CONDITION OF MA CUT CORES IN THE RF CAVITIES OF J-PARC MAIN RING AFTER SEVERAL YEARS OF OPERATION

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Abstract

J-PARC 3 GeV Rapid Cycling Synchrotron (RCS) and 50 GeV Synchrotron (MR) employ the Magnetic Alloy (MA) loaded RF cavities. We observed the impedance reductions of MR RF cavities. Opening the RF cavities, we found that the impedance reductions were caused by corrosion on the core cutting surfaces. The copper ions in the cooling water from hollow conductors of main magnets might accelerate the corrosion process.

INTRODUCTION

We have been operating the MA core loaded RF cavities to achieve a high accelerating voltage. We observed the impedance reductions of RCS RF cavities due to the un-cut core buckling. The detail of the un-cut core buckling is shown in ref. [1]. We also observed the impedance reductions of MR RF cavities during several years of operation. Opening the RF cavities, we found corrosion on the core cutting surfaces. In this paper, we discuss the influence of the cutting surface condition to the RF cavity impedance and the mechanism of corrosion on the cutting surface.

MA CORES LOADED RF CAVITY

The MA core loaded RF cavity consists of 6 water tanks and has 3 accelerating gaps. A set of 2 water tanks is in push-pull for one gap and three sets are in parallel. One RF cavity has 18 MA cores. We employ the un-cut cores for RCS RF cavities and cut cores for MR to increase the Q-value from 0.6 to 26 [2].

MA cores for J-PARC Synchrotrons are produced by a winding process using amorphous thin ribbons. In order to create enough electrical insulation, a coating of SiO_2 with in average 2 μm thickness was put on one side of the ribbon. The ribbon consists of mainly Fe, Si, B, and a small amount of Cu and Nb. The MA core cutting process has 2 relevant steps. The first step is cutting with water jet. After water jet cutting, the electrical insulations between spiral ribbons on the cutting surface are broken. In the second step, the electrical insulation is recovered by polishing with diamond powder. After polishing, the cutting surface has a mirror quality. The picture of sample cutting surfaces is shown in Fig. 1.

We employ a direct water cooling system, and MA cores are coated with glass fiber sheets and epoxy resin except the core cutting surfaces. Before 2010, we were not able to develop a satisfying coating technology on the mirror-like cut surfaces.

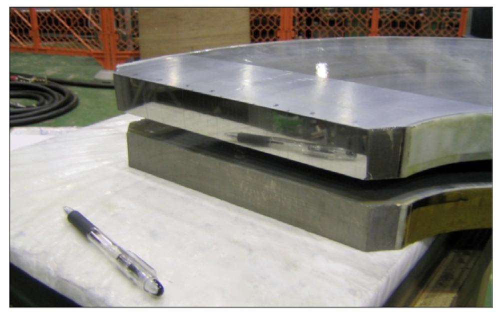

Figure 1: Picture of core cutting surfaces. The lower cutting surface is obtained after water jet cutting and the upper one is after polishing with diamond powder.

IMPEDANCE MEASUREMENTS

We started the MR beam commissioning with 4 RF cavities in December 2008, and we installed two more RF cavities in August 2009 and September 2010. We measured RF cavity impedances in shutdown periods. The results of impedance measurements of RF cavities are shown in Fig. 2.

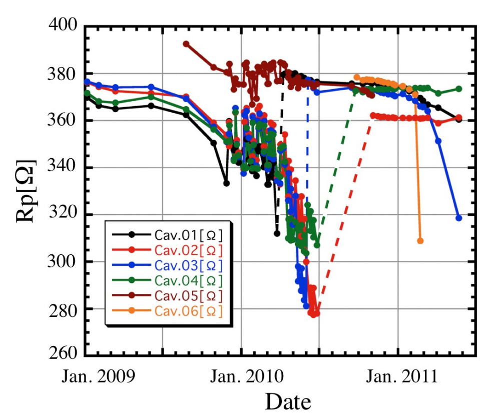

Figure 2: The results of impedance measurements of MR RF cavities. The horizontal axis shows the date and the vertical axis shows the real part of the cavity impedance at the resonance frequency. The broken lines represent the core replacements.

Figure 2 shows that during the first one year half of operation, all 4 RF cavities, RF cavity #1 to #4, show impedance reductions [3]. We replaced the MA cores of those 4 RF cavities. The impedance fluctuations from December 2009 to July 2010 are caused by draining off the cooling water and exposing to air. The reason why the impedance was recovered to some extent might be an oxidization process.

To study the impedance reduction carefully, we pick up the RF cavity #3 that showed typical impedance reduction, and check the RF cavity #3 impedance and each water tank impedance. The RF cavity consists of 6 water tanks. The impedance change of RF cavity #3 and each water tank are shown in Figs. 3 and 4, respectively. Fig. 3 shows that the impedance is declining slowly until Apr. 2010 and in May 2010 the impedance drops largely. From Fig. 4, it is known that this large impedance reduction is caused by the water tank #5.

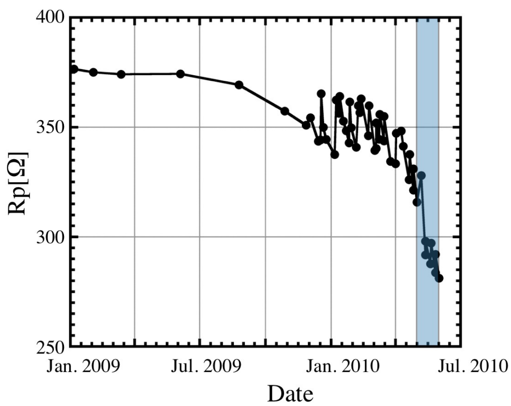

Figure 3: The results of impedance measurements of RF cavity #3. The blue region represents May 2010.

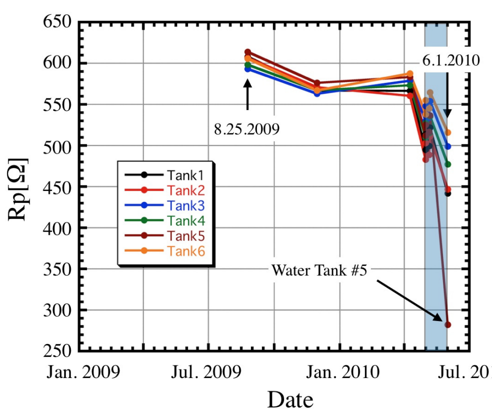

Figure 4: The results of impedance measurements of RF cavity #3 each water tank.

We show the impedance curves of the cavity #3 tank #5 and tank #6 at Aug. 25, 2009 and Jun. 1, 2010 in Fig. 5. Both water tanks show the impedance reductions. The water tank #6 keeps its resonance frequency. On the other hand, the water tank #5 lowered its resonance frequency. The mechanisms of impedance reductions are discussed in next section.

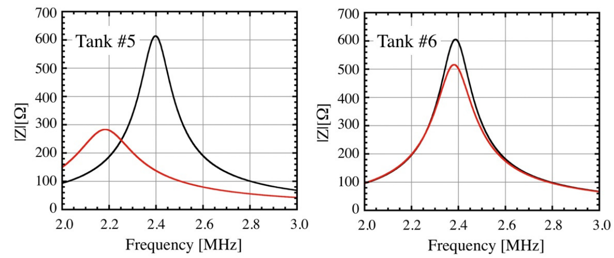

Figure 5: Impedance curve of water tanks #5 and #6. The horizontal axis shows frequency and the vertical axis shows absolute value of tank impedance. The black and red line represents the impedance data at Aug. 25, 2009 and Jun. 1, 2010, respectively.

INFLUENCE OF THE CUTTING SURFACE CONDITION TO THE RF CAVITY IMPEDANCE

Opening the RF cavity #3, we found corrosion on the core cutting surface of all cores. A typical example of corrosion on the cutting surface is shown in Fig. 6. The cutting surface of the core that was set at the accelerating gap side in the tank #5 that showed large impedance reduction was damaged. The damaged cutting surface is shown in Fig. 7.

The slow impedance reduction in Fig. 3 is thought to be caused by the rust on the cutting surface, like in Fig. 6. From X-Ray Diffraction analysis, the rust mainly consists of Fe_3O_4. Fe_3O_4 is a typical rust that is generated in water and it has an electrical conductivity. We study the influence of the resistance due to the rust on the cutting surface to the water tank impedance. A circuit diagram of the water tank that stacks three cores is shown in Fig. 8. The capacitances C_{in} and C_{out} are about ten times larger than C_{core}, and hence the resistance R due to the rust reduces the impedance. In this case the core radial capacitance C_{core} is not changed, and hence the resonance frequency is not changed. This thought can explain the impedance reduction of tank #6 in Fig. 5.

On the other hand, the large impedance reduction in Fig. 3 might be caused by the damage of the cutting surface. See. Fig. 7. From Fig. 8, it is understood that the radial direction of the core at the accelerating gap side is exposed to the highest RF voltage in the three cores. In the large impedance reduction, at first the cutting surface was rusting, and next the cutting surface at the accelerating gap side core was damaged due to the RF voltage, and then the electrical insulations between ribbon layers on the cutting surfaces were broken. The impedance reduction might be caused by the electrical insulation breaks on the cutting surfaces. These electrical insulation breaks cause the resonance frequency reduction because the core radial capacitance is increased by the electrical insulation breaks. This thought can explain the impedance change of tank #5 in Fig. 5.

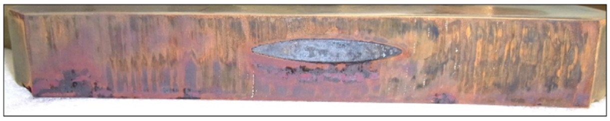

Figure 6: Picture of cutting surface of the core at the accelerating gap side in water tank #6.

Figure 7: Picture of cutting surface of the core at the accelerating gap side in water tank #5 that showed large impedance reduction. The cutting face edge was damaged due to the RF voltage.

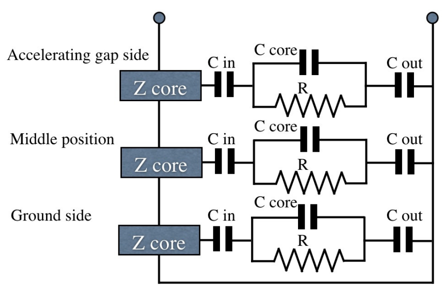

Figure 8: A circuit diagram of the water tank that stacks three MA cores. C_{in} and C_{out} represent the capacitances of the inner and outer space between water tank and cores, respectively. C_{core} represents the capacitance in radial direction of core and is a sum of the capacitances between ribbon layers. R represents the resistance due to the rust on the core cutting surface.

MECHANISM OF CORROSION ON THE CUTTING SURFACE

Before the installation of MA cut cores loaded RF cavities in the MR main tunnel, we had more than 1000 hours long run tests at a test stand. After long run tests, we didn't observe the impedance reduction due to corrosion on the cutting surface. The main difference between the test stand and MR related to corrosion is cooling water quality. MR cooling water contains the copper ions from copper hollow conductors of main magnets. The MA core contains a small amount of Cu originally, but we didn't observe the impedance reduction at the long run tests. The copper ions in cooling water are thought to accelerate the corrosion process.

The mechanism of the corrosion process is described below. At first, a contact between copper hollow conductor and cooling water generates $Cu(OH)_2$ in cooling water through below reactions.

$$Cu \rightarrow Cu^{2+} + 2e^-.$$

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-.$$

Next, $Cu(OH)_2$ reacts with the Fe component on the core cutting surface through below reaction. Copper is reduced and iron is oxidized.

$$4Cu(OH)_2 + 3Fe \rightarrow Fe_3O_4 + 4Cu + 4\ H_2O.$$

Finally, Fe_3O_4 is generated on the cutting surface. We also detected Cu_2O, which might be generated additionally to above reaction, on the cutting surface by X-Ray Diffraction analysis.

To confirm that the copper ions in cooling water accelerate the corrosion process, we set a cutting piece of MA core in water without copper ion at a test bench, and we start to observe the surface of it carefully.

HOW TO PREVENT CORROSION ON THE CORE CUTTING SURFACE

To solve the issue of corrosion on the core cutting surface, we have two plans. One is separating the cooling system of RF cavities from the main magnets one. We can use this new cooling water system at the end of this year. Another is coating of core cutting surfaces. We replaced the cores of RF cavity #4 with the cores of which the cutting surfaces were coated with inorganic polymer and RF cavity #2 with the cores of which the cutting surfaces were coated with inorganic polymer and covered with RTV gum. Fig. 3 shows no impedance reduction of both RF cavities #2 and 4 during a half year of operation. Operation time is not sufficient long-term, but the coating of core cutting surfaces might be effective for preventing corrosion on the cutting surfaces.

SUMMARY

We observed the impedance reductions of MR RF cavities due to corrosion on the cutting surfaces. The slow impedance reductions were caused by the resistance due to the rust on the cutting surfaces and the large impedance reductions were caused by the electrical insulation breaks between ribbon layers on the core cutting surfaces. In the case of large impedance reduction, the resonance frequency was reduced due to the electrical insulation breaks. The copper ions in cooling water from hollow conductors of main magnets might accelerate the corrosion process. To prevent corrosion, we reduce the copper contents in cooling water by separating the RF cavity cooling system from the main magnets one and coat the core cutting surface with inorganic polymer and RTV gum. The coating of cutting surfaces might be effective for preventing corrosion of the cutting surfaces.

REFERENCES

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[2] C. Ohmori *et al.*, Proc. of EPAC2004, p123-125
[3] M. Nomura *et al.*, Proc. of IPAC10, p3723-3725