DESIGN OF A NEW J-PARC RF CAVITY FOR SHORT MUON BUNCH

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Abstract

The J-PARC 3 GeV Rapid Cycling Synchrotron (RCS) accelerates a high intensity beam using 11 sets of Magnetic Alloy loaded cavities [1, 2]. It supplies the proton beam to the MLF (Material Life Science Facility) for the neutron and muon experiments. For a high resolution muon experiment, a short proton beam with a bunch width of few ten ns is necessary. To reduce the bunch width, bunch compression using a bunch rotation scheme before extraction will be useful. A preliminary beam test using the scheme has been carried out. For the bunch width of few ten ns, a much higher RF voltage than the standard pattern is also required. Based on a new magnetic alloy core technology, a design of a new RF cavity to increase the maximum RF voltage by a factor of two will be described in this paper. A sample of a new core was also investigated using a powerful μSR technique to study the mechanism to improve the magnetic characteristics.

INTRODUCTIONS

J-PARC 3 GeV RCS [3] is a compact accelerator and the circumference is 348.333 m and the repetition rate is 25 Hz. It requires a total RF voltage of 380 kV for a few 100 kW beam acceleration. Around 450 kV will be necessary for one MW beam acceleration. The voltage will be managed by 12 RF stations. So far, 11 systems are installed in a 44-m long straight section. The length of each cavity is 2 m and it can generate 40 kV. The high field gradient of 20 kV/m is achieved by using MA (magnetic alloy) loaded cavities [4]. The MA is a soft magnetic material and has a very high permeability [5, 6]. It is produced from an amorphous metal through crystallization. The magnetic saturation of about 1 T is one order higher than that of ferrite materials, which have been used for RF cavities long time. Because of this feature, the MA core still has a high shut impedance at high RF field. The field gradient of such a cavity is twice as high as that of a ferrite one.

The RF voltage pattern of the RCS was estimated using the code, RAMA [7], and adjusted to fit the high intensity beam acceleration using the second harmonic RF. The maximum voltage is required around 1 GeV to form a large RF bucket. The RF voltage is reduced gradually

from then and will be 60-180 kV before beam extraction. The typical bunch width is 80-120 ns.

Some MLF users require a short bunch of 30 ns for high resolution μSR (muon Spin Rotation/Relaxation/ Resonance) experiments. To achieve the short bunch, a higher RF voltage is required. The present RF system was designed to achieve the RF voltage obtained by the RAMA code. It is difficult to generate a much higher voltage because of a power supply limit [8].

BUNCH ROTATION

A preliminary beam test was performed using a bunch rotation technique, which does not cause large power consumption in the RF systems. Figure 1 shows the RF voltage for bunch rotation. In case of 240 kV before extraction, a bunch width of 60 ns was obtained as shown in Fig. 2. As this voltage is applied for few 100 μs, this operation only marginally increases the power consumption of the whole system. Obvious beam loss was not observed during the bunch manipulation. To obtain a very short bunch of 30 ns which muon beam users in the MLF facility require, 700-800 kV is necessary. However, the available RF voltage is limited up to 450 kV because of limited space in the RCS tunnel.
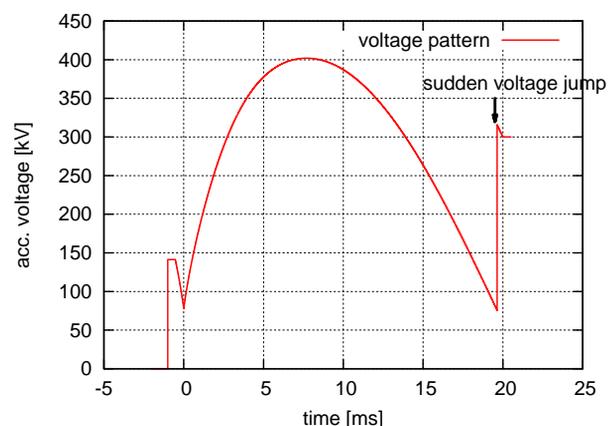
Figure 1: RF voltage pattern for bunch rotation in the RCS. Before the beam extraction, the RF voltage was increased to excite a quadrupole oscillation. After a quarter turn of the synchrotron motion, the beam was extracted.
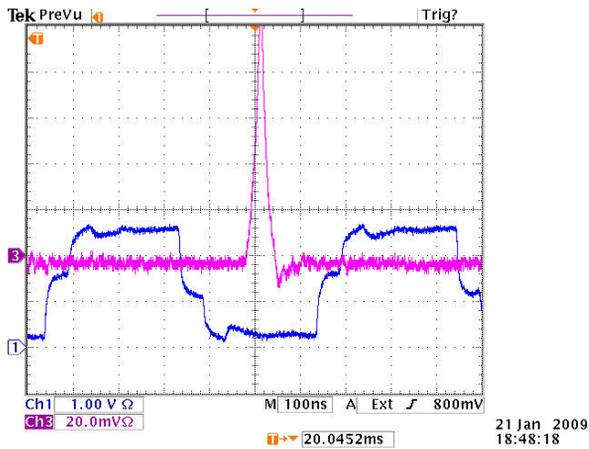
Figure 2: The longitudinal profile of the circulating beam in the RCS before beam extraction.

DESIGN OF A NEW RF CAVITY

The J-PARC RCS cavity consists of 3 cells and each cell generates up to 15 kV. The maximum voltage is limited by the specification of the anode power supply to deliver more than 1 MW to a final stage amplifier. And, the power dissipation in the cavity also limits the available RF voltage. To increase the available RF voltage, it is necessary to design a 4-cell cavity and each cell should have higher shunt impedance than the present cell.

In 1998, a different magnetic alloy, FT3L has been tested and showed better performance than the present material FT3M as shown in Fig. 3 [6]. However, the large size core for particle accelerator use was not available as a special oven with high magnetic field was necessary to produce FT3L. For the RF cavities, the material FT3M, is used in many accelerators (J-PARC, CERN LEIR [9], etc.). Recently, the thickness of the MA ribbon was reduced from 18 μm to 13 μm. It was found that the characteristics of FT3L depend on the thickness and the shunt impedance became about 2 times higher than ordinary material (FT3M). However, the shunt impedance is larger than the expectation from effects of the eddy current loss and the mechanism was not clear.

Based on a new MA technology, an RF cavity was designed. It consists of 4 cells as shown in Fig. 4. In the cavity, the thickness of ring cores is also reduced to 20 mm from 35 mm, which is used for the present system. Although the cores are thinner, the impedance will be 14 % higher because of high μQf product of FT3L cores. Table 1 shows the comparison of RF systems. The gap voltage for the beam acceleration will be 10 kV because of 4-gap cavity. The maximum voltage of 15-17.5 kV is necessary for few hundred microseconds to rotate the beam bunch in longitudinal phase space. Because the duration for the rotation is very short, the power dissipation will increase by less than 1 kW per gap. Therefore, the power dissipation per gap will be 19 kW and it is about a half of the present operation (37 kW).
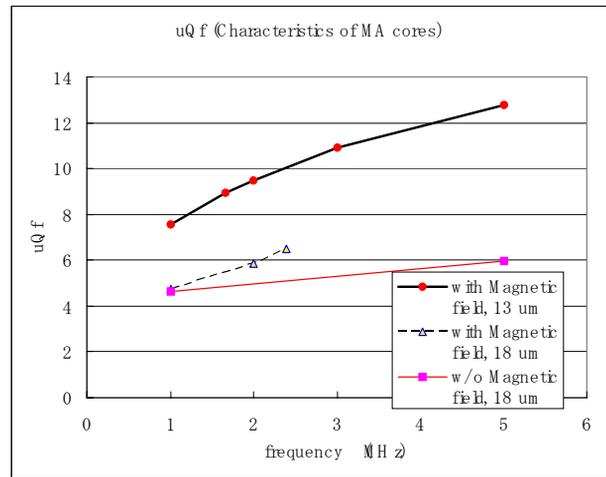
Figure 3: Characteristics of different MA materials. Red circles and triangle symbols mean the μQf products of FT3L cores for different ribbon thickness 13 μm and 18 μm, respectively. Rectangular symbol is that of a FT3M core.
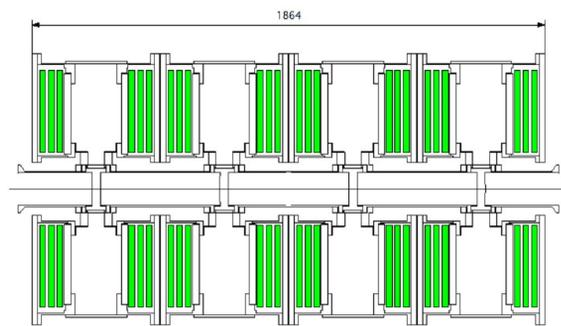
4-Gap 70-kV Cavity

Figure 4: Cross section of a 4-gap RF cavity for bunch rotation.

Table 1: Parameters of RF systems

	Present system	New design
Length	1.95 m	1.864 m
Number of gaps	3	4
Total RF voltage	40 kV	40 kV (acc.) 60-70 kV (B.R.)
Voltage per gap	13. 3 kV	10 kV (acc.) 15-17.5 kV (B.R.)
Number of cores	18 (3 X 6)	24 (4 X 6)
Thickness of core	35 mm	20 mm
Gap impedance	800 Ω	910 Ω
Power dissipation per core	6.1 kW	3.0 kW

STUDY USING μSR

μSR is one of the most powerful tools to investigate magnetic properties of the materials [10]. It injects spin-polarized muons into the material and detects the spin motion in crystalline and material in real time. A preliminary experiment was carried out using a muon beam at MLF. Small magnetic alloy toroidal cores were irradiated by the muon beam from different direction. Figure 5 shows the set up of the experiment. The sample was located between the forward and backward counters to detect decayed positrons. The asymmetry between forward and backward counters was measured. The decay and oscillation of asymmetry suggests the spin motion of implanted muons.

Preliminary experimental results are shown in Fig. 6. Small MA cores of 3cm φ X 1 cm were used. An amorphous ribbon of 18 μm thickness was wound and annealed with/without magnetic field. It clearly showed the effects on magnetic properties by applying the magnetic field during the crystallization process in production. It suggests that the magnetic axis of nano-scale crystalline in FT3L are aligned to the direction of the magnetic field during the annealing process. In the case that the initial spin direction of implanted muons is perpendicular to the assumed easy-axis of nano-crystalline FT3L, the polarization of muons showed a quite fast damping. In contrast, a slow relaxing time spectrum was obtained when the initial direction was aligned with the axis along which the magnetic field had been applied during the annealing, suggesting that the muon polarization is retained due to the local magnetic field. On the other hand, such a drastic change was not seen in the case of FT3M. It turned out, however, that an anisotropic behaviour against the initial muon spin direction in FT3M was still observed, in spite of the absence of the magnetic field during the production. The muon implanted in parallel to the ribbon surface depolarizes slightly faster than that implanted in perpendicular. This may suggest that the shape of MA, e.g. thickness, causes magnetic anisotropy. It hints that the characteristics of FT3L depends more on the thickness of ribbon than on an expected eddy current effect. Further experiments are necessary to study these properties.
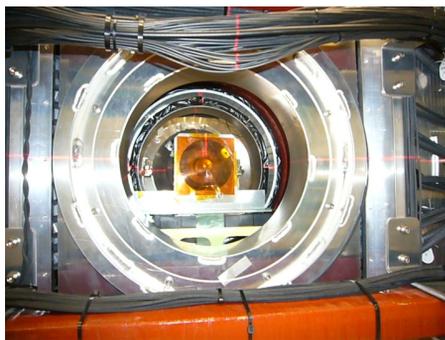
Figure 5: Set up for μSR experiment for MA core. A small MA sample was hold on a thin kapton foil.
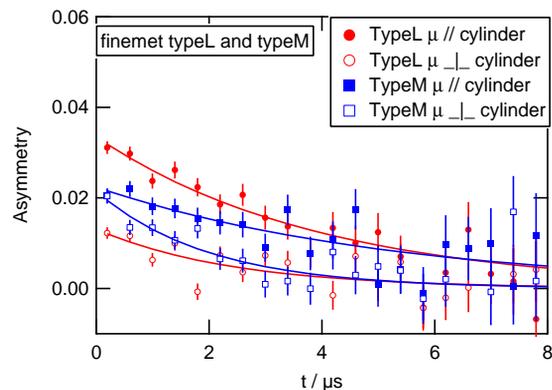
Figure 6: Preliminary results of μSR experiment. Red and blue symbols are asymmetry of FT3L and FT3M, respectively. Outline symbol means the direction perpendicular to the ribbon surface. Filled symbol means the muon beam was implanted in parallel to ribbon surface. This direction is parallel to the magnetic field in case of FT3M.

CONCLUSIONS

A new cavity design to generate a high voltage for bunch rotation in J-PARC RCS to form a short bunch is presented. A new MA core which has higher impedance than the present MA core fits the requirements.

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