RECENT PROGRESS ON THE DEVELOPMENT OF A HIGH GRADIENT RF SYSTEM USING HIGH IMPEDANCE MAGNETIC ALLOY, FT3L

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Abstract

The future high intensity upgrade project of J-PARC MR (Main Ring) includes developments of high gradient RF cavities and magnet power supplies for high repetition rate. A dedicated production system for high impedance magnetic alloy (MA), FT3L, cores was assembled in J-PARC. This setup demonstrated that we can produce material with two times higher μ'_pQf product compared to the cores used for present cavities. And, the new results also show up to 20 % higher impedance than the 2011 production with the former setup. In this summer, the system will be used for mass production of 280 FT3L cores for the J-PARC MR. The cores produced in 2011 are already used for standard machine operation. The operation experience shows that the power loss in the cores was reduced significantly as expected. The scenario describing the upgrade plan of the MR and the cavity replacements is reported. By the replacement plan, the total acceleration voltage will be almost doubled, while the number of RF stations remains the same.

INTRODUCTION

J-PARC aims to deliver 1 MW beam from Rapid Cycling Synchrotron (RCS) to MLF and 750 kW beam from the MR to the Neutrino experiment facility[1]. Both RCS and MR adopt Magnetic Alloy (MA) loaded cavities for beam acceleration[2]. The MA loaded cavity system provides two advantages to handle a high intensity beam:

- Higher field gradient can be obtained than other ferrite-loaded cavies because the characteristics of the material is stable at high RF field. This is a very important point to design the RCS to be a compact machine.
- Simple RF system without tuning loop is suitable to handle a high intensity beam. Because the MA-loaded system has a wide and variable bandwidth, the frequency variation for proton acceleration can be performed without tuning circuit which has to be used for ferrite-loaded system. In case of the RCS, the dual harmonic RF system, which is necessary to reduce the space charge effect during injection, can be realized by a single cavity system. This is also helpful to save the space in a compact synchrotron.

It is known that the magnetic property of MA can be changed by applying an external magnetic field during annealing[3]. The magnetic hysteresis loop tilts by it. The magnetic alloy, which is annealed with an external magnetic field, is called FT3L. Magnetic alloy annealed without the magnetic field is called FT3M and, so far, the FT3M is used for the RF cavities. And, it is also known that the characteristics depend on the thickness of the ribbon, which forms the ring. Figure 1 shows the difference of material and ribbon-thickness dependence. The vertical axis is the product of μ'_pQf (relative parallel permeability, Q-value and frequency) which is proportional to the shunt impedance. μ'_pQf is given by:

$$R_p = \mu_0(\mu'_p \mathrm{Qf})\mathrm{t}\ln\frac{\mathrm{O.D.}}{\mathrm{I.D.}}, \qquad (1)$$

where O.D., I.D., and t are the outer diameter, inner diameter, and the thickness of a toroidal core. The suffix p means parallel to express the magnetic materials are treated as a parallel circuit. The product μ'_pQf is independent of the size and shape of the magnetic core and is used to evaluate magnetic materials. Figure 1 clearly shows that the μ'_pQf product becomes two times larger when the external magnetic field was applied during annealing on the MA core using 13 μm thick ribbon. Although the FT3L seems to have a better characteristics than the FT3M, there existed no production system to make a large FT3L core for accelerator use. The first proof-of-principle experiments to produce large FT3L cores were performed in 2011. All FT3L cores which were produced showed good characteristics as expected[4].

TEST OF FT3L CAVITY

The first FT3L large cores for accelerator use were manufactured, according to the recipe which is used for the FT3M cores. There was no significant difficulty to process the FT3L cores. Six FT3L cores were installed in a MR RF cavity in summer 2012. The cavity impedance is 1300 Ω and this is 20 % higher than other FT3M cavities. The cavity has been working properly. Figure 2 shows the power consumption in a half cell of cavity calculated by the temperature rise of the cavity cooling water. It shows

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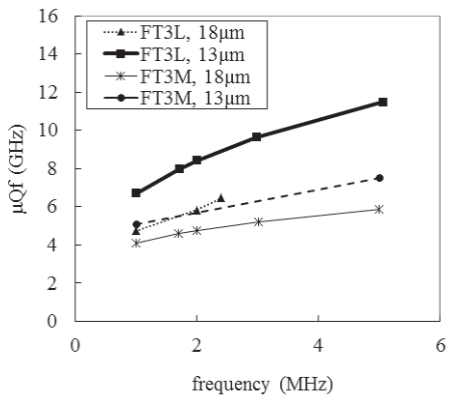

Figure 1: Characteristics of MA cores. The present FT3M core (solid line) with 18 μm layer thickness can be improved by the FT3L with 13 μm thickness (bold line).

the power loss in the cavity is much less than that in other existing FT3M cavities as expected.

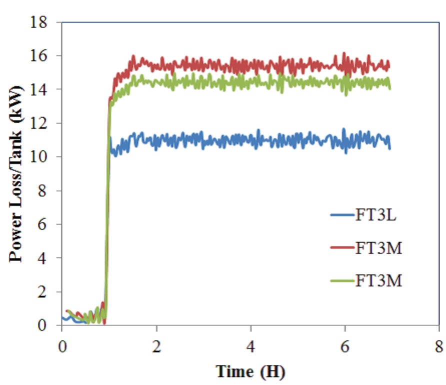

Figure 2: Power consumption in half cavity cell calculated by temperature rise of cooling water during machine operation. Because of the higher impedance compared to the other cavities, the temperature rise of the FT3L cavity cell is much lower than that of the other FT3M cavity cells.

A NEW MASS-PRODUCTION SYSTEM FOR FT3L CORES

The large FM magnet[4] which was used for the first test production of the FT3L cores was returned for a nuclear physics experiment in J-PARC. A new set up for long term use was assembled using the "Kappa" magnet in J-PARC. Figure 3 shows the Kappa magnet and the annealing oven. The Kappa magnet was modified to fit the large oven. Because the distance between the oven and magnet pole pieces becomes close, the speed to cool the annealed core becomes faster compared to the test production. It is helpful to anneal the cores in a limited time and to control the oven temperature.

Figure 3: The FT3L core production system using the Kappa magnet. The inner size of the oven is 1.1 m(W) X 0.37 m(H) X 1.4 m(L) to anneal the large size core up to 0.85 m diameter.

The production of the FT3L cores was started in December 2012 and the results are shown in Fig. 4. This shows an additional improvement of μ'_pQf product compared to the test production in 2011[4]. The product increased by 17 %. One of the major improvement was the smoothness of the ribbon surface. It increased the so-called packing factor which means the volume of ratio of magnetic material. The packing factor increased by 12 %. The other part of the improvement is considered as the magnetic property. Figure 4 also shows the comparison with company-made FT3L cores with about 30 cm size. In both cases, the packing factor is about 70 %. The hysteresis curve measurement shows that the initial permeability of the test production in 2011 is the highest, the commercial one is the lowest, and the recent production is medium. It is understood as we accidentally chose an almost-optimized temperature and magnetic field patterns for our purpose to use in a few MHz region.

MASS PRODUCTION OF FT3L CAVITIES

J-PARC is planning to increase the MR repetition rate from 0.4 Hz to 1 Hz[5]. This project includes the replacement of the magnet power supplies, upgrade of beam injection and extraction systems, and an upgrade of the RF systems. The present FT3M cavities will be replaced by new FT3L cavities to increase the RF voltage without modifying the other components of the RF systems. As shown in Fig. 4, the μ'_pQf product of the FT3L cores becomes two times higher than that of the present FT3M cores. This factor-of-two improvement can be used to design a compact cavity putting less materials in a cavity and/or to de-

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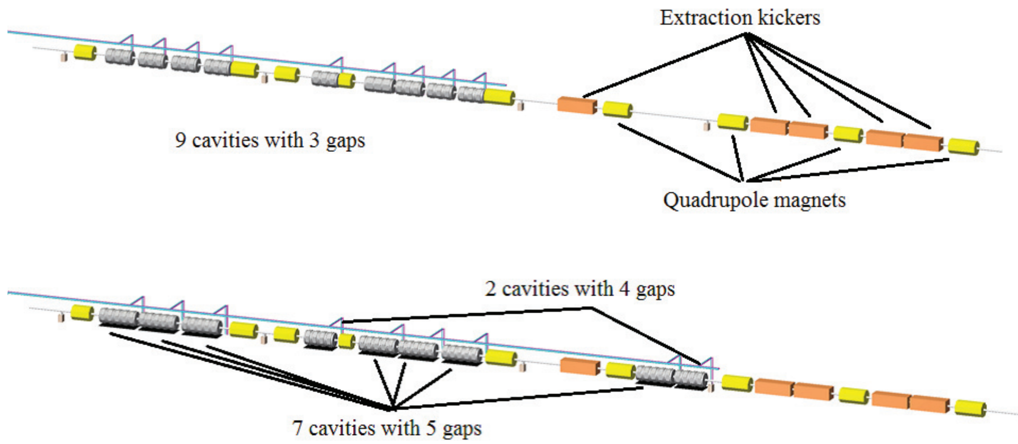

Figure 5: Upgrade scenario of J-PARC MR cavities. The present cavities (upper) will be replaced by the FT3L cavities (lower) in 2014-2016. The total RF voltage will become 560 kV providing enough margin as the required RF voltage for 1 Hz operation is 440 kV according to a simulation.

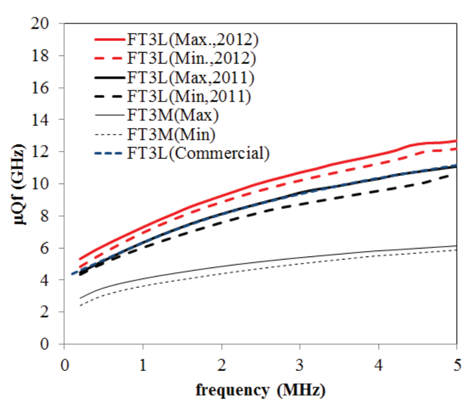

Figure 4: Characteristics of MA cores for J-PARC accelerator use. The FT3M cores (black lines) are currently used for J-PARC. And, FT3L cores in 2011 (bold black lines) are also used in the MR from summer 2012. The recent production (red lines) shows the highest performance. The J-PARC-made cores are even better than the commercial available FT3L cores (blue line) with smaller size. The blue line is overlapping on the bold black line.

sign a high impedance cavity.

We chose a compromise to design upgrade cavities for J-PARC. The factor-of-two improvement is used to reduce the materials by 40 % and to increase the cavity impedance by 40 %. The length of cavity cells can be reduced from the present 590 mm to 505 mm. And, the number of cells which can be driven by the present amplifier can be increased from the present 3 to 5.

Figure 5 shows the upgrade scenario of the cavities. Seven cavities will be replaced by new 5-cell cavities and two by 4-cell ones. The total RF voltage will be 560 kV while the minimum RF voltage for 1 Hz operation is 440 kV. The margin is necessary to obtain the large RF bucket to handle the high intensity beam without beam loss and to increase the system reliability.

The mass-production system of the FT3L cores was disassembled to move to the company. The production will start in this summer for new FT3L cavities. The mass production of the FT3L cores for the MR will continue until 2016. It is also considered to start the production of the FT3L cores for the second harmonic cavities of the MR after it. The FT3L technique will be applied for the RCS systems to increase the beam power.

CONCLUSIONS

This paper reports the recent progress of a magnetic alloy cavity using a material, FT3L. An MR cavity, where one cell was loaded with FT3L cores has been in stable machine operation for half a year. A new mass-production system of the FT3L cores for accelerator use worked very well. The mass-production system was moved to a company for the production of the FT3L cavities. All J-PARC MR cavities will be replaced with the FT3L cavities for the J-PARC upgrade.

REFERENCES

[1] Accelerator technical design report for J-PARC, JAERITECH 2003-044 (2003).

[2] C. Ohmori *et al.*, PAC99, New York, U.S.A., March 1999, p. 413 (invited) (1999).

[3] Y. Tanabe *et al.*, APAC98, Tsukuba, Japan, March 1998, p. 390 (1998).

[4] C. Ohmori *et al.*, IPAC11, San Sebastian, Spain, September 2011, p. 2885 (2011).

[5] Y. Sato *et al.*, IPAC11, San Sebastian, Spain, September 2011, p. 598 (2011).