# A NEW METHOD OF MA CUT-CORE COOLING FOR THE RF CAVITIES OF THE JKJ PROTON SYNCHROTRONS

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## *Abstract*

Design of the synchrotron rf cavity for the JAERI-KEK joint project(JKJ) is reported. In the cavity, the power dissipation at the core is very high and is 16kW per core. In order to remove the power dissipation, it is important to improve the thermal contact between the core and the cooling copper disk. The R&D studies of the cooling of magnetic cores are described in detail.

## 1 INTRODUCTION

The JKJ is one of the high intensity proton accelerator projects in the world. In such a synchrotron, a high accelerating field gradient is required. That means the power dissipation of the rf cavity becomes very large and efficient cooling of the cavity is very important.

In the JKJ synchrotrons, magnetic alloy(MA) is to be used as core material of the rf cavity. Its impedance is constantly kept high at a high rf field as 2kG at least. The averaged rf power dissipation will be 210kW/cavity, which corresponds to 0.50W/cc for the 3GeV and 0.89W/cc for the 50GeV synchrotron. In fact, the impedance change of the MA material due to the heat is quite small compared to those of ferrites because of the high Curie temperature of $> 500°\mathrm{C}$. Accepted temperature is thought to be about $100°\mathrm{C}$, which comes from the stability limit of the other electronics.

We are planning to adopt indirect core cooling in the JKJ synchrotron rf cavities. This paper reports the detail of the method. The general parameters of the cavity design is shown in section 2. In the next section, we review several cooling methods and compare their advantages and disadvantages. A new method is described in section 4.

## 2 RF CAVITIES OF THE JKJ SYNCHROTRONS

Table 1 shows the main rf parameters of the JKJ synchrotrons. Both rf cavities are identical except the size of the cores and quality factor. The core material is FT-3M, which is a kind of MA. The intrinsic quality factor of the FT-3M is about 1, but can be raised by the cut-core configuration. The core sizes are 800mm(O.D.), 240mm(I.D.) and 25mm(thickness) in the 50GeV synchrotron, and 800mm(O.D), 360mm(I.D.) and 25mm(thickness) in the 3GeV one. More detailed description of the cavity is seen in Ref.[1].

Table 1: The rf parameters of the 3GeV- and 50GeV- synchrotrons. The shunt impedance is evaluated at 2MHz.

| parameter | 3 GeV | 50 GeV |
|---|---|---|
| rf frequency | 1.36-1.86 MHz | 1.86-1.91 MHz |
| repetition rate | 25 Hz | 0.3 Hz |
| peak rf voltage | 420 kV/ring | 280 kV/ring |
| no. of cavities | 10 | 6 |
| no. of gaps | 3 | 3 |
| no. of cores | 24/cavity | 24/cavity |
| shunt impedance | 700Ω/gap | 1kΩ/gap |
| quality factor | 3 | 10 |
| power dissipation | 0.50W/cc | 0.89W/cc |

## 3 COOLING METHODS

There are three types of cooling methods. The first one is the air cooling with blowers. In this method the cooling devices can be located far from the cores and the structure around the cores becomes simple. The cooling efficiency is not so good. In the MA barrier-cavity at the BNL-AGS, which adopts the air cooling, the temperature of the MA cores rose up to $60°\mathrm{C}$ at 0.04W/cc of the averaged rf-power dissipation[2].

The second one is the direct-water cooling. The cores are installed in a water tank and cooled by water directly. With a test cavity with direct-cooled MA cores, the voltage of 2.2kV/core has been achieved, which corresponds to the average power dissipation of 2.0W/cc[3]. On of the disadvantages of the method is the dielectric effect of the water($\varepsilon$=80). Moreover, in order to keep the high impedance, the cooling water must be demineralized. The cores will be coated with polyimide to avoid the rusting. It is difficult to change the gap distance of the core when we have to readjust the quality factor. Though this method is still one of the possible solutions, we are trying the next method.

The last one is the indirect cooling. The cores are attached to conductor disks which are cooled by water-flow inside. The cooling efficiency directly depends on the thermal contact between the cores and the cooling disks. Existence of the cooling disks near the cores reduces the impedance, because of the capacitive effect between them. In the experiment with three MA cores and cooling aluminum disks attached, the impedance reduction was $10 \sim 15\%$. To suppress the effect, It is desirable to place the cooling disks apart from the cores. Thus the cooling efficiency and the suppression of capacitive effect bring a se-

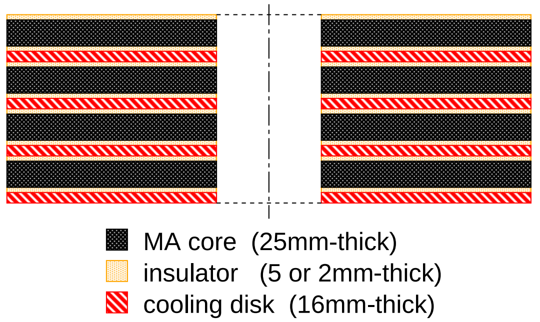

Figure 1: Stack of the cores and cooling disks with insulator inserted. The thickness of the insulators are 2mm for the top one and 5mm for others.

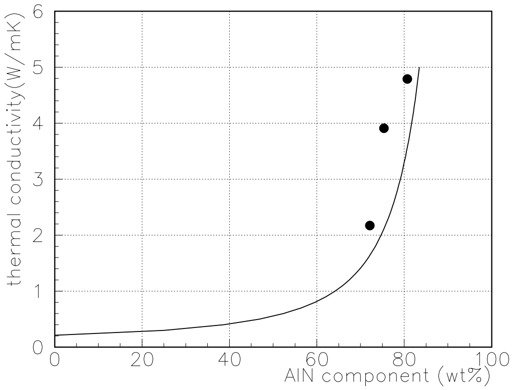

Figure 2: Thermal conductivity of the insulator composed of polyimide resin and AlN. The circles show the measurements.

rious trade off.

In order to obtain a high cooling efficiency without a large impedance reduction due to capacitive effect, we are planning to place the cooling disks at a distance of 5mm from the cores, and insert an insulator with a high thermal conductivity. The design of the core stack is shown in Fig.1.

## 4 INDIRECT COOLING

As is written in the previous section, we are planning to adopt the indirect cooling with insulators inserted. In this section, we describe the method in detail.

### 4.1 *Insulating Material*

Between cores and cooling disks, we insert insulators made of polyimide resin with aluminum nitride filler. The polyimide resin is stable against heat and radiation. The thermal conductivity is about 0.21W/mK. On the other hand, the AlN has a high thermal conductivity of $70 \sim 270/^{\circ}\mathrm{C}$, which is comparable to that of aluminum($240/^{\circ}\mathrm{C}$). The thermal conductivity of a mixture ($\lambda_c$) of two components is calculated with the Bruggeman's formula[**?**];

$$\nu = \frac{\lambda_c - \lambda_2}{\lambda_1 - \lambda_2}\left(\frac{\lambda_1}{\lambda_c}\right)^{1/3}, \qquad (1)$$

where $\lambda_{1,2}$ are the thermal conductivities of two components, and $\nu$ is the volume ratio of the component 1. The resultant conductivity in our case is shown in Fig.2 as a function of AlN weight ratio. We choose the AlN weight ratio of 75%, where the thermal expansion is comparable to that of copper ($1.8\times10^{-5}/^{\circ}\mathrm{C}$) in order to minimize the thermal stress between the insulators and cooling copper disks. The thermal conductivity will be about 4W/mK, which is much higher than that of the air(0.024W/mK). Figure 3 shows the picture, where the insulators are put on a core. The insulator material is divided in the azimuthal direction in order to release the stress.

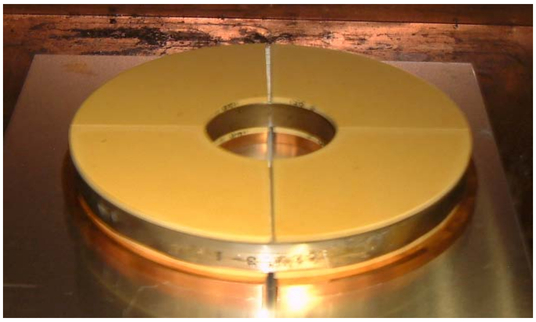

Figure 3: Four pieces of the insulators are put on a MA core. Under the core are the insulators and cooling copper disks.

### 4.2 *Test Cavity*

Figure 4: Core stack of the test cavity for indirect-cooling. The first core from the gap and cooling disks are seen on the left.

In order to test the method, we developed a test cavity with three MA cores. The cooling disks are made of aluminum instead of copper and are larger than the cores. Each surface of the insulators is attached with an inorganic glue before harden it, to increase the tightness of the adhesion between cooling disks and cores. The complex is bound with glass tapes. The gap capacitance is 500pF, and the total shunt impedance is 380Ω at resonant frequency of 1.9MHz. Fig.4 shows the picture.

The peak power of 7.6kW is induced to the cavity at 25% duty, which corresponds to 0.24W/cc of the averaged core dissipation. The equilibrium temperature of the cores were $90^{\circ}\mathrm{C}$ in average and $110^{\circ}\mathrm{C}$ at the maximum. The temperature rise is very high.

By decomposing the complex into the components, it was found that the glue does not work completely and there are voids at the surfaces of the glue layers. It may be a cause of the low cooling efficiency. Model calculations with ANSYS code[1] showed that the equilibrium temperature of the core is strongly affected by the air pockets. If there is a uniform air gap of 0.1mm thick at the boundary between glue and a core, the core temperature becomes $260^{\circ}\mathrm{C}$ at 0.3W/cc heat, while it is $52^{\circ}\mathrm{C}$ without the air gap. Thus, it is important to remove the air between cores and cooling disks severely.

### *4.3 Improvement Status*

Taking account the result of the test cavity into account, we investigated the adhesion without the glue. It was accomplished by loading a heavy pressure on the piled set of the cores in hardening the insulator by heat. The adhesion to the cores seemed good, but not good to the copper. The latter one will be improved by pre-processing of the copper surface, such as roughening by a bluster of a sand paper. Mechanical support of the complex is also being investigated.

## 5 SUMMARY

We are planning to adopt the indirect cooling of the cores in the rf cavities of the JKJ synchrotrons. Insulating materials made of a polyimide resin with AlN filler will be inserted between cores and cooling disks. The material has a high thermal conductivity of 4W/mK. Optimizing the adhesion of the insulator is being investigated.

## 6 REFERENCES

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