muon beam is one of most important requirements for the future $\mu \to e$ conversion experiment which aims a sensitivity of more than BR \sim 10⁻¹⁷. PRISM uses a FFAG ring to make a mono-energetic muon beam by adopting the phase rotation [1]. In the ring, muons with higher energy are decelerated and those with lower energy are accelerated by a high gradient RF field. An initial momentum spread of 68 MeV/ $c \pm 20$ % can be reduced to 68 MeV/ $c \pm 2$ % after 7 turns in the ring.

An R&D program for the PRISM-FFAG was started at 2003 aiming for construction of a full scale PRISM-FFAG ring and demonstration of the phase rotation using the ring [2][3]. There are two key components to be developed for PRISM-FFAG: FFAG magnets with a large aperture to accept muons as much as possible and an RF system to produce a high gradient field, which is indispensable for a quick phase rotation. These components were developed successfully as reported in previous accelerator conferences [4][5]. As the final step of the program, a ring has been constructed, and the phase rotation will be studied in this year. Because of a financial reason, the demonstration will be carried out using a FFAG ring consists of six PRISM-FFAG magnets and one RF system. This ring is called as "six-sector FFAG".

SIX-SECTOR FFAG

The construction of the six-sector FFAG was started at the end of September 2007, and finished at December of the year. Figure 1 shows the ring at the M-experimental hall in Research Center for Nuclear Physics (RCNP) of Osaka University. The procedure for the ring construction and results of field measurements are described in Ref. [6]. In



Figure 1: Picture of the six-sector FFAG ring at M-experimental hall of RCNP.

order to simplify the experiment, we use alpha particles emitted from a commercially available radioactive source $^{241}\mathrm{Am}$ for the studies on beam dynamics of the ring and the phase rotation [7] .

Lattice

The original PRISM-FFAG was designed to circulate 68 MeV/c muons using ten magnets. In order to modify the lattice for the alpha particles using only six magnets, tracking simulations were performed. As a result, the magnets were shifted to the ring center by 325 cm, keeping their original current settings. Table 1 summarizes parameters of the six-sector FFAG. The target momentum of the alpha particle was set to $100 \, \text{MeV/}c$.

A layout of the ring is illustrated in Fig. 2. The ring diameter for the orbit center is about 6.2 m. The beam duct has an inner width of 375 mm and an inner height of 131 mm at its center. An injector system was installed at the position of θ =0 deg. There are six ports to install detectors (at θ =90, 120, 240, 270, and 300 deg). An RF cavity was located at θ =60 deg. Two large chambers at θ =0 and 180 deg equip a moving and rotating stage, which can be controlled remotely. The injector and detector system can be mounted on the stages.

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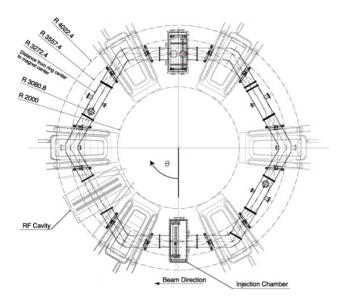


Figure 2: Layout of the six-sector FFAG. The ring has about 6.2 m in diameter. An injector with 241 Am is located at θ =0 deg, and a RF cavity is at θ = 60 deg.

Table 1: Parameters of the six-sector FFAG ring.

Particle	alpha particle
Momentum	$100~{ m MeV}/c$
Cell	DFD-triplet
Number of cells	6
Ring diameter	6.2 m
Revolution period	$2.4~\mu \mathrm{s}$
RF gap voltage	$33 \mathrm{kV}_{peak}$
RF frequency	2.1 MHz (h=5)

Alpha Injector

An injector system was installed in a vacuum chamber at θ =0 (deg). The injector consists of a sealed alpha source 241 Am, a degrader foil, and collimators. The 241 Am emits alpha particles of 5.486 MeV (which corresponds to 202 MeV/c). In order to reduce their energy to the target region, an aluminum foil 15.5 μ m thick was used as a degrader with a 3 MBq 241 Am source. The obtained mean energy and standard deviation were 1.021 MeV (87.2 MeV/c) and 0.4 MeV (15.7 MeV/c), respectively. Two aluminum plates with a hole were used as collimators to the limit initial emittance of the alpha beam. Some collimators with different geometric configuration and dimensions were prepared. One example is described in a later section.

Diagnostics

Two kinds of detector were used for beam diagnostics: a scintillating bar and a silicon surface-barrier solid state detector (SSD). The scintillating bar consists of a plastic scintillator with a thin ZnS(Ag) sheet on its one surface and two PMTs at both ends of the scintillator. The dimension of the bar is illustrated in Fig. 3. The phoswitch technique

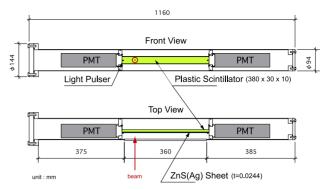


Figure 3: Scintillating bar for quick orbit measurements. Light pulsars on the scintillator are used for the gain calibration of the PMTs. A whole system in the figure was plugged into the beam duct through a port.

was used to identify alpha events from many background events. The hit position of an alpha particle can be calculated from an ADC ratio of the left and right PMTs. The position resolution of the detector for single hit was $\sigma_{single} \sim 3$ cm. Therefore, a position of the beam center can be determined with resolution of σ_{single}/\sqrt{N} , where N is a number of hit particles. This detector is useful to measure the orbits quickly, because its sensitive area is enough long (360 mm) to cover the width of a beam duct.

The SSD had a diameter of 22 mm, an energy resolution of 32 keV in FWHM at 5.486 MeV, and a time resolution of ~ 2 ns. Moving the SSD position, we can determine position, energy, and timing of the alpha beams.

Closed Orbit Study

Particles on the closed orbit takes a same phase at every turns at one position θ in the ring. It is very simple to

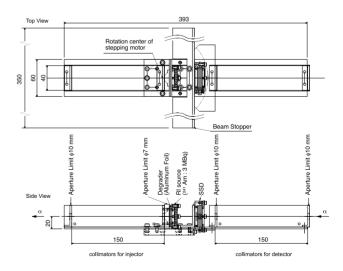


Figure 4: Injector and detector system for the closed orbit study. Both of the injector and the detector have a set of collimator plates. The system was mounted on the moving and rotating stage in a vacuum chamber.

determine a closed orbit by measuring an initial phase and that of after one turn. If a particle takes a same phase of position and angle as that of at injection, the particle is on the closed orbit. Closed orbits of the alpha particles with some momenta has been determined by this method. Figure 4 is a drawing of a injector and a detector used in this study. It was mounted on the moving stage in the chamber at θ =0 deg. Two sets of collimators were set for the injector and the detector to determine position and angel of the alpha beam at injection and after one turn. Using energy information from the SSD, we determined closed orbits as shown in Fig. 5. Tracking simulations were also carried out by two different codes based on geant3 [8] and g4beamline [9] using same magnetic field maps calculated by TOSCA. Difference between results from the tracking codes was about 5 cm, while the measurement results were middle of the tracking results. Integration errors in the tracking steps might cause these differences.

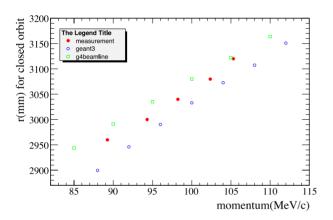


Figure 5: Comparison of closed orbits between measurements and simulation results. Red filled circles indicate closed orbits from measurements. Blue and green open circles are tracking results using geant3 and g4beamline, respectively.

RF System

The RF system was re-optimized for the phase rotation of the alpha particles. The operation frequency of the RF is \sim 2.1 MHz (h=5), because the alpha particle of the target momentum 100 MeV/c has a revolution period of 2.4 μ s. The RF duration is 30 μ s with $\sim 0.3\%$ duty. Figure 6 shows the RF system for the six-sector FFAG. The cavity has a large aperture of about 1 m (H) \times 0.3 m (V). Its consists four magnetic alloy cores, and has one gap. The shunt impedance of the cavity is 400 Ω . The obtained gap voltage with this RF system was 33 kV $_{peak}$ with sinusoidal waves at 2.0 MHz. The detail of the RF system is described in Ref. [10]. Simulation studies showed a sawtooth RF voltage makes narrower energy spread beams than a sinusoidal one. Due to a low Q-value of the MA cavity, higher frequency harmonics can be added to one gap to form the sawtooth RF voltage. Tuning to make the sawtooth voltage is in progress.



Figure 6: RF system of the ring. A MA cavity has a race tracker shaped large aperture. The amplifier is located on the top of the cavity. An anode power supply is set beside of cavity. The anode voltage is delivered to the amplifier by a bus bar.

SUMMARY

A six-sector FFAG ring is working at RCNP, Osaka University. Beam dynamics studies of the ring, such as tune measurements, are currently in progress using alpha particles emitted from a radioactive source ²⁴¹Am. A demonstration of the phase rotation will be performed in this year.

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