HIGH GRADIENT MAGNETIC ALLOY CAVITIES FOR J-PARC UPGRADE

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Abstract

Magnetic alloy cavities are used for both MR and RCS synchrotrons at J-PARC. Both cavity systems operate successfully and they generate a higher voltage than could be achieved by an ordinary ferrite cavity system. For the future upgrade of J-PARC, a higher RF voltage is needed. A new RF cavity system using the material FT3L, is designed to achieve this higher field gradient. A large production system using an old cyclotron magnet was constructed to anneal up to 85-cm size FT3L cores in the J-PARC Hadron Experiment Hall. The μSR (Muon Spin Rotation/Relaxation/Resonance) experiments were also carried out to study the magnetic alloy. The status of development on the J-PARC site and a new RF system design will be reported.

INTRODUCTIONS

The first Magnetic Alloy-loaded cavity was developed in 1980's for the MIMAS RF system [1]. Cobalt-based amorphous magnetic alloy was used, then. The reason why the MA was used was to cover the very wide frequency sweep of 130 kHz to 3 MHz. In Japan, development of MA cavity was started in 1995. The purpose of development was to use it for a high intensity proton synchrotron. A soft-magnetic nano-crystalline material was used. Permeability and shunt impedance of the MA are stable with high RF magnetic field because the saturation field level is high. These characteristics are very suitable for a high gradient RF system which is necessary for a compact proton accelerator [2]. Therefore, the MA cavities are used for both RCS [3] and MR [4] of J-PARC. Furthermore, the MA has a wide band impedance. It is also suitable for the RF system of a rapid cycling synchrotron which needs a fast frequency variation for beam acceleration and dual harmonic operation [5]. The bandwidth of RCS cavity is controlled using an external inductor to reduce the beam loading effects [6]. The bandwidth of MR cavities is controlled using a cut-core configuration [2].

During the beam operation for several years, buckling problems ccurred at the J-PARC RCS system. It was caused by the stress force on MA cores and solved by modifying the production process [7].

Degradation of MA cut cores was observed for the J-PARC MR RF system. It was caused by corrosion on cut core surfaces which was enhanced by copper oxide in the cooling water. Separation of cooling water systems for RF cavities and for magnets is undergoing in this summer [7].

J-PARC UPGRADE

J-PARC aims to deliver 1 MW beam to MLF and 750 kW beam to MR users. We plan the energy recovery of the linac from 181 MeV to 400 MeV in FY2014. The recovery is effective to reduce the loss in RCS and achieve the design value according to simulations [8]. The scenario to achieve the design intensity for MR includes two more items [9];

- Fast repetition cycle of MR from present 3 seconds to 1.2 seconds.
- Increase the beam intensity per cycle by reducing and controlling beam loss.

For this scenario, magnet power supplies will be replaced to manage fast cycling. And, in total of about 500 kV is necessary for RF system. Furthermore, the second harmonic RF systems are necessary to reduce the space charge effects which cause the beam loss. As the space for RF systems is limited it is necessary to increase the field gradient of RF cavity. For this purpose, we pursue to develop a high gradient cavity using high impedance MA cores.

A HIGH IMPEDANCE CORE

Production System of FT3L

Improvements of the MA materials were reported [10] for small size. It is shown that the impedance characteristic of the material, FT3L, is about two times larger than ordinary, FT3M, MA core. The FT3L can be produced by applying a magnetic field during the crystallization process while annealing. However, MA cores for a high intensity

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proton accelerator needs a large size of 80 cm. The production system for such a large core did not exist. A collaboration across J-PARC worked together to make a production system on the J-PARC site. Figure 1 shows the production system using an old cyclotron magnet in the J-PARC Hadron Hall.

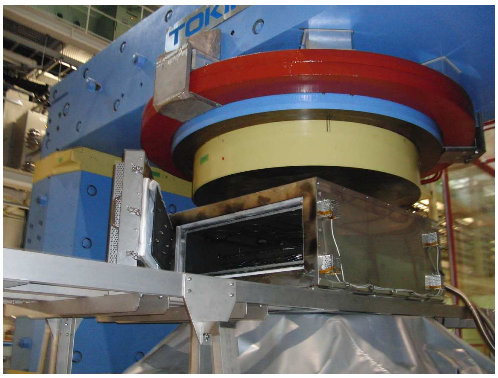

Figure 1: A large MA core production system using a cyclotron magnet. In a large magnet aperture, an oven is located.

Characteristics of FT3L Cores

Figure 2 shows the characteristics of FT3L, MA cores, which are annealed in a magnetic field and ordinary FT3M core. The outer diameters of the cores are 850 mmϕ for RCS and 800 mmϕ for MR (Fig. 3), respectively. The μQf values of large FT3L cores are about two times larger than those of FT3M ones as expected. The mechanism of low loss has been investigated by a collaboration with the muon group of MLF, Material and Life Science Facility of J-PARC using a new high-temperature μSR technique. The phase transition of material from amorphous phase to nano-crystalline was clearly observed (Fig. 4).

Cavity Design

Based on the results measured using large size MA cores, high field gradient cavities were designed for the J-PARC RCS and MR as follow:

- The length of cavities are about same to fit the present spaces.
- The cavity will be driven by the present amplifier and power supply to avoid extra cost.
- The number of cell per cavity increases from 3 to 4. The impedance per cell increases by more than 40 %. The load impedance from the amplifier is changed little.
- Beam impedance increases, however, the present feed forward system can compensate the beam loading.
- The direct water cooling scheme will be used for cooling as the present system.

Main parameters of the cavities are summarized in Table 1 and 2. The drawing of the RCS cavity is shown in

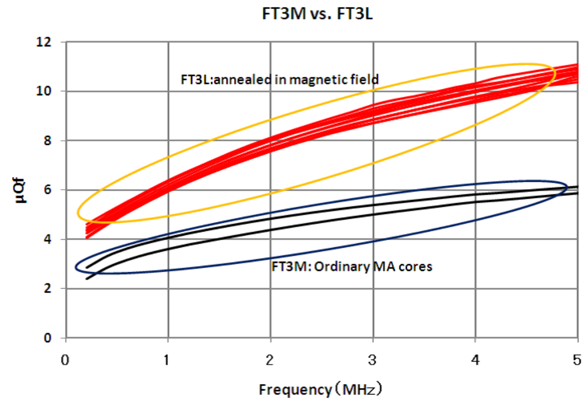

Figure 2: Characteristics of MA cores. μQf is a product of permeability, Q-value and frequency and given by dividing the shunt impedance with a form factor. Red lines mean the characteristics of 8 different FT3L cores. Black lines mean maximum and minimum characteristics of FT3M cores in 2010.

Figure 3: The first high impedance core annealed in J-PARC.

Fig. 5. For both designs, the direct water cooling scheme is adopted to remove the heat from the MA cores. So far, the direct water cooling seems to work sufficiently, however, we also consider an alternative solution using forced air cooling as a back up [11]. The FT3L cores will be processed to assemble a test cavity next year.

CONCLUSIONS

KEK and JAEA are planning to upgrade J-PARC and to increase the beam power. One of the key issues is a high field gradient cavity using FT3L material. We built a test production system for large FT3L cores for RCS and MR. The impedance and characteristics of FT3L cores are consistent with small samples. The second production system will be ready in next fiscal year. The high gradient cavities are designed for RCS and MR. The FT3L cores will be assembled and high power test of MR cavity is planned in next year.

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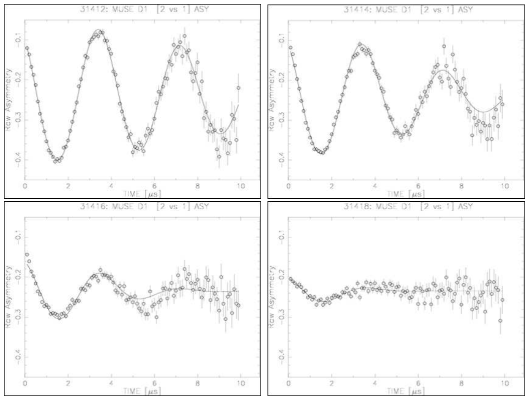

Figure 4: Muon spin asymmetry at different temperatures in an outer magnetic field. From left-top to right-bottom, they are 460, 470, 480 and 490 °C, respectively. Low magnetic field was applied to see spin precession. At 460 °C, material is amorphous phase. Muons shows spin precession by the outer field because Curie temperature of amorphous is below 460 °C. At 490 °C, nano-crystalline has been formed. Curie temperature of the crystalline is higher than 490 °C. Muon spin decays quickly because muons are affected from internal field of crystals.

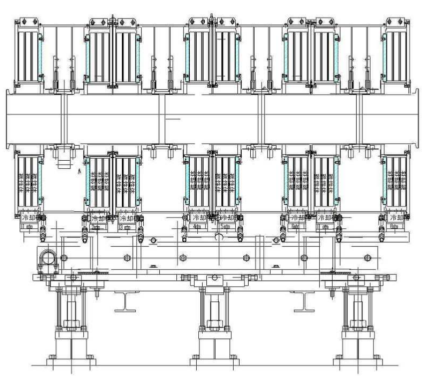

Figure 5: 4-Cell RF cavity for J-PARC upgrade.

ACKNOWLEDGEMENTS

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Table 1: RCS Upgrade

	Present System	Upgraded System
Cavity Length	1950 mm	1950 mm
Number of cells	3	4
Voltage / cell	12.7 kV	15 kV
Total Voltage	38 kV	60 kV
Field Gradient	19.5 kV/m	30.7 kV/m
Impedance / cell	800 Ω	1100 Ω
Number of MA cores	6 /cell	6 /cell
Thickness of MA core	3.5 cm	2.5 cm
Power Dissipation / cell	30.1 kW	30.6 kW

Table 2: MR Upgrade

	Present System	Upgraded System
Cavity Length	1780 mm	1950 mm
Number of cells	3	4
Voltage / cell	13.3 kV	17.25 kV
Total Voltage	40 kV	70 kV
Field Gradient	22.5 kV/m	36.0 kV/m
Impedance / cell	1100 Ω	1700 Ω
Number of MA cores	6 /cell	6 /cell
Thickness of MA core	3.5 cm	2.5 cm
Power Dissipation / cell	48.5 kW	54.0 kW

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