HIGH FIELD GRADIENT CAVITY FOR J-PARC 3 GEV RCS

Chihiro Ohmori, Shozo Anami, Eizi Ezura, Keigo Hara, Yoshinori Hashimoto, Akira Takagi, Makoto Toda, Masahito Yoshii, KEK, Tsukuba, 305-0801 JAPAN
Masahiro Nomura, Alexander Schnase, Fumihiko Tamura, Masanobu Yamamoto, JAERI, Tokai-Mura, 319-1195 JAPAN

Abstract

A new type of rf cavity using a magnetic alloy (MA) will be used for the J-PARC project [1]. To reduce the beam loading effects, the quality factor of the MA core stack is increased by a cut core configuration. High power test of the rf system has been performed. Temperature rise around the cut surface of the cores was observed. It is reduced by improving the cooling efficiency.

J-PARC 3 GEV RCS RF SYSTEM

The J-PARC accelerator complex consists of a proton linac, a 3 GeV Rapid Cycling Synchrotron(RCS) and a 50 GeV Main Ring(MR). Both rings require a large accelerating voltage. To satisfy the voltage requirements in the limited length for the rf systems, a high field gradient is necessary. Recently, the linac energy has been changed to 181 MeV in Phase I and the required band width of RCS RF system has been expanded. The injection energy of the RCS will be upgraded to 400 MeV in Phase II. Cavity parameters are listed in Table 1 [2]. Because the reduction of the space charge effects is essential for high intensity accelerator, dual harmonic rf will be applied at the injection of the RCS to extend the bunch length.

Table 1. Cavity parameters in Phase I

	3 GeV RCS	50 GeV MR
System	Dual Harmonic	Single Harmonic
Frequency 1st	0.94-1.67 MHz	1.67-1.72 MHz (or 3.34-3.44 MHz)
2nd	1.88- MHz	
Harmonic number	2	9 (18)
Max. rf voltage	450 kV	280 kV
Number of Systems	11+(1)	6+(1)
Cavity Length	About 1.8 m	1.776 m
Optimum Q-value	2-	10-20
Average Power Dissipation	6.6 kW/core	13.3 kW/core
Cavity Impedance	840 Ω/gap	1 kΩ/gap
Number of gaps	3	3

MAGNETIC ALLOY LOADED CAVITY

For both synchrotrons, a MA (Magnetic Alloy) loaded cavity is used. The core is made of alloy ribbon tape of 18 μ thickness. The advantages are followings [3];

- Stable characteristics under the high magnetic field and high voltage. In other words, high field gradient for the acceleration to fit the present ring lattice is available.
- Because of low Q value, the tuning circuit is not necessary for acceleration and the feedback system becomes simple and stable. Using a cut-core technique, the quality factor of the cavity is variable by changing the gap height between two halves of core and an optimum Q-value can be chosen.

We have developed three different cooling schemes for MA-loaded cavities; forced air [4], indirect [5] and direct [3] water cooling. Because of the most powerful cooling efficiency, we adopt the direct water cooling for both RCS and MR cavities although there is 10-20 % impedance deterioration by the large dielectric constant of the water. In case of the direct cooling, the MA cores are installed in the water tanks and cooled by the demineralized water directly.

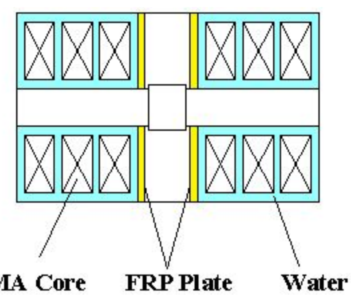

Fig. 1. Schematic of direct water cooling.

Beam Loading and Optimum Q-value

The original Q-value of MA core is about 0.6. In case of high intensity beam acceleration, a bucket distortion may occur by the heavy beam loading if the multi-harmonic rf feedback or feed forward compensation has not been applied [6]. The required bandwidth for the compensation is usually about 10 MHz which corresponds to that of MA cavity. To simplify the complicated multi-harmonic compensation, the Q-value of MA core should be increased. The optimum Q-value for the MA core is given by the required bandwidth for the acceleration and expected beam loading. In case of 3 GeV RCS, the optimum value is about 2 to cover both fundamental and second harmonic frequencies.

Recent simulation results [7] show an emittance growth and beam loss if the Q-value is 0.6 and the bandwidth of beam loading compensation is restricted to 5 MHz. In case of the optimum Q-value, the growth is small and loss has not been observed if 6 harmonics (H=1,..,6) are compensated. Practically, the bandwidth of an rf amplifier using big tetrodes is limited because of a large capacitance at the control grid. In case of J-PARC, the TH558 will be used and 5 MHz is the expected bandwidth for the whole system [8].

Because the second harmonic frequency at the injection is 1.9 MHz, it is covered by the cavity impedance. It is planned to add the second harmonic rf on the accelerating gap simultaneously [9, 10].

Cut Core

A cut core configuration has been adopted to increase the Q-value of MA core. Each core has two gaps and the height is adjustable. By this technique, the effective permeability of the core is given by original permeability of MA and the ratio of cut core gaps to averaged length of magnetic flux in the core. The impedance, Rp, of the core is changed by the cut core configuration. Figures 2 show typical impedances of two different cavities using cut cores (A) and non-cut cores (B).

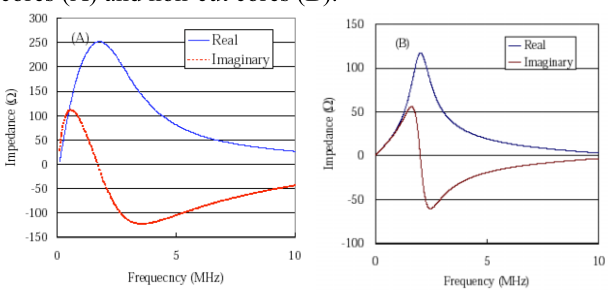

Fig. 2. Typical impedances of the cavities with non-cut cores (A) and cut cores (B).

Power Loss in Cut Core

In general, the power loss in a cut core should be more uniform than that in a non-cut core. In case of low Q-value (1-5), the RF flux in the core is mainly determined by the height of the cut core gap. Figures 3 show the temperature distributions of a small cut core in cases of Q=2 and 4 after the RF power density of 0.1 W/cc has been driven for 15 min without any cooling.

In case of cut cores for J-PARC, localized temperature rise around gap has been occurred in case of a few mm cut core gap (Q=6) as shown in Figs. 4. This kind of temperature rise has not been observed in case of a small core with the gap height larger than 0.1 mm (Q=2, 4 and 8). However, a similar temperature rise is shown in case of 0 mm gap, in other word, two halves are touched without spacer. Although the main cause of the heat loss is still under investigation, the most possible explanation is the flatness and smoothness of the cut surface because the rise is observed if the gap height is close to the flatness of the cores. The flatness of the cores is below 0.1mm for a small core and about 0.5 mm for J-PARC cores. The microscopic photos are shown in Fig. 5. These photos suggest that the rough surface by a water jet cut may cause the concentration of rf flux at the point which is close to the other half of core. The way to improve the cut surface is under development.

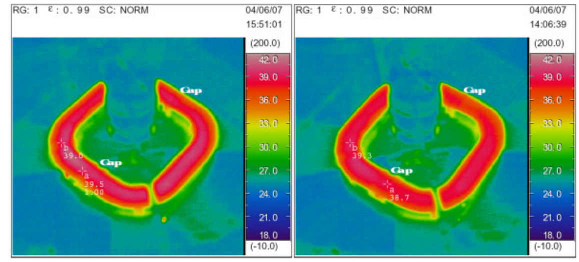

Fig. 3. Temperature distribution in case of a small core which has a good cut surface. The left and right figures correspond to Q=2 and 4, respectively.

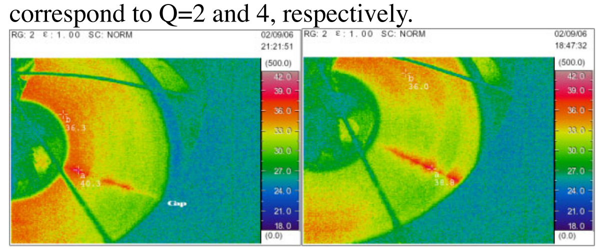

Fig. 4. Typical temperature distributions in case of Q=2-3 for the present J-PARC cores. The localized power loss has been observed. Although the cut core gap is 1.5 mm for both cases, the temperature distributions are different.

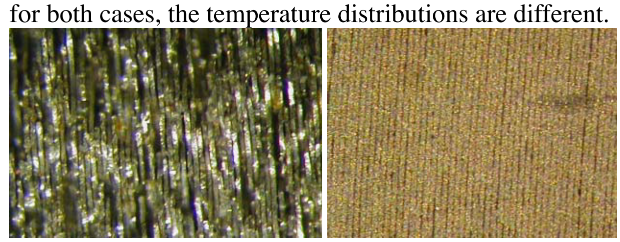

Fig. 5. Microscopic views of cut surfaces. The left figure shows the cut surface by water jet. The surface is not flat and the roughness is more than 0.2mm in small area and about 0.5 mm for a whole cut surface. The right one shows the surface made by a grindstone. The surface is very smooth and flat (0.1 mm). Both figures show the layer of the MA tapes (18 μm)

RESULTS OF HIGH POWER TEST

Several high Power tests have been performed. To evaluate the core temperature during the operation, "thermo paint" has been painted around the cut core gap as shown in Fig. 6. The paint will change colour if the temperature exceeds 130 deg. C. By improving the shape of spacers and the water flow around the cut core gap, the areas with high temperature have been reduced and limited at the edge of cut core as shown in Fig. 6.

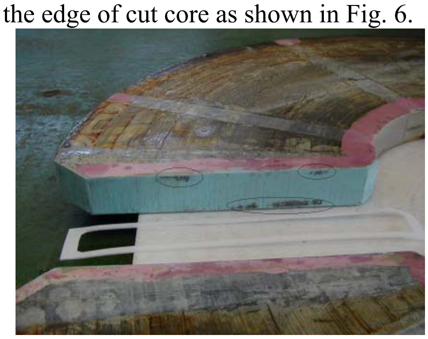

Fig. 6. Cut core gap after 8 hours power test. The places touched by water directly are cooled (light blue colour).

The grey colour spots which are encircled indicate the temperature rise of the points that were covered by the spacer.

Cavity Impedance and Frequency Band Width

The impedance of cavity with 1 mm gap is shown in Fig. 7. The bandwidth for the acceleration, 940 kHz-1.67MHz is covered. In this case, the MA cores for 50 GeV MR are used for the test of the RCS mode. Because the cores were not cut with high accuracy, it was difficult to reduce the Q-value with keeping the distance required for cooling. It is necessary to improve the flatness of the cut core surface to reach the desired Q-value and cavity impedance to reduce the anode current during dual harmonic operation.

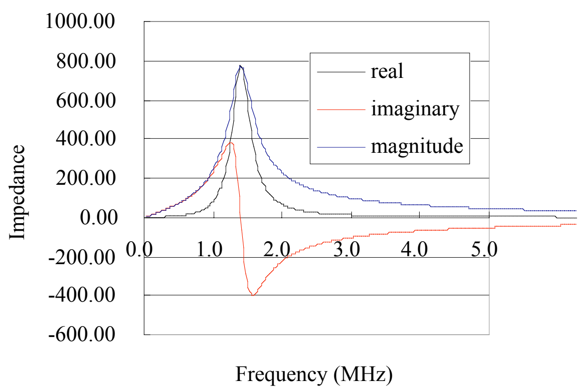

Fig. 7. Cavity impedance during the high power test.

Gap Voltage Distortion

As the Q-value of the cavity is low, the cavity is driven by a push-pull amplifier using two tetrode tubes to obtain the RF voltage with less distortion (see red line in Fig. 8). However, the RF voltage at each gap includes the distortion (see blue and yellow lines in Fig. 8-A), because the tubes are driven by the class B mode.

Because of the distortion on each gap voltage, the power dissipation in the MA cores increased. Power loss is 14 % larger than that of the class A operation (Fig. 8-B). Practically, the class A operation is not possible. It is considered to add a figure-of-eight loop and/or coupling circuit between the amplifier and cavity to balance the tube operation.

CONCLUSIONS

MA-loaded cavities will be used for J-PARC synchrotrons. A cut core configuration will help to reduce the beam loading effects by increasing the Q-value of MA cores. However, localized temperature rises are observed around the cut core gap. The local temperature rise seen at some of the cut core surfaces is probably, caused by the inaccurate machining using a water jet cut. By improving the water flow in the tank, the temperature rise is acceptable and no damage was observed on the cores. The accuracy will be improved and it is expected the temperature rise will be reduced furthermore.

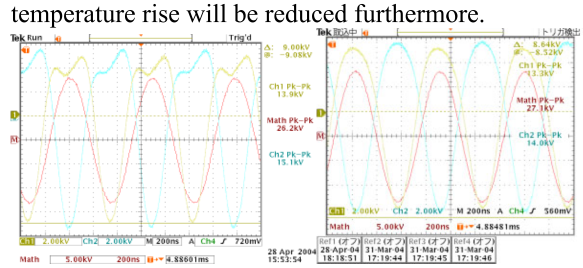

Fig. 8. Gap voltages in case of classes B (left) and A (right) operation. Light blue and brown traces indicate the rf voltage on each gap side. Red lines mean the subtraction of each gap voltage (difference between yellow and blue lines).

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