ULTRA-HIGH FIELD GRADIENT RF SYSTEM FOR PRISM-MUON BUNCH ROTATION

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Abstract

PRISM is a project to produce a high quality, high purity and high intensity muon beam by the bunch rotation technique in FFAG synchrotron using ultra-high field gradient RF systems. The system to achieve the field gradient of 200-300 kV/m at 5 MHz is designed and under construction.

INTRODUCTION

PRISM [1] is an experimental proposal for construction of a highly intense muon source based on a novel idea of phase rotation in a FFAG synchrotron. PRISM stands for Phase Rotated Intense Slow Muon source. It would provide a muon beam having an intensity of about 10^{11}-10^{12} μ/sec, a narrow momentum width of a few % and no pion contamination. The energy of the PRISM beam is relatively low (20 MeV in kinetic energy), since it is aimed to be used for stopped muon experiments in general.

PRISM will use a pulsed proton beam from the J-PARC 50 GeV proton synchrotron [2] by fast extraction. Experimental apparatus and PRISM will be placed at a proposed pulsed proton beam facility which is not included in the Phase I plan of J-PARC.

PRISM consists of

- a pulsed proton beam to produce a short pion pulsed beam,
- a pion capture system with large-solid angle by a high selenoidal magnetic field,
- a pion decay and muon transport system in a long solenoid magnet of about 10 m long,
- and a phase rotation system which accelerates slow muons and decelerate fast muons by an RF field.

Schematic layout of PRISM is shown in Fig. 1. One of features of PRISM is to do phase rotation at a Fixed-Field Alternating Gradient synchrotron (FFAG), which has several advantages, such as a large momentum acceptance. Because of a short life time of muons, the bunch rotation should end in 5 turns (1 μs) and RF voltage of 2-3 MV is required.

To obtain the beam which has a small momentum spread after the rotation, the shape of RF voltage is important. Figure 2 shows the proposed saw tooth like RF voltage [3]. In case of the saw tooth RF voltage, the particle motion in the longitudinal phase space is linear and angular speed of rotation is constant. The other advantage of saw tooth RF is that it has larger acceptance than an ordinary sinusoidal wave. Figure 3 shows a preliminary result for the bunch rotation in the phase space. It shows that the particles which have ±20 % spread will be rotated and the final momentum after 4 turns is less than ±5 %. In case of the optimum energy and RF voltage shape, the final momentum spread of ±3% will be obtained for initial spread of ± 30 %.

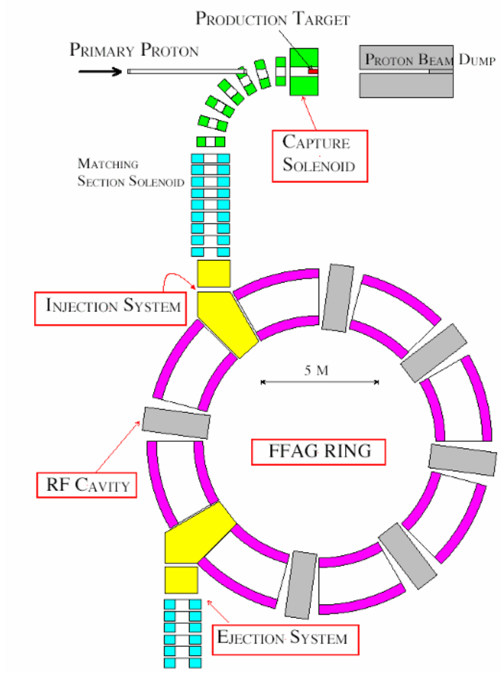

Fig. 1. Schematic layout of PRISM.

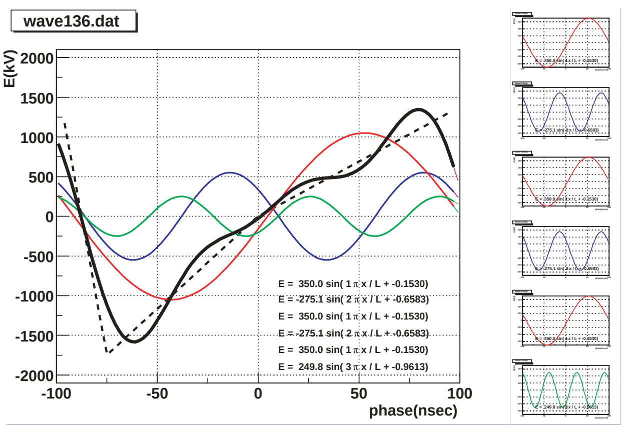

Fig. 2. Saw-tooth-like RF voltage. The bold line is the sum of three harmonics(thin lines), H=1, H=2 and H=3 .

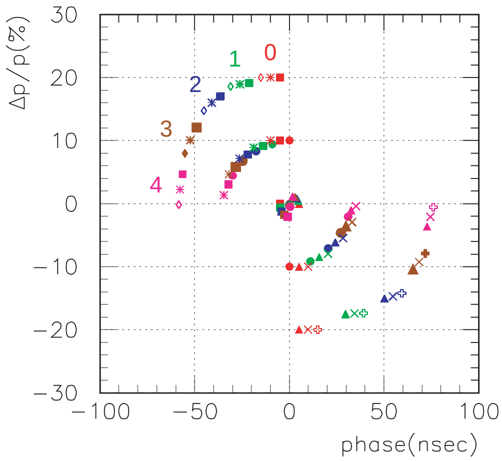

Fig. 3. Bunch rotation in case of saw-tooth-like RF voltage. Test particles which have different initial momentum and phase are tracked. The initial beam includes the bunch width of initial proton beam (± 5 ns).

RF SYSTEM

High Field Gradient

PRISM requires very high field gradient of 200-300 kV/m at the low frequency (5 MHz). To realize such a gradient, we have solved following problems;

- Magnetic core :Magnetic Alloy
- Way to drive the cavity: Tetrode tube which stand for 40 kV operation
- Length of cavity : 25 m/gap.

Magnetic alloy (MA) cavity [4] has been employed. One of advantages of MA is that the characteristics is stable at the high rf field. Figure 4 shows the characteristics of magnetic cores [5]. Ferrites are the material which is used in some accelerators, however, they show the impedance change at the high RF field. In case of MA, the characteristics are constant at the required magnetic field for PRISM (320-490 Gauss).

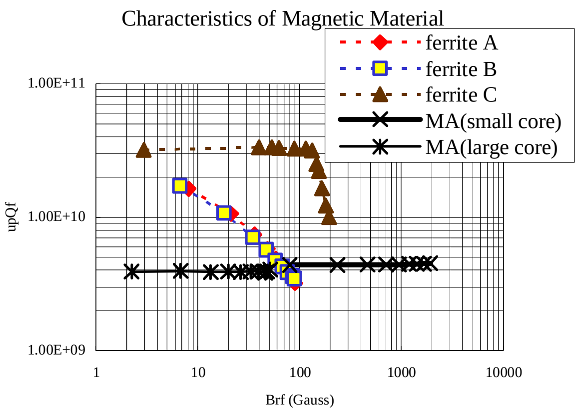

Fig. 4. Characteristics of magnetic cores. Solid lines mean MA cores with different size. Dashed lines are ferrite cores.

To resonate at 5 MHz, the cut core configuration [6] will be used to reduce the large core inductance to the optimum value. Another advantage of MA cavity is that it is possible to design it as a wide band system [6]. By choosing the optimum air gap of cut core and minimising the gap capacitance, it is possible to change the quality factor of the cavity at the fixed frequency. We are also considering the dual harmonic operation of RF system by minimising the air gap.

The cavity will be driven by push-pull amplifiers using tetrode tubes, 4CW150,000E. The tube can be used at the high DC voltage of 40kV and RF current of 60 A is possible to generate. In case of 1 kΩ cavity impedance, 60 kV will be available as a gap voltage.

To achieve the required field gradient, we also adopt the ultra-thin cavity design. The 1 m cavity consists of 4 gaps and each gap has 4 MA cores. Two sets of cavity are installed in a straight section as shown in Fig. 4. The side and front views of two cavities are shown in Fig. 5. Each gap generates the RF voltage of ± 25-37.5 kV and is driven by two bus bars which are connected to a RF amplifier. To drive 4 gaps in a cavity, 4 push-pull amplifiers are used. Two amplifiers are located above the cavities and others are set below it.

Table 1: Parameters of PRISM cavities

Number of cavities	12
Number of gap per cavity	4
Length of cavity	1 m
Core material	Magnetic Alloy
Core size	1.4 m X 1.0 m X 3.5 cm
Core shape	Racetrack
Number of cores	16/cavity
RF frequency	5 MHz
Required field gradient	200 kV/m
Flux density in core	320 Gauss
Duty	<0.1% (15 μs X 100 / 3.4sec)

Racetrack Core

Because of a large horizontal physical aperture of FFAG, the racetrack shape for MA core is adopted. In case of racetrack and rectangular shapes, the shunt impedance of a core is given by the following equation,

$$R_p = \mu_0 \mu_p \mathrm{Qf} \ln(L_2/L_1)t \qquad (1)$$

where L_2 and L_1 mean the inner and outer circumferences of the racetrack core.

Table 2: Parameters of Racetrack core

Inner size	74 cm X 34 cm
Outer/Inner circumference	3942mm/1868 mm
μQf @ 5MHz (design value)	5.5 X 10^9
Shunt Impedance	> 180 Ω/core

Power AMP system

Because of low duty factor, the push-pull operation of the tubes, 4CW150.000E, will generate the maximum RF power of 1.8 MW. Operation of the power amplifier was analysed using a typical constant current characteristics of the tube. During the high power period, the cathode peak and DC currents will be 120 A and 40 A, respectively. To generate the RF current of 60 A, the required voltage swing on the control grid is about 700 V. To drive the power amplifier, 1.5 kW solid state amplifier is considered. In case of the narrow band operation to generate only 5 MHz at the gap, the control grid circuit will have a narrow band impedance and 1:3 step up transformer will be used. In case of the dual harmonic operation, the driving circuit is under consideration.

The anode power supply is designed to be suitable for the pulse power operation. The maximum current is 400 A for 15 μs pulse duration to supply 4 sets of the amplifiers. Although the peak power of 12.8 MW is necessary for 4 AMP systems, the average power is below 10 kW. The required power is stored in 4 high voltage capacitors. To protect the tubes from the destruction by sparking, crowbar circuit is used.

The filament, control grid and screen grid power supplies for 4 amplifiers are installed in an auxiliary unit. The control grid power supply has a function to add the voltage of 150 V in short time. By this function, we can choose the class AB operation although the idling tube cathode current during off-operation is almost 0 A.

Table 3: Parameters of AMP system

Operation mode of tube	Push-pull, class AB
Number of tubes per AMP	2
Size of AMP	1.35 m X 0.8 m X 0.7 m
Tetrode	4CW150,000E
Max. RF current	60 A
Max. cathode current (DC)	50 A
Max. plate voltage	40 kV
Max. RF power	1.8 MW

CONCLUSIONS

The RF system for the PRISM project has been designed. The amplifier system is now under construction and will be tested using a test cavity at the RCNP, Osaka university in this winter. The ultra-thin RF cavity will be tested in the next year.

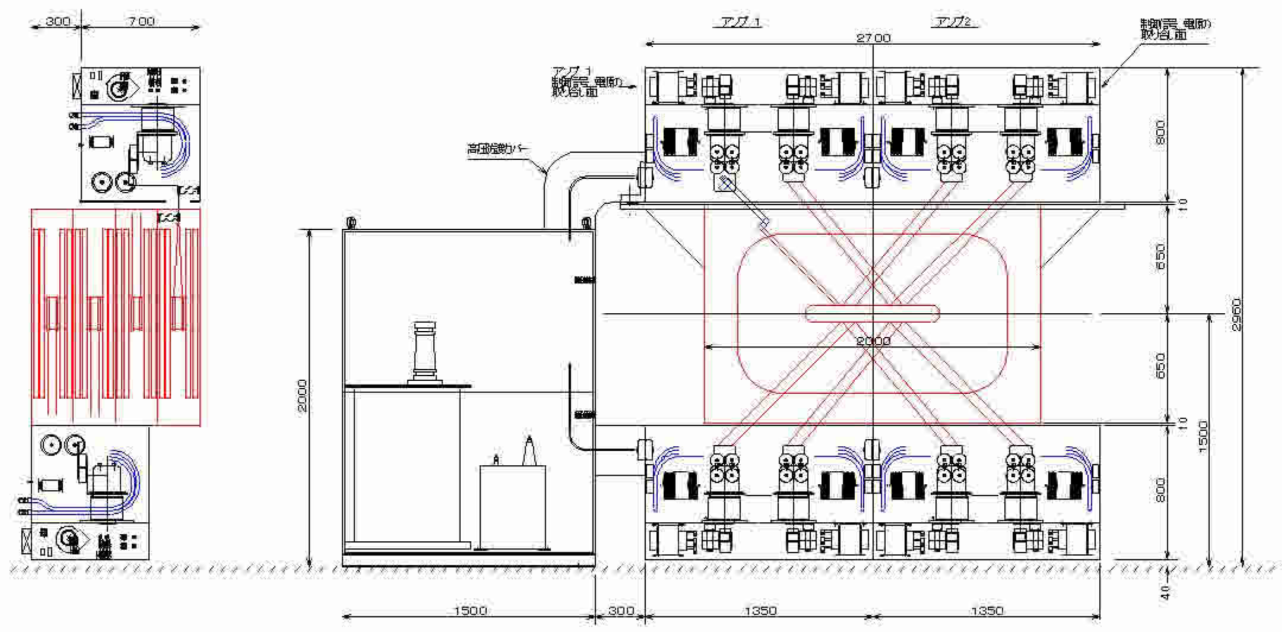

Fig. 5. Side(left) and front(right) views of RF system

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