AIR-COOLED MAGNETIC ALLOY CAVITY FOR J-PARC DOUBLED REP.-RATE SCENARIO

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Abstract

The upgrade project of the J-PARC MR (Main Ring) based on doubled repetition-rate scenario is in progress to deliver the beam power of 750 kW. The present RF section will be occupied by 9 sets of new magnetic alloy, FT3L, cavities using the direct water cooling scheme. The direct water cooling is the efficient scheme to cool the magnetic alloy core although it requires dedicated high-quality cooling water which does not contain copper oxide and copper ions because copper ions may cause the severe corrosion damage on the magnetic alloy cores. These cavities will be used for the fundamental RF for acceleration which requires high duty operation.

The second harmonic RF is necessary to increase the bunch length. This allows to enlarge the beam current because it relaxes the space charge effects during the injection. Thanks to the high impedance FT3L and low duty operation of the second harmonic RF, the power loss in the second harmonic RF system becomes moderate. The air cooled cavity is designed to fit in any locations in the MR where the dedicated high-quality water is not available. This paper reports the design of the second RF system, technical issues to produce the magnetic alloy cores to fit the air cooling, and construction of the system.

INTRODUCTION

During the long shut down in 2013, the J-PARC linac energy is upgraded from 181 MeV to 400 MeV. Thanks to the energy upgrade and a new ion source which is under testing, the beam power of 1 MW will be available from the J-PARC RCS (Rapid Cycling Synchrotron) to the MLF (Materials and Life Science Experimental Facility) [1]. J-PARC is planning to increase the beam power of the MR to 750 kW [2] by increasing the repetition rate and number of protons in the ring. For the doubled repetition scenario from 0.4 Hz to about 1 Hz, the replacement of all existing cavities to the new FT3L high gradient cavities is ongoing (Table 1). The first 5-gap FT3L cavity has been tested and will be installed in the MR tunnel in this summer. Full replacement of cavities allows us to increase the operational voltage from the present 280 kV to 560 kV [3].

Table 1: Cavity Replacement Plans

	Present Cavities	**New Cavities**	
Cycle Time	2.48 s	about 1 s	
Accelerating Cavities			
Core Material	Magnetic Alloy FT3M [4]	Magnetic Alloy FT3L	
Cooling Scheme	Direct Water	Direct Water	
Location	RF Straight Section	RF Straight Section	
Typ. Impedance	1100 Ω	1450 Ω	
Q-value	21.4-22.6	22	
Number of Cav.	8	7	2
Number of Cells	3	5	4
Cavity Voltage	35 kV	75 kV	60 kV
Test Voltage	45 kV	80 kV	64 kV
Total Voltage	280 kV	645 kV	
Required Voltage	280 kV	560 kV	
Second Harmonic Cavities			
Core Material	Magnetic Alloy FT3M	Magnetic Alloy FT3L	
Cooling Scheme	Direct Water	Forced Air	
Location	RF Straight Section	Injection Straight Section	
Typ. Impedance	1300 Ω	4000 Ω	
Q-value	13.8	14	
Number of Cav.	1	2	
Number of Cells	3	4	
Cavity Voltage	35 kV	60 kV	
Test Voltage		64 kV	
Total Voltage	35 kV	120 kV	
Required Voltage	80 kV	80 kV	

To increase the number of protons in the ring, the control and reduction of the beam losses are necessary. It has been observed that the beam loss in the MR is related to the space charge effects [2]. The relaxation of the space charge by the extension of the beam length is effective. Adding the second harmonic RF which was applied during the injection period showed the remarkable loss reduction in case of the high intensity beam. Although the second harmonic RF is an useful tool for high intensity accelerators, the RF voltage of the present FT3M cavities is not enough to satisfy the required voltages for acceleration and the second harmonic RF as shown in Table 1. During the beam study, one of the accelerating cavities was modified for the second harmonic

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RF. As the accelerating cavities which need an efficient cooling of the magnetic alloy cores [4] require the high quality water to dip the core in, the possible locations of these cavities are limited to the long RF straight section. It is reported that copper oxide in the cooling water which might come from the conductors of the magnets caused the damage on the cut surfaces of the magnetic alloy cores [5]. In 2011, the water circuit for the cavities were separated from other devices like MR magnets and degradation of the cavity has not been reported after the separation. The RF straight section will be occupied with the accelerating cavities, the second harmonic cavities will be located in the other straight section where the high quality water not including the copper oxide is not available. Therefore, the forced air cooled cavity is built for testing as shown in Fig. 1.

Figure 1: Shroud of the second harmonic cavity. The cavity is a single cell type using forced air cooling.

CAVITY DESIGN

Although the power consumption in the second harmonic cavities will be much smaller than the present one, it is necessary to test the system before the mass production followed by installation into the MR tunnel. Therefore, we built a single cell cavity for testing. Table 2 shows the parameters of the second harmonic cavity. The cavity was designed as a high impedance and low power loss system which can be managed by the air cooling. A commercially available simulation code was used to estimate the temperature in the magnetic alloy cores. The simulation shows the air flow to cool the cores is not uniform and depends on the location of the cores and position of the air inlet. Figures 2 show the air flow and temperature distribution in the core. The temperature in the magnetic alloy will be about 75 degree Celsius which is much lower than the glassy-transition temperature of the epoxy resin using for the molding. The Curie temperature of the magnetic alloy is higher than 500 degree Celsius.

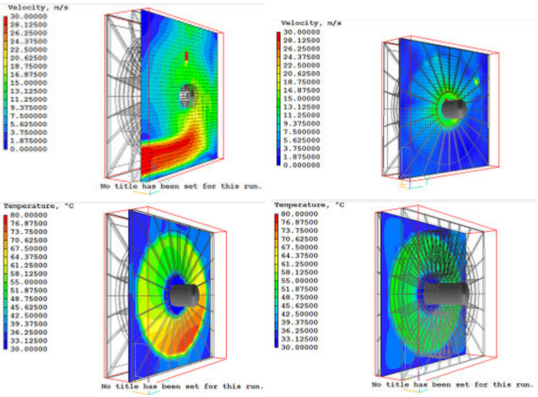

Figure 2: Upper figures show the air flow in the cavity. Upper left shows the inlet air flow and right shows the air flow between the magnetic alloy cores. Lower figures show the temperature distributions. The left and right figures are temperature in the cores near the accelerating gap and end side.

Table 2: Single Cell Cavities

RF frequency	3.4 MHz
RF Voltage	10 kV
Number of Cores	10
Cavity Impedance	4 kΩ
Duty	30 %
Power Loss	3.75 kW
Air Flow	52 m^3/min.
Max. Temperature	75 deg. C
Glassy-Transition Temperature	120 deg. C

FT3L CUT CORE PRODUCTION

Although the magnetic alloy cavities are used in the J-PARC MR and RCS, there is a difference in the core production. The RCS uses un-cut cores because the RCS RF is the wideband system. In contrast, MR uses the cut one because the MR needs the narrow band system to handle the periodic transient beam loading. The advantage to use the cut core configuration is the reduction of the effective inductance of the magnetic alloy cores without reducing the shunt impedance [4]. The cavity parameter, R/Q can be reduced.

The cut cores for the MR accelerating cavities are coated with epoxy resin and glass fiber to avoid the corrosion in the water. For the air cooled core, the water proof coating is not necessary and can be removed for efficient air cooling. Thus a new method to produce the cut cores was applied. For the efficient cooling the thickness of the coating is reduced as thin as possible and the glass fiber sheets were used only for supporting the core to cut. Figure 3 shows a cut core for the air cooled cavity. The quality of the cut surface is the key issue to avoid the destruction of insulation between the ribbons as shown in Fig. 4. The poor treatment causes a large heat loss on the cut surface.

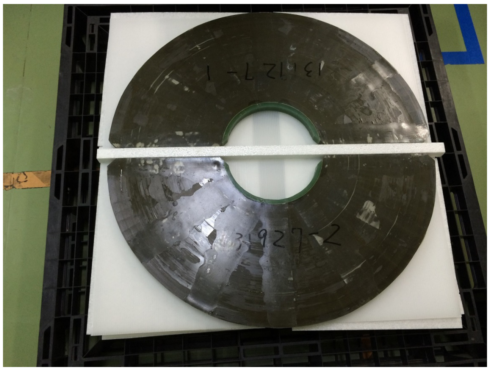

Figure 3: A cut core for the air cooled cavity.

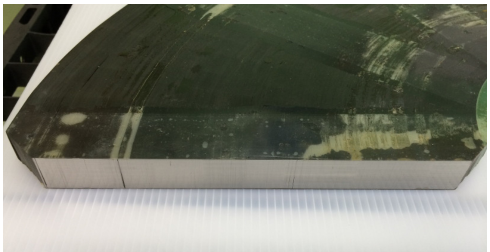

Figure 4: Cut surface of the core.

Because of the stress force during the epoxy molding process for cut core production, some degradation of the shunt impedance was expected. Although the first two cores showed relatively large degradation, the others did not show much as shown in Fig. 5. The vertical axis is the product of μ'_pQf (relative parallel permeability, Q-value and frequency) which is proportional to the shunt impedance. The reason why the difference occurred between the first two productions is not very clear. We considered that the improvements is related to the handling including immersion.

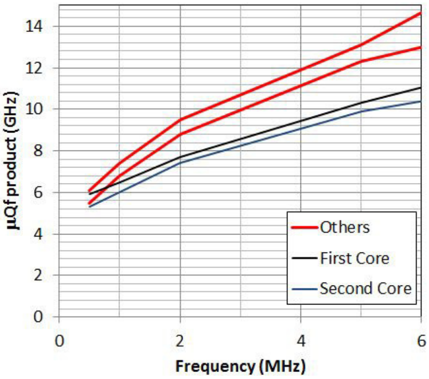

Figure 5: Characteristics of cut cores. The μQf product of 10 cut cores are shown. Except for the first two cut cores, the μQf product was as high as the uncut cores.

AMPLIFIER

Because the second harmonic cavity will have a higher impedance than the present accelerating cavities and the second harmonic components of the beam loading will not be heavy, we designed the final amplifiers smaller than the present one for the acceleration. Two sets of 100 kW vacuum tubes will be used instead of large 600 kW ones for acceleration. The size of the present amplifier is 1.4 m × 1.0 m× 2.4 m. Figure 6 shows a new amplifier using two sets of EIMAC 4CW100,000. It has the size of 1.35 m× 0.7 m× 1.57 m. The advantage of the small amplifiers is that they can be located in the injection straight section where the space is limited. The amplifier is designed to drive a 4-gap cavity.

Figure 6: Tube amplifier for the second harmonic RF.

CONCLUSIONS

This paper reports the second harmonic RF cavity using the material, FT3L for the J-PARC MR. The second harmonic system is designed and produced as a compact system. And, the forced air cooling is adopted to cool the FT3L cores. The high power test of the cavity is planned in this summer.

REFERENCES

[1] H. Hotchi *et al.*, Prog. Theor. Exp. Phys. 02, 003 (2012).

[2] T. Koseki *et al.*, Prog. Theor. Exp. Phys. 02, 004 (2012).

[3] C. Ohmori *et al.*, Phys. Rev. ST Accel. Beams 16, 112002 (2013).

[4] C. Ohmori *et al.*, Proceedings of the 18th Particle Accelerator Conference, New York, U.S.A., March 1999, p. 413 (invited) (1999).

[5] M. Nomura *et al.*, Proceedings of the IPAC10 conference, Kyoto, Japan, p. 3723(2010).