IMPEDANCE MEASUREMENTS OF MA LOADED RF CAVITIES IN J-PARC SYNCHROTRONS

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Abstract

Eleven RF cavities have been installed in the J-PARC RCS. We have been measuring the impedance of each RF cavity after installation. The RF cavity 7 showed an impedance reduction. We disassembled the cavity 7 and checked the cores in it. We found buckling in eleven cores in the cavity 7. The buckling of one of the cores was very severe. We found that the impedance reduction of cavity 7 was caused by this core's buckling.

INTRODUCTION

J-PARC consists of a 181 MeV linac, a 3 GeV Rapid Cycling Synchrotron (RCS) and a 50 GeV Synchrotron. In the cavity, we employed MA (Magnetic Alloy) cores instead of convenient ferrite cores in order to achieve the high accelerating gradient of 20kV/m [1, 2]. We installed 10 RF cavities in the RCS in May 2007 and one more cavity in November 2008. In order to check the MA core conditions, we have been measuring the RF cavity impedance in the RCS at the shutdown periods after installation. In this paper, we show the results of impedance measurements and the condition of MA cores.

RF CAVITY

We show the picture of the RF cavity in Fig.1. The RF cavity consists of six water tanks and each water tank is loaded with three MA cores. One RF cavity is loaded with eighteen MA cores in total and has three accelerating gaps. The accelerating voltage of one cavity is about 40 kV.

The MA cores are produced through the winding process of ribbons with the thickness of about 18 μm. A coating of SiO_2 with thickness of 2 μm was put on one side of the MA ribbon to keep the electrical insulation. Through the early high power tests, we observed damages in the MA cores caused by poor electrical insulation. We found that the most important point is keeping the electrical insulation between the ribbons because the MA cores at the accelerating gap side are exposed to the high voltage which is same as the accelerating voltage. To improve the electrical insulation, the winding process was changed from vertical to horizontal and a ribbon tension control system was introduced. We evaluate the electrical insulation between ribbons from both DC and RF measurements [2]. From these evaluations, we select out the cores with good electrical insulation and set them at the accelerating gap side.

For the cavity cooling, we adopted a direct water cooling system so that the MA core must be waterproof. For the early core coating method, we coated only the MA core surfaces with fiber sheets and high viscosity epoxy resin. The fiber sheets are for the thickness control and the thickness of them is 50 μm. After the early high power tests, we found pinholes and some parts of the fiber sheets had lost contact to the surface at some cores. We changed the thickness of the fiber sheets from 50 μm to 180 μm. We also changed the coating method. In the modified coating method, before coating with fiber sheets and high viscosity epoxy resin, the cores are impregnated with a low viscosity one to increase the mechanical strength and adhesion between the core surface and fiber sheets.

Figure 1: RF cavity.

IMPEDANCE MEASUREMENTS

To check the MA core conditions, we have been measuring the impedance of each RF cavity in the RCS at the shutdown periods after installation. The impedance measurement results are shown in Fig. 2. All cavity impedance values show long-term fluctuations. We think that these fluctuations are related to the temperature of the cooling water. To understand the relationship between cavity impedance and temperature of cooling water, we assumed that the cooling water temperature dependence of each RF cavity impedance was the same and then we averaged over all RF cavity impedances except cavity 7, because the impedance of cavity 7 is different from the other cavities. We show the average of the cavity impedance and cooling water temperature in Fig. 3. In Fig. 3, we fitted roughly the impedance line to temperature at the first half year by adjusting the ratio of $\Delta Z/\Delta T$. The ratio of $\Delta Z/\Delta T$ is 0.18 [Ω/deg.].

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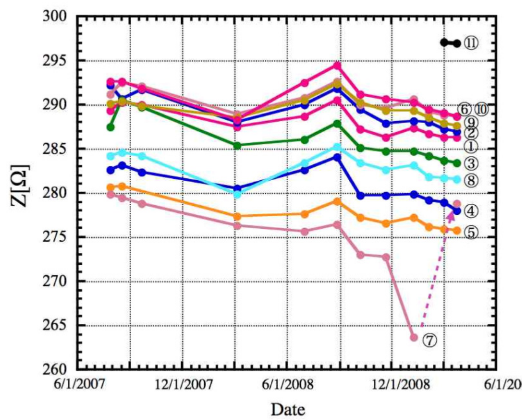

Figure 2: Real value of RCS RF cavity impedance. The vertical axis shows the cavity impedance at the resonance and the horizontal axis shows the date. The circled number in the figure means cavity number. The dotted arrow line shows the impedance change after core replacement.

Fig. 3 shows clearly that the cavity impedance strongly depends on the temperature of cooling water. The mechanism of the temperature dependence is not clear yet. It seems to be caused by the temperature dependence of the dielectric constant of water and the thermal expansion of the cores. In Fig. 3, the difference between the cavity impedance and the cooling water temperature is very small after 18 month operation. This means the total cavity impedance is not reduced so much in this 18 month operation.

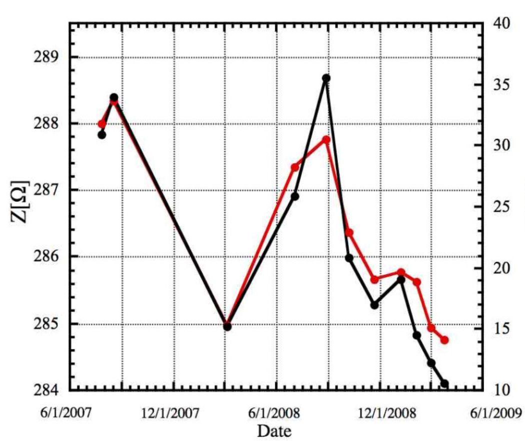

Figure 3: Average of the cavity impedance and temperature of cooling water. The black and red lines show the average of the cavity impedance and temperature of cooling water, respectively.

We show the difference of impedance between each cavity and the average in Fig. 4. Fig. 4 shows clearly that the cavity 7 impedance is different from the other cavities. The impedance of cavity 7 had been decreasing slowly until December 2008 and after that the RF cavity 7 showed rapid reduction in impedance.

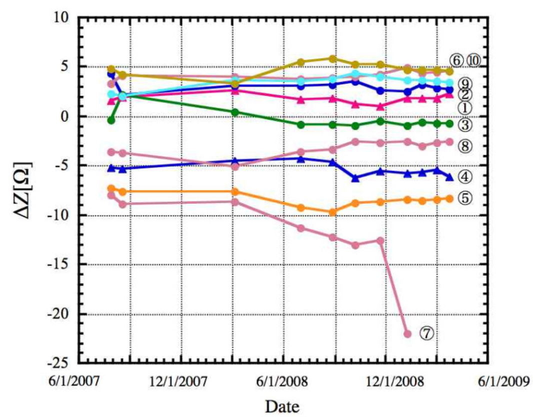

Figure 4: Difference of impedance between each cavity and average. The ΔZ means the difference of impedance between each cavity and average.

Just after this rapid reduction, we measured the impedance of all six water tanks of the cavity 7 and we found that the impedance of water tank 6 was drastically changed. The impedance data of water tank 6 is shown in Fig. 5. It shows at least one of the MA cores in the water tank 6 was damaged.

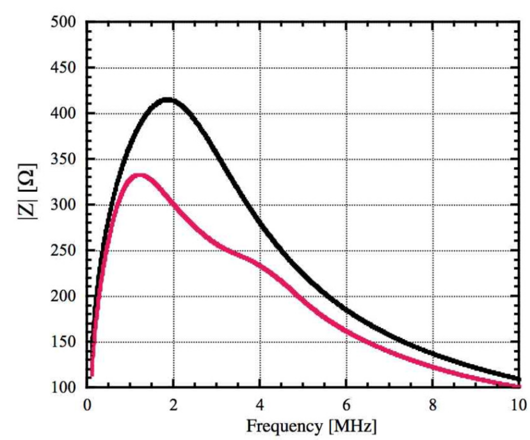

Figure 5: Impedance of water tank 6. The black and red lines show the impedance at the installation time and on January 2009, respectively.

MA CORES IN RF CAVITY 7

We disassembled the cavity 7 and found buckling in the MA cores in the cavity 7. The number of the buckled cores is eleven out of a total of eighteen. We show the typical core with buckling in Fig. 6. Fig. 6 shows that the FRP inner ring was broken and the fiber sheet on the core surface was stripped off by buckling. The most severe buckled core with serial number NGT06199 was located at the accelerating gap side of water tank 6. Fig. 7 shows the picture of buckling of NGT06199. In Fig. 7, the buckling part hit a column of the FRP inner wall of the water tank and then ribbons were ripped. The close-up picture of the buckling is shown in Fig. 8. It is clear that there is tear in the core.

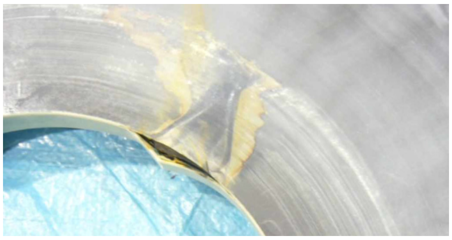

Figure 6: Typical example of buckling.

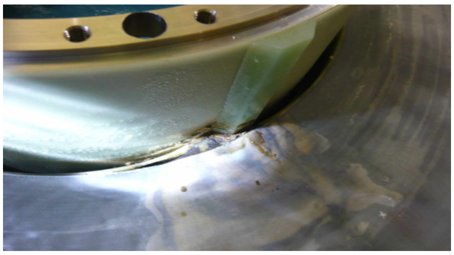

Figure 7: Buckled core NGT06199.

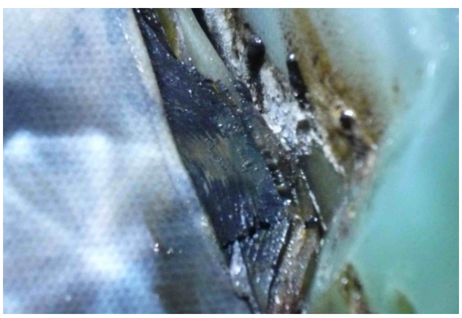

Figure 8: Close-up of buckling.

We measured the individual impedance of all eighteen cores in the cavity 7. We observed the impedance reduction of NGT06199 in the water tank 6. This reduction was caused by the tear in the core. See Fig. 8. We show the impedance data of NGT06199 in Fig. 9. We found that the rapid reduction in impedance of cavity 7 was caused by this core's buckling. About the other cores, we observed little reduction in impedance.

We replaced three buckled cores in the cavity 7 with new ones. Impedance of cavity 7 was back to the initial value. See Fig. 2.

Table 1: Core position, winding, coating and buckling. The blue and red mean no buckling and buckling of the core, respectively. The H+T.C. means horizontal winding with tension control. The H and V mean horizontal and vertical winding, respectively. The C+I means both coating and immersion and the C means coating only.

	Accelerating gap side	Middle	Ground side
Tank 1	H+T.C., C+I	H, C+I	V, C
Tank 2	H+T.C., C+I	H, C+I	V, C
Tank 3	H+T.C., C+I	H, C+I	V, C
Tank 4	H+T.C., C+I	H, C+I	V, C+I
Tank 5	H+T.C., C+I	V, C+I	V, C
Tank 6	H+T.C., C+I	H, C+I	H, C+I

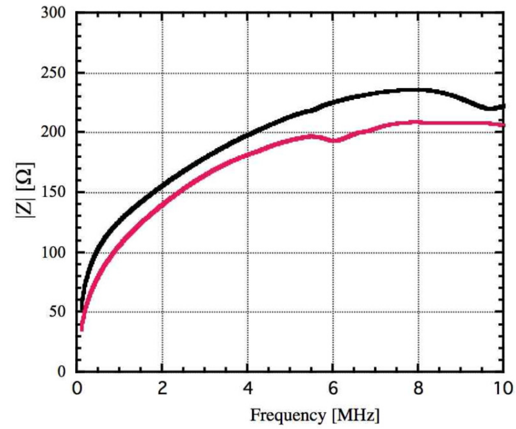

Figure 9: Impedance of core NGT06199. The black and red lines show the impedance at the installation time and on January 2009, respectively.

BUCKLING

In this section, we discuss the relationship between the core winding, coating and buckling. We summarized the core position of the water tank, winding, coating and buckling in Table 1. In this cavity, three different winding schemes were used and buckling was observed for all cases. We think core winding doesn't relate to the occurrence of buckling. However, there is an obvious difference in the coating process. The buckling happened in eleven cores within low viscosity epoxy immersion but no buckling happened in cores without low viscosity one. In cores within low viscosity epoxy resin, the large linear expansion coefficient of epoxy seems to make buckling easy to happen. On the other hand, in cores without low viscosity one, there is a small space between the ribbons and we speculate that mechanical strength is not strong so that the stress caused from thermal expansion was released by core deformation. Another possible cause is imperfect hardening during coating process.

Understanding the mechanism of buckling and how to suppress the buckling are subjects of future investigation.

SUMMARY

We have been measuring cavity impedance to check the MA core conditions. The cavity 7 showed a rapid reduction in impedance. We found the buckling in eleven cores out of a total of eighteen cores. The damage of one of the buckling cores is very severe and this core showed an impedance reduction. We found that the rapid reduction in impedance of cavity 7 was caused by this core's buckling.

REFERENCES

[1] M. Yamamoto et al., “High power test of MA cavity for J-Parc”, Proc. of EPAC06, pp 1322.

[2] M. Yamamoto et al., “High Power Test of MA Cavity for J-PARC RCS”, Proc. of PAC07, pp 1534.