ULTRA HIGH GRADIENT RF CAVITY FOR THE PHASE ROTATION

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Abstract

A high gradient and low frequency rf cavity for the PRISM (Phase Rotation Intense Slow Muons) project and neutrino factory which is under development at KEK has been presented in this paper.

1 INTRODUCTION

A high gradient and low frequency rf system is very important to realize the muon beam acceleration for obtaining an intense monochromatic muon beam. We are designing a longitudinal phase rotator of the secondly muon beams, named PRISM project.[1] In this phase rotator a field gradient of more than 1.0MV/m at the frequency of 5MHz is requested. Another project is a neutrino factory. In the neutrino factory, a muon beam has to be accelerated up to 50GeV as quick as possible. In both projects, FFAG ring is adopted because of large or almost infinite momentum acceptance.[2] Thus, the accelerating time and acceptable momentum spread are solely limited by the rf voltage. We have carried out the calculation and simulation for both longitudinal and transverse directions to estimate the parameters of rf system. A very high gradient low frequency rf cavity is highly desirable and an ultra high gradient low frequency cavity using new type of ferrite, SY20, is under development at KEK. [3]

2 SIMULATION

The magnetic field B of a scaling type of FFAG synchrotron can be expressed in the following equation.

$$\frac{B}{B_0} = \left(\frac{r}{r_0}\right)^k, \qquad (1)$$

where r is the distance from the machine center to the equilibrium orbit and k is a constant for the machine. Thus, a phase shift $\Delta\phi_n$ between the synchronous particle ϕ_s and the other particle ϕ_n can be written as follows.

$$\Delta\phi = 2\pi h\left\{\left(\frac{P}{P_S}\right)^{\frac{1}{k+1}}\frac{\beta_S}{\beta} - 1\right\}. \qquad (2)$$

Here h is the harmonic number, P is the momentum and β is Lorentz factor. Thus, the longitudinal particle motion can be obtained by simulating the two difference equations numerically.

$$\phi_n = \phi_{n-1} + 2\pi h\left\{\left(\frac{P}{P_S}\right)^{\frac{1}{k+1}}\frac{\beta_S}{\beta} - 1\right\}, \qquad (3)$$

$$\Delta E_n = \Delta E_{n-1} + eV_{rf}(\sin\phi_n - \sin\phi_s). \qquad (4)$$

Here, ΔE_n is the difference in the energy between the synchronus particle and the other particle and V_{rf} is the peak voltage of the rf.

3 RF PARAMETER FOR THE PHASE ROTATION IN PRISM

In the PRISM project, we aim to obtain an intense and monochromatic slow muon beam with more than 1kHz repetition rate. The phase rotation is a method to obtain a monochromatic muon beam with synchrotron oscillation. When the short bunched beam is injected into the longitudinal phase space, the bunch starts to rotate and its momentum spread becomes minimized after a quarter of the synchrotron oscillation period.

The parameters of the muon bunch injected to the phase rotation ring are listed in Table 1. The momentum spread has to be changed from +/-25% to less than +/-5%.

The nonlinearity of the rf voltage caused by sinusoidal wave form decrease the synchrotron frequency. The frequency shift caused by the nonlinear effect is plotted in Fig1. The rf voltage requested to capture the whole particles of there momentum spread of +/-25% is also shown in Fig.1 as a function of the phase of the largest amplitude particle. In order to keep the momentum spread of less than +/-5% after the rotation, the rf voltage of 10MV is necessary. The rf frequency calculated from the parameters shown in table1 is about 5.3MHz.

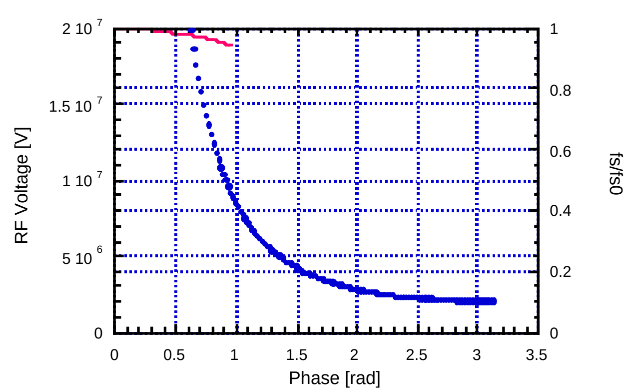

Fig.1 Line: The frequency shift caused by rf nonlinearity. Dots: The rf voltage requested to capture the whole particles of which momentum spread are +/-25%.

The multi particle simulation has been carried out with these parameters where the bunch length is 2nsec and the rf voltage is 12MV respectively. Figure 2 shows the simulation results at the injection and after the second turn of the revolution. As can be seen from this figure, the momentum spread becomes less than +/-5% after the phase rotation.

From these calculation, it is found that the rf cavity whose frequency of 5MHz and field gradient of about 0.5MV/m are necessary for the PRISM project.

Particle	μ^-
Momentum	70MeV/c
Repetition rate	1kHz
Machine radius	5m

Table1. The parameters of the muon beams injected to the phase rotation ring at PRISM project.

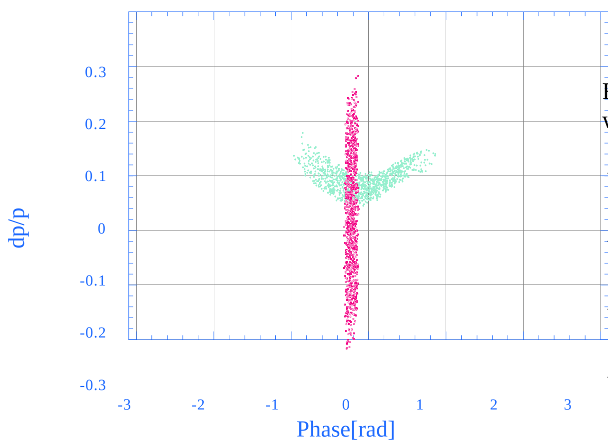

Fig.2 Simulation results at the injection and after the second turn of the revolution.

4 NEUTRINO FACTORY

In the neutrino factory, the requested final energy of the accelerated muon is 20-50GeV. We are considering of muon acceleration with FFAG synchrotrons. A schematic layout of the conceptual design of the accelerator complex for neutrino factory is shown in Fig.3. Muon beams are accelerated through the four rings from the momentum of 0.3GeV/c to 50GeV/c.

The first ring consists of a scaling type of FFAG which accelerates the muons from the momentum of 0.3GeV/c up to 1GeV/c. The momentum distribution of the particles after the pion capture solenoid is shown in Fig.4 [4]. The FFAG has a large momentum acceptance of about +/-50%, if the high gradient rf cavity becomes available.

We carried out the multi particle simulation under the condition of the rf voltage from 100 MV at the synchronous phase of 80 degree. The bunch length is 20nsec at the injection when the machine radius is 9.25m. The rf frequency is changed from 4.72MHz to 4.89MHz. Since the frequency shift is 3.6% the requested Q value for the rf cavity should be less than 20. Here, high field gradient more than 1MV/m is necessary.

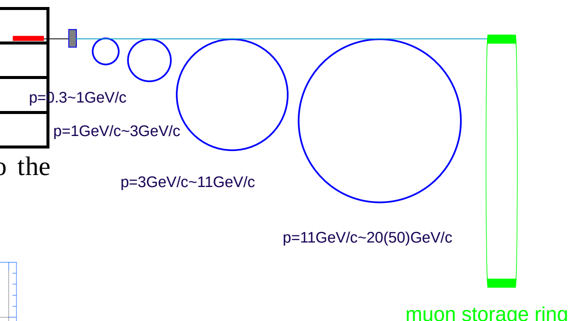

Fig.3 The conceptual design of the accelerator complex with FFAG acccelerators for neutrino factory.

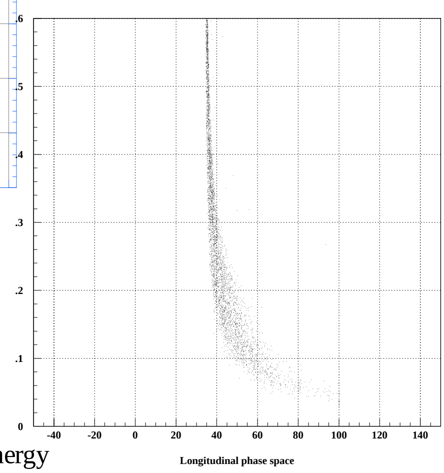

Fig.4 The momentum distribution of the particles after the pion capture solenoid.

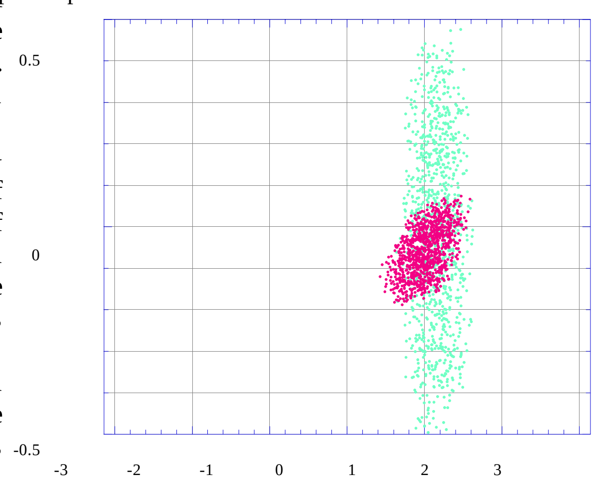

Fig.5 The simulation result under the condition of the rf voltage of 100 MV at the synchronous phase of 80 degree.

5 DEVELOPMENT OF THE RF CAVITY USING NEW FERRITE CORE, SY20.

A new type of ferrite, SY20 which includes a large amount of cobalt oxide has been developed by TDK company.

A ferrite has relatively large Q value, and its µQf-product becomes large. However, µQf value decreases when the Brf increases, because the ferrite is easily affected by high loss effect as shown in Fig.6. Fortunately, for both the muon phase rotation in PRISM project and the muon acceleration in the neutrino factory a very short burst mode operation is expected. The required pulse length would be less than 100µsec. The requested Q-vale is less than 20. A phase rotation and acceleration could be completed before the high loss effect is developed. The ferrite has a large shunt impedance if we can avoid the high loss effects.

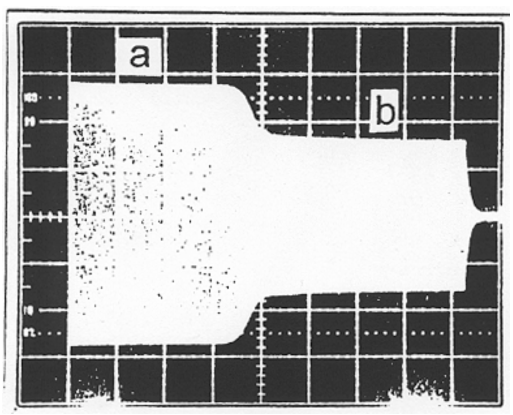

Fig.6 A ferrite core is affected by high loss effects.

We have measured shunt impedance and Q-value of the SY-20 as a function of input voltage at the burst mode . The measured µQf values are plotted as a function of Brf as shown in Fig.7. From these results, it was found

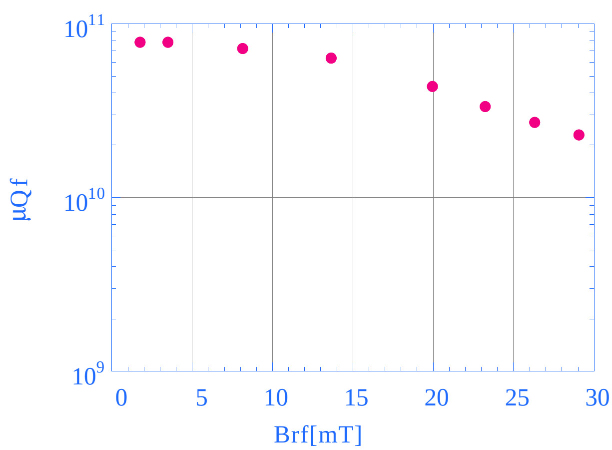

Fig.7 The measured shunt impedance of the SY-20 as a function of Brf.

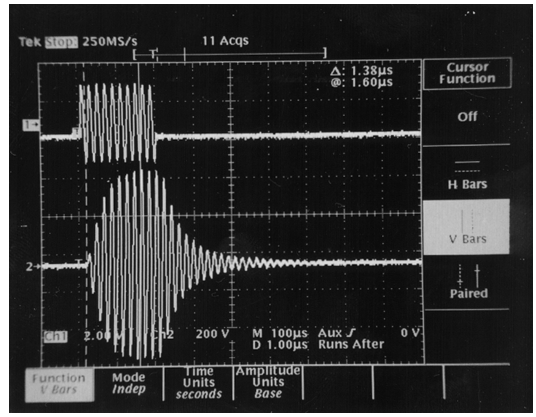

Fig.8 The measured Q-value of the SY20.

a field gradient of 1MV/m could be achievable with SY20 cores where the inner diameter and outer diameter of the core are chosen to be 0.5m and 3.5m, respectively.

The measured Q-value as shown in Fig.8 was around 10 which enough for the requirements.

6 SUMMARY

A high gradient and low frequency rf cavity is important for the PRISM project and Neutrino Factory. We found that a field gradient of more than 1 MV/m could be obtained with a new type of ferrite SY20 at the frequency of MHz range.

REFERENCE

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