HIGH FIELD GRADIENT RF SYSTEM FOR BUNCH ROTATION IN PRISM-FFAG

C. Ohmori, KEK/J-PARC, Ibaraki, Japan
A. Sato, M. Aoki, Y. Arimoto, T. Itahashi, Y. Kuno, Y. Kuriyama, M. Yoshida, Osaka University, Osaka, Japan
Y. Mori, KURRI, Osaka, Japan
Y. Iwashita, Kyoto ICR, Uji, Kyoto, Japan

Abstract

PRISM is on the way to build a future intense low energy muon source, which combines mono chromaticity and high purity. In the PRISM project, an FFAG is used as the phase rotator to achieve the monochromatic muon beams. This paper will describe the high field-gradient RF using a Magnetic Alloy (MA) cavity for the phase rotation. In 2007, a 6-cell ring has been constructed and an RF system was installed. The system has achieved the field gradient of 100 kV/m at 2-3 MHz.

INTRODUCTION

The PRISM project aims to study a lepton flavor violating process: μ-e conversion in a muonic atom [1,2]. Required beam intensity is about $10^{11} < 10^{12}$ muons per sec, which is almost four orders of magnitude higher than that available at present. To realize this beam intensity, a phase rotation in an accelerator is required to make the beam energy spread narrower. In order to achieve phase rotation, a fixed-field alternating gradient synchrotron (FFAG) [3] is used. To obtain the high-quality high-intensity muon beam, the RF system for phase rotation needs to satisfy following demands:

(1) Very high field gradient of 200kV/m at low frequency (4.0 MHz) is required because the muon is an unstable particle (lifetime<2.2 μs). It is crucial to complete phase rotation as quickly as possible in order to increase the number of surviving muons. Such an operation can be achieved by a low duty factor and ultra-thin magnetic alloy (MA) cavities. The MA core has stable impedance at the required magnetic field [4]. Cores are all air-cooled since the RF power loss into the core is very small owing to the small duty factor (about 0.1%) [5].

(2) A high repetition of 100 Hz is also required. For the PRISM project, the J-PARC proton beam will be extracted by a fast extraction scheme. More than 90 bunches are separated longitudinally and/or horizontally. In case of higher repetition rate more than 100 Hz, the duration for RF will be optimized to below a few μs.

(3) To optimize phase rotation, an RF voltage with a saw-tooth shape [6] can be generated. According to our simulations, a saw-tooth RF voltage makes a final energy spread narrower than that by a sinusoidal one. Therefore, adding higher frequency harmonics to form a saw-tooth pulse shape is being considered.

(4) A very large aperture to handle muons with large emittance and momentum spread. PRISM magnets and RF system will have about 1 m (H) x 0.3 m (V) aperture [7].

6-CELL RING

To demonstrate the bunch rotation in a FFAG, a 6-cell ring, which consists of 6 FFAG magnets and RF cavity was constructed as shown in Fig. 1. As a beam source, an ^{241}Am radioisotope was installed [8]. In this paper, the test result of the RF system for the 6-cell ring is described. Table 1 shows the RF system parameters compared with the PRISM FFAG design.

Table 1: Main RF parameters for 6-cell ring and PRISM

		6-cell ring	**PRISM**
Number of cells		6	10
Particle		Alpha	muon
Momentum	MeV/c	100	68
Number of Cavity		1	48
Cavity length	cm	33	
Straight section length	m	1.5	2
Number of cores per cavity		4	6
Core material		MA	
Core size	m	1.7 (H) x 1.0 (V)	
Shunt Impedance	Ω	400	900
RF frequency	MHz	2.1	4.0
Field Gradient	kV/m	100	170
Gap Voltage	kV	33	66
Total RF voltage	kV	33	2700
Core cooling		Air	
Power Tube		4CW100KE	
Plate voltage	kV	28	33-37
Duty	%	0.3 %	0.1 %
AMPs per APS		1	4

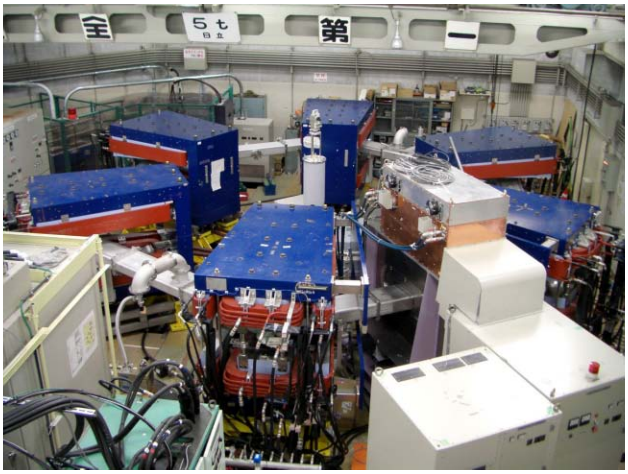

Fig. 1: 6-cell FFAG ring to demonstrate bunch rotation. A MA cavity system is also shown. The amplifier is located on top of the cavity. An anode power supply is set beside of cavity. The anode voltage is delivered to the amplifier by a bus bar.

RF SYSTEM

The RF system [5] was optimized for the bunch rotation of muons. For PRISM, it was designed to match a very short time (10 μs) and high repetition (100 Hz) operation. For the 6-cell ring, alpha particles are used to demonstrate the bunch rotation. To increase the statistics, it is required to increase the duty factor. The RF duration is 30 μs. The energy of the alpha particles is decelerated to 1.2-1.4 MeV using a degrader. The energy modulation by the RF system will be detected by high-resolution silicon detectors.

The cavity impedance is less than a half of the PRISM cavity, because the operation frequency is low and the number of cores is reduced. So far, the gap voltage of 33 kV has been obtained. The anode voltage was set at 28 kV. To reduce the anode dissipation by the idling tube current, the control grid voltage was modulated by 500 V. A typical idling current is below 0.01 A. However, the current is increased to about 5 A while generating RF voltage. The typical variation of tube current is shown in Fig. 2. A few microseconds after increasing the idling current, the RF signal is driven by the control grid. While the RF signal is amplified, the cathode currents of both tubes are about 45 A and the gap voltage of 33 kVp is obtained. When the repetition rate is 100 Hz, the duty factor is 0.3 % and the average cathode current is 0.14 A for each tube. The anode power supply can deliver 1 A. Figure 3 shows a typical gap voltage when the duration was extended. In case of PRISM operation, the anode power supply will deliver the current to 4 RF amplifiers. At each output terminal in the anode power supply, a current transformer for tube protection using a crowbar circuit is prepared. Simultaneous peak RF output power is more than 1.3 MW. However, the average power dissipation in the cavity is 3.9 kW. For the core cooling, small air fans are used.

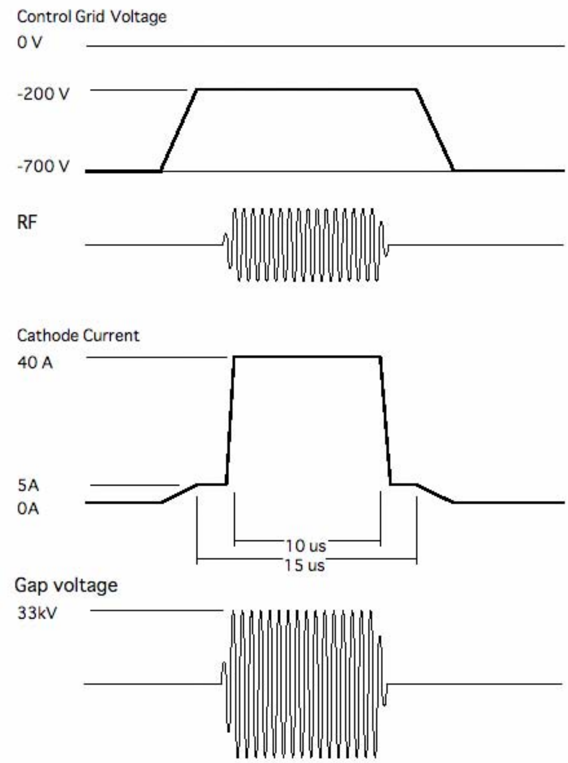

Fig. 2: Typical timing chart in case of PRISM. For the 6-cell ring, RF on time is extended to 30 μs.

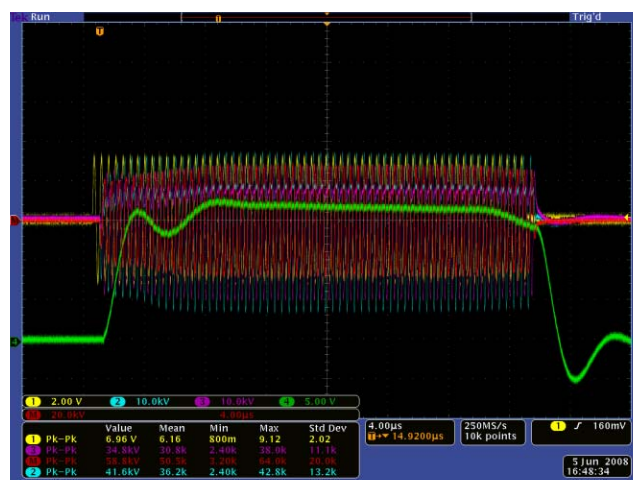

Fig. 3: Typical gap voltage for 100 Hz repetition. The duration was extended to 30 μs. The timing has not yet been adjusted. Yellow and red lines mean input and gap voltages, respectively. The green line shows the anode current.

When the anode voltage is higher than 30 kV, X-ray radiation from the tetrode tubes is expected. For safety, the amplifier was covered with an additional iron shield. And, copper shields were added to surround the anode of both tubes. When the anode voltage was 33 kV, the X-ray was measured using a low-energy sensitive X-ray monitor and it was as low as the background level. In case of 6-

cell ring, the anode voltage was set at 28 kV as cavity impedance is low at 2 MHz.

The beam test using alpha particle has started. The experimental results will be reported [9].

CONCLUSIONS

A 6-cell ring has been constructed to demonstrate the bunch rotation by FFAG. The beam test using alpha-ray source has been started to study the beam tracking and bunch rotation. An MA cavity system was installed and the gap voltage of 33 kV was obtained.

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