DESIGN OF MAGNETIC ALLOY RESONANT SYSTEM (MARS) CAVITY FOR J-PARC MR

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Abstract

The Magnetic Alloy Resonant System (MARS) cavity is a new type of Magnetic Alloy (MA) cavity using an external energy storage system. It is proposed as a back-up system of the present J-PARC Q=26 MA cavity using cut cores. MARS consists of un-cut core loaded wideband MA cavities combined with an energy storage system using high-impedance, FT3L[1], cut cores. The main cavities are water-cooled and already established at J-PARC RCS. The energy storage system will be high-Q ($\geq$100) to be stable under heavy beam loading. It also has a higher impedance than the main cavity and is air-cooled. Because the external resonator is air-cooled, the RF voltage on each cut core is below 1 kV.

We also propose the MARS system as a second harmonic RF cavity. As the duty factor of the operation is low, a simple forced-air cooling is considered for the main cavity. The design of these fundamental and second harmonic cavity systems will be presented.

INTRODUCTION

Magnetic Alloy loaded cavities[2] are successfully used for both J-PARC RCS (Rapid Cycling Synchrotron) and MR (Main Ring). A remarkable feature of the cavity is the high field RF gradient. Another remarkable feature is an optimum "wideband" system for proton beam acceleration. The bandwidth of the RCS cavity system is controlled using an external inductor. The bandwidth should be wide enough to cover the RF frequency for the acceleration and dual harmonic manipulation. And, it should be narrow enough to reduce the beam loading effects including higher harmonic and transient effects. The Q-value of the RCS system is set at about 2[3]. In case of the MR, the optimum Q-value is set at 26 to reduce the periodic transient beam loading effects as much as possible within the limit to cover the acceleration frequency (1.67 MHz-1.72 MHz). It is also helpful to handle a very narrowly bunched beam with a peak current of over 100 A. A cut core configuration is adopted to realize the Q-value of 26[4]. By cutting, the permeability of a magnetic alloy core reduces and thus the inductance can be controlled with the distance between two halves. The process to cut the magnetic alloy core is the key issue of the production. For J-PARC, a diamond polishing is adopted to finish the cut surface without destruction of the structure of magnetic alloy ring.

Figure 1 shows the present MR cavity using cut cores. The cut cores are cooled by demineralized water directly. During the beginning of operation, the quality of the cooling water was poor and it was contaminated by copper oxide particles from magnets which share the same water circuit. The damages on cut core surface were caused by depositing a conductive material[5, 6]. Although the MR cut core cavities work properly after separating the water circuit from common one and protecting the cut surface from the corrosion, it is still considered that the cut surface might be the potentially weakest part in the MR cavity. Because water has a high permittivity, a high RF voltage of several kV appears on the core as shown in Figure 2.

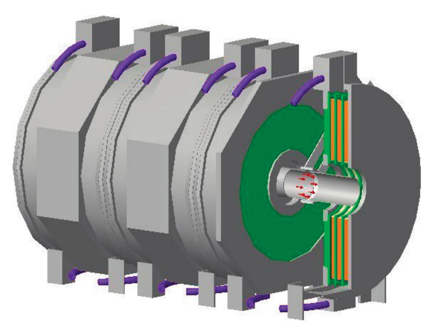

Figure 1: A present MR cavity. Cut cores are installed in the water tanks.The rightmost tank is cut open so that 3 cut core halves are seen. The cut cores were cooled by water directly.

MAGNETIC ALLOY RESONANT SYSTEM CAVITY AS A BACK-UP FOR THE MR

External Inductor for RCS Cavity

The idea to apply the external inductor which is used for the RCS was proposed[3]. The RCS cavity consists of 18 magnetic alloy ring cores, resonant capacitor of 200 pF and an external inductor of 12 μH. Each magnetic alloy core has the inductance of about 5 μH and 150 Ω impedance as a parallel circuit. Without the external inductor, the Q-value

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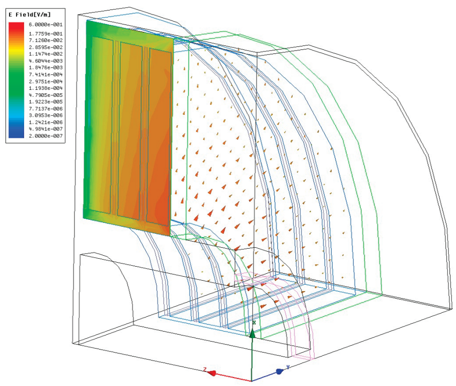

Figure 2: Electric field in the cavity. Because of the large dielectric constant of water, a high RF voltage appears on a core near the accelerating gap. This can explain that a severe damage occurred on the core near the gap while the quality of water was poor.

of the resonant system is about 0.6. Adding the external inductor, the total inductance of the parallel circuit reduces to about 10 μH and the Q-value becomes about 2.

It was considered to apply the same scheme to the MR cavity instead of the cut core configuration. That means un-cut core cavity instead of cut core one. However, there are two major issues to solve before applying it. They are;

(1) The duty factor of MR is higher than that of the RCS. To manage this problem, we choose the MR core size of 245 mm inner diameter to increase the impedance and to reduce the power dissipation. However, adopting the small inner diameter causes higher power concentration because the RF flux density is proportional to 1/r. The un-cut core cavity for the MR needs to handle a higher power density than the RCS one and it seems very difficult.

(2) To obtain the Q-value of 26, the external inductor needs to have a small inductance of about 1 μH. The resonant current between the inductor and resonant capacitor will be several hundred ampere. It seems too high to be handled by single inductor and many external inductors might be necessary.

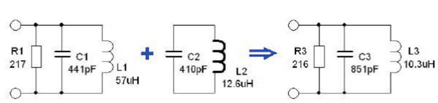

Figure 3: Adjusting the Q-value of J-PARC RCS Cavity[3]

Energy Storage Cavity and FT3L Cavity

The Magnetic Alloy Resonant System (MARS) consists of a main cavity loaded with high impedance FT3L cores[1] and external energy storage cavity using cut cores. Although the cut cores are still used in the external cavity, potential risks of failures will be reduced and the replacement of an external cavity is relatively easy as the machine

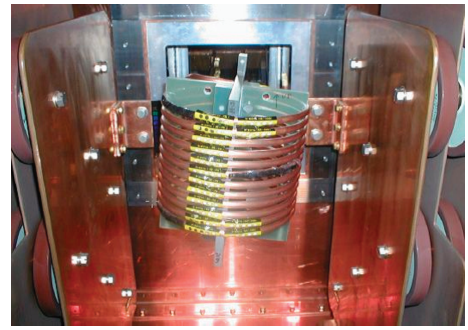

Figure 4: External inductor in the J-PARC RCS Final Stage Amplifier[3]

vacuum does not need to be broken.

Figure 5 shows the MARS cavity. The main cavity is similar to the present RCS cavity although the high impedance FT3L cores are loaded. To reduce the power consumption in MA cores, 4 MA cores will be installed. The FT3L core is a magnetic alloy core which has about two times higher performance than the present material and the production of such cores was recently demonstrated in J-PARC. Thus, the cavity impedance will be higher than the present cut core cavity. Using the FT3L material, the problem on high power density is resolved. Table 1 shows the MARS cavity can be operated under the same condition as the present MR cavity. As the beam does not go through the external cavity, the length of the cavity can be long and many cut cores can be installed. The RF voltage appearing on each single core reduces according to the number of cores in the external cavity. And, by adopting the cavity structure, a large resonant RF current can be handled and the second problem is solved. The power in a cut core also reduces according to the number of core and the cooling scheme will be simpler. The size of cut cores for the external cavity can be small because the inner radius of cut cores can be small because the beam pipe limitation does not exist.

However, a higher voltage is required for J-PARC upgrade. Further improvements are necessary to use the MARS for rapid cycling acceleration.

Table 1: RF Cavity Using MARS

	Main Cavity	External Resonator
Cavity Length	1800 mm	1200 mm
Number of cells	3	1
Impedance / cell	1480 Ω	4000 Ω
Number of MA cores	8 /cell	40 /cell
O.D. of MA core	85 cm	30 cm
Power Dissipation / cell	23 kW	8.5 kW
Power Dissipation / core	2.8 kW	210 W
Duty Factor	60 %	60 %

ISBN 978-3-95450-115-1

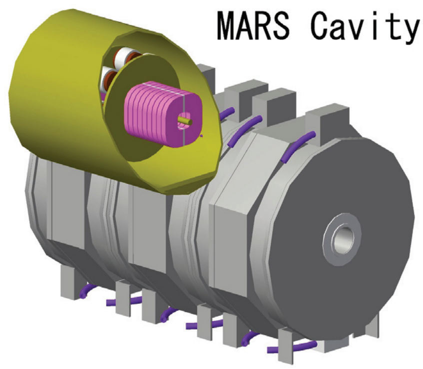

Figure 5: MARS cavity using an external resonator with cut cores.

Second Harmonic Cavity

The MARS cavity scheme is also applicable for the second harmonic cavity in the MR (see Table 2). The second harmonic RF is required mainly during the injection and beginning of acceleration. Because the duty factor of the second harmonic RF is low, the forced air cooling can be applied for the main cavity of the MARS system as shown in Fig. 6. The forced air cooling scheme is also considered as a back-up solution of the J-PARC RCS cavity although these RF cavities work sufficiently. As an R&D of the air cooling, a mock-up cavity was constructed to evaluate the efficiency of the air cooling (see Figure 7). The air cooling cavity can share the cooling water with magnet and will be located in a different straight section where a dedicated water circuit is not available.

Table 2: Second Harmonic RF Cavity Using MARS

	Main Cavity	External Resonator
Cavity Length	1800 mm	1200 mm
Number of cells	4	1
Impedance / cell	1850 Ω	3000 Ω
Number of MA cores	10 /cell	30 /cell
O.D. of MA core	85 cm	30 cm
Power Dissipation / cell	9 kW	5.6 kW
Power Dissipation / core	900 W	188 W
Duty Factor	15 %	15 %

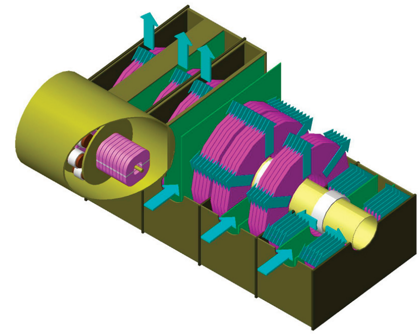

Figure 6: Second Harmonic RF Cavity with an external resonator using cut core cavity. The arrows show the flow of air in the main cavity.

Figure 7: Mock up of air cooling cavity using plastic core and frame covers.

CONCLUSIONS

A Magnetic Alloy Resonant System (MARS) cavity using an external energy storage system is proposed as a back-up system of the present J-PARC Q=26 MA cavity.

REFERENCES

[1] C. Ohmori *et al.*, "HIGH GRADIENT MAGNETIC ALLOY CAVITIES FOR J-PARC UPGRADE" IPAC11, San Sebastian, Spain, September 2011, p. 2885 (2011).

[2] C. Ohmori *et al.*, "HIGH FIELD-GRADIENT CAVITIES LOADED WITH MAGNETIC ALLOYS FOR SYNCHROTRONS" PAC99, New York, U.S.A., March 1999, p. 413 (invited) (1999).

[3] A. Schnase *et al.*, "MA Cavities for J-PARC with Controlled Q-value by External Inductor" PAC07, Albuquerque, NM U.S.A., June 2007, p. 2131 (2007).

[4] M. Yoshii *et al.*, "Present Status of J-PARC Ring RF Systems" PAC07, Albuquerque, NM U.S.A., June 2007, p. 1511 (2007).

[5] M. Nomura *et al.*, "Condition of MA Cut Cores in the RF Cavities of J-PARC Main Ring after Several Years of Operation" IPAC11, San Sebastian, Spain, September 2011, p. 107 (2011).

[6] M. Yoshii *et al.*, "Present Status of J-PARC Ring RF Systems" in this conference.