HIGH FIELD GRADIENT CAVITY FOR JAERI-KEK JOINT PROJECT

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Abstract

A new type of rf cavity will be used for the JAERI-KEK Joint Project. A high field gradient for the rf acceleration becomes possible using magnetic alloy cores. To minimize the beam loading effects, the quality factor of the core stack is increased by a cut core configuration. Cooling of cores is improved by using an insulator with a very good thermal conductivity. High power test of the rf system has been started. Unexpected heat loss which is very localized has been observed. It is caused by inhomogeneity of core and related to the shape of edge.

1 INTRODUCTIONS

The accelerator complex of the JKJ project consists of a high intensity proton linac, a 3 GeV Rapid Cycling Synchrotron(RCS) and a 50 GeV Main Ring(MR). Both rings require a large accelerating voltage in the frequency region of 1.2-3.4 MHz. To satisfy the voltage requirements in the limited length for the rf systems, a high field gradient cavity is necessary. Cavity parameters are listed in Table 1. Because the reduction of the space charge effects is the essential for high intensity accelerator, dual harmonic rf will be applied for both accelerators.

Table 1. Cavity parameters

	3 GeV RCS	50 GeV MR
Frequency 1st 2nd	Dual Harmonic 1.23-1.67 MHz 2.46-3.34 MHz	Dual Harmonics 1.67-1.72 MHz 3.34-3.44 MHz
Harmonics	2	9
Accelerating voltage(Max.)	450 kV	280 kV
Number of Cavities	11+(1)	6+(1)
Cavity Length	1.776 m	1.776 m
Optimum Q-value	2-3	10-20
Power Dissipation Peak Average	 13.8 kW/core 5 kW/core	 15.1 kW/core 9 kW/core
Cavity Impedance	840 Ω/gap	1 kΩ/gap
Number of gaps	3	3

We have developed several different types of MA-loaded cavities for the project. The first generation is very wideband cavities which were cooled by air [1]. The second one is a high field gradient cavity cooled by water directly. It could achieve a field gradient of 50 kV/m [2, 3]. The third one is a cavity using a cut core configuration [3, 4]. The quality factor of the core can be changed by this scheme. Optimum Q-value for the 3 GeV RCS is 2-3 to generate the fundamental and second harmonic frequencies at the same gap, simultaneously and to minimize the beam loading effects. Optimum value for 50 GeV MR is given by the need to manage the transient beam loading and bucket distortion by the short bunch beam. The cores were put in the water tank and cooled by the water or other coolant, directly. Because of large dielectric constant of the water, this direct water cooling scheme is applicable only for a band up to few MHz. To operate at higher frequency (12MHz), direct cooling using another coolant was necessary [5]. Because the rf frequency of JKJ synchrotron is few MHz, this direct water cooling is still applicable. The fourth one is using the indirect water cooling [6] with a cooling plate which is similar to the ordinary ferrite-loaded cavities. So far, this indirect cooling had a problem because of the conductivity of the MA cores. When the cores were combined by the cooling plate, cavity impedance was reduced, significantly. This problem was solved using an insulator with 5 mm thickness which has a very good thermal conductivity. We are developing this cooling method for the rf cavities of both 3 GeV RCS and 50 GeV MR.

2 COOLING METHODS

2.1 Direct Water Cooling

We have developed two efficient cooling methods. One is the direct water cooling and the other is the indirect method. In case of the direct water cooling, MA cores are installed in water tanks and cooled by the water directly. This is the most efficient way to cool the core and 12 kW was dissipated per core. However, cavity impedance was reduced by about 50% because the dielectric constant of the water surrounding the core is very large. There are two ways to improve the impedance. One is to use another coolant instead of water and the other is to put some insulator to remove the water from the points where high electric field exists.

We have used FLUORINERT to cool the core for the second harmonic cavity in KEK 12 GeV PS. The impedance is almost recovered up to 12 MHz. However, it is not applicable for the JKJ project because of the cost of the coolant. Another method using insulators is applicable up to few MHz which is the frequency region of the project. The impedance was recovered up to 80 %.

The other problem of the method is the corrosion of cores during the long term operation. We started the R&D to protect the core while keeping the good cooling

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condition.

Because the required rf power to achieve high field gradient is large, it is very important to make a proper water flow to cool the core. Especially, cooling of the gap of cut core becomes essential in case of low Q operation for the 3 GeV RCS.

2.1 Indirect Water Cooling

Indirect water cooling is another powerful way to cool the core. In this scheme, a mixture of polyimide resin and Aluminium Nitride powder has several roles to combine the cores with the cooling plates, to insulate each other to reduce the capacitance effect and to transfer heat from core to cooling plate. A set of core, mixture and cooling plate was put in an oven and heated to make the mixture solid. The mixture is heat-proofed and has a very good thermal conductivity of 2-4 W/mK which is 10 times higher than polyimide and plastic. Expected temperature during the operation was calculated using a code, ANSYS. The result shows that the maximum temperature should be about 60 degree C under the ideal condition. All core stacks with cooling plates were tested using a 5 kW solid state amplifier. The temperature distribution was measured with a thermo camera. Figure 1 shows a typical temperature distribution when the cooling is only on one side and 5 kW was put. We found few core stacks have problems with the contact between core and cooling plate. These were processed at the beginning of production and are under repairing.

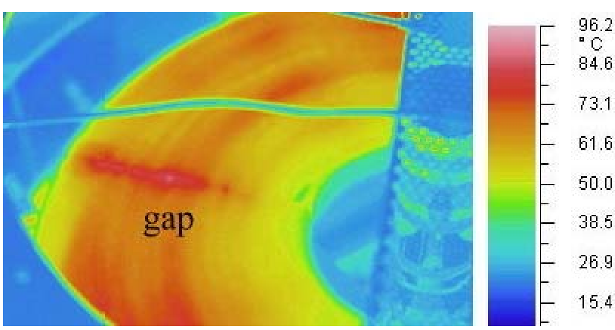

Fig. 1. Typical temperature distribution of a cut core is shown. The gap is 1.5 mm. It corresponds to the quality factor of 2-3 which is the optimum value for the 3 GeV RCS. It shows a hot point around the gap.

3 POWER TEST OF INDIRECT WATER COOLING CAVITY

The indirect water cooling cavity has been tested using a 1 MW high power amplifier. Figure 2 shows one acceleration gap of the indirect cooling cavity. It consists of 2 sets of core stack. Each stack consists of 4 cores, 4 cooling plates and insulators between these. Three of four MA cores are cooled from both sides as shown in Fig. 2. The core near the acceleration gap is cooled from only one side to avoid the impedance reduction by the cooling plate.

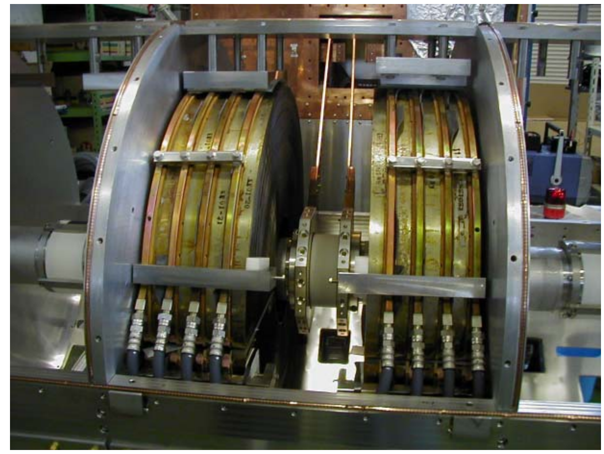

Fig. 2. Indirect water cooling cavity.

Figure 3 show the cavity impedance. The designed value of 1 kΩ/gap is almost achieved. It becomes clear that the precise alignment of the cores is very important to set the resonant frequency of the both core stacks at the same value to avoid the impedance loss by the difference.

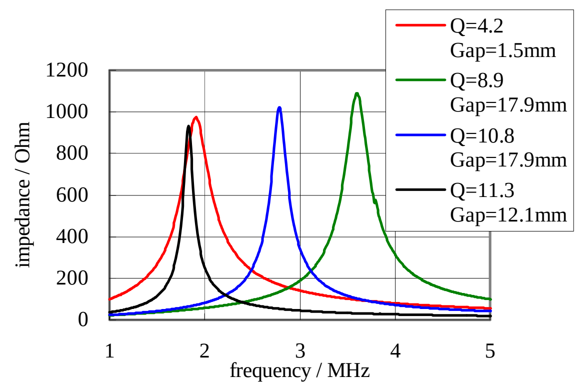

Fig. 3. Cavity impedances at the different gap height and resonant capacitance.

We put up to 40 kW rf power on the cavity. All heat was removed by the water and temperature rise of water was consistent with the rf power. Here, 40 kW is corresponding to the average power density in a core on the 3 GeV RCS cavity. We successfully put the power. The hottest point in the cavity was the surface of a core which was cooled from only one side and it became 120 degree C. All material which we use in the cavity is heat proofed and can stand up to 200 degree C. We are going to improve the cooling on this core by adding another cooling plate and/or to improve the contact by pressing them. It is expected using the code ANSYS that the cooling from both sides should improve the efficiency by more than a factor of 2.

The power consumption of 9 kW/core is required for the cavity of 50 GeV MR. We are going to improve the cooling efficiency to handle this power.

4 LOCALIZED HEAT LOSS ON CORES

4.1 Localized Heat Loss

One problem to improve the cooling is a localized heat loss on the core when the gap is large (5-20 mm). The loss occurs at the outer side of the core. It is observed although the core has a large edge cut of 30 mm to avoid the flux concentration around the gap. This effect was not severe when the gap is small and quality factor is below about 3. According to the increase of the gap and quality factor, the heat loss is more concentrated. This effect is not consistent with a simple model for the cut core. In the case of cut core, flux should be equal because the magnetic resistance is mainly determined by the gap height. Figure 4 shows the typical temperature distribution when the gap is 20 mm and the quality factor of cavity is around 10. This core is not cooled by the cooling plate to remove the effects of cooling efficiency and contact between the cooling plate and core.

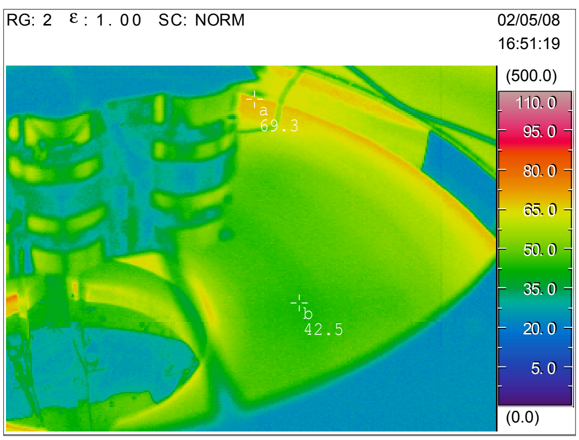

Fig. 4. Temperature distribution of MA core when 3 kW rf power was put. Because the cavity Q-value is set to a high value, the localized heat loss at the outer side of the core was observed. The speed of the temperature rise at these points is several times faster than at the other points.

4.2 Inhomogeneity of core

To investigate this effect more clearly, we cut a core with 80cm O.D and 24.5 cm I.D into two pieces, inner and outer cores. The sizes of the cores are 60 cm O.D and 24.5 cm I.D for inner core and 80 cm O.D. and 62 cm I.D for outer core, respectively. Impedances of these cores were measured. It shows the difference of characteristics. The outer core has higher Q, μQf-product and permeability. And, the difference on Q and μQf-product becomes larger at higher frequency. One possible explanation of this effect is the stress force during crystallizing process of MA which may have a radial dependency.

Including the inhomogeneity of MA, the localized heat loss can be explained as the magnetic flux has a tendency to go through the high quality material. To reduce the localized loss, we are considering to apply two schemes; (1) rather large edge cut to reduce the rf flux to go through the outer side and (2) another cut to prevent the flux in inner side escapes to the outer side. For example, the cut of the core as described in section 4.1 will help to reduce the loss density by 20 % without loosing the impedance. The cut also helps to stack the core and cooling plate tightly, because it is possible to insert rods between the outer and inner cores through the cooling plates.

And it is also considered to cool the core from the other side. An additional cooling plate to cool only the outer surface is prepared and will help because it does not cause significant impedance reduction and cools the hottest points at the outer side, efficiently.

5 CONCLUSIONS

For rf cavities of JKJ synchrotrons, a high-field gradient MA cavity will be used. To minimize the transient beam loading and potential distortion, the quality factor of the cavity should be increased up to 10-20 for the MR and a cut core configuration will be employed for this purpose. The 3 GeV RCS requires a Q-value of 2-3 to reduce the effects by the higher harmonics of the beam. There are two different schemes to cool the cavity cores. One is direct water cooling and another is indirect cooling. The direct cooling is the most powerful scheme to cool the cores however the development to prevent the corrosion in the water is necessary and undergoing. Recently, we started the R&D for the indirect one. We stably put the rf power of 5 kW/core which is the required value for the 3 GeV RCS. The localized heat loss at the outer side of core was observed when the quality factor of the cavity was set at the optimum Q-value for 50 GeV MR. To achieve the requirements (9 kW/core) for the 50 GeV MR, further developments on the indirect cooling cavity are planned.

6 REFERENCES

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