HIGH POWER TEST OF MA CAVITY FOR J-PARC RCS

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Abstract

We have been constructing the RF system for the J-PARC RCS. All of the power supplies and tube amplifiers have been manufactured and the cavities are under construction. All of them are tested at the experimental hall before installing in the J-PARC RCS building. The results of the test and the improvements are described.

INTRODUCTION

The RF cavities for the J-PARC Rapid Cycling Synchrotron (RCS) and Main Ring (MR) need very high field gradient to accelerate a high intensity proton beam [1]. We have been developing the Magnetic Alloy (MA) loaded cavities for both synchrotrons to obtain a high field gradient of over 20 kV/m [2, 4]. Furthermore, the RF cavity for the RCS covers a wide frequency range to accelerate protons from 181 MeV to 3 GeV and to provide the 2nd higher harmonic voltage at the same cavity, which alleviates the space charge effect near injection energy [5]. We chose a Q-value around 2 to satisfy such requirements, and we planned to use a cut core technique for the MA to realize such a Q-value [2].

The construction of the cavities for RCS was started in 2005, and we have been performing the high power test of them before installing in the RCS building. Then, it was found that we needed more development to get reliable cut cores, so the R & D works for the cut cores are still under way [3]. Now, we concentrate the test on the non-cut cores and we also find that some cores suffered damage. We describe the high power test results and some improvements to prevent the damage.

RCS MA CAVITY

We constructed 3 RCS cavities; all of them were used for testing the non-cut cores. The parameters of the RCS cavity are listed in Table , which is related to the non-cut core. In case of the cut core, the resonant frequency and the shunt impedance are changed to 1.7 MHz and 800 Ω, respectively.

The Figure 1 shows the RCS cavity. The cavity employs the direct water cooling scheme, each cavity has 6 water vessels, which includes 3 stacked MA cores inside. The 3 accelerating gaps are connected in parallel with bus-bars, and the cavity is driven in push-pull mode by a final stage amplifier with high power Tetrodes.

Table 1: The parameters for the RCS cavity.

Frequency range	0.939∼1.672 MHz
Maximum voltage	45 kV / cavity
Cavity length	1950 mm
Number of gaps	3
Number of cores	18 / cavity
Core outer diameter	850 mm
Core inner diameter	375 mm
Core thickness	35 mm
Shunt impedance	700 Ω / gap (Non-cut)
Q-value	0.6 (Non-cut)
Resonant frequency	1 MHz (Non-cut)
Average power dissipation	120 kW / cavity

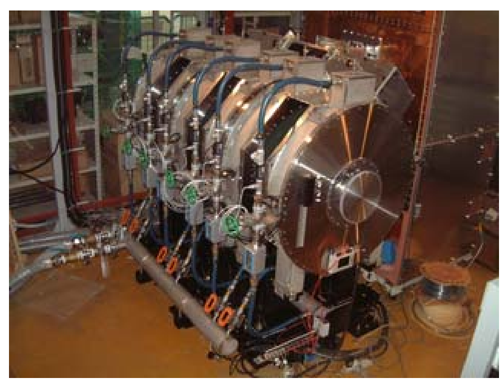

Figure 1: The MA cavity for the RCS.

HIGH POWER LONG RUN TEST

We perform the high power test of the MA cavity at the experimental hall to confirm the reliability of the MA cores. We use a complete set of the high power RF system to be installed in the RCS building, which consists of the anode power supply using IGBT, the final stage amplifier with two TH558K Tetrodes [6] and the 8 kW driver amplifier designed by CERN using RF power MOSFETs.

We started the high power test with constant cavity voltage of 45 kV and 30 % duty with 0.3 Hz instead of real RCS acceleration pattern with 25 Hz because we can examine the durability against the high voltage and the power

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dissipation on the MA core, and we can also check measurement parameters easily.

Test results

The 1st RCS cavity was tested in 2005; the operation time amounted to 300 hours. One of the water vessels showed a very strange impedance curve around 50 hours. Then, we found one core nearest to the accelerating gap, which experiences highest electric field was damaged on the surface. And, we also found that another water vessel showed a large impedance reduction; there we also found a damaged core nearest to the accelerating gap. After inspection, we continued the high power test without the damaged cores, so that we operated up to 300 hours without any further problem.

The 2nd RCS cavity was tested this year; the operation time also amounted to 300 hours. Two of the water vessels showed a large impedance reduction of 7 % at the first high power input; again we found a damaged core in one of them. The position of the core was also nearest to the accelerating gap. We replaced the damaged core with a fresh core, and then started the long run operation up to 300 hours. There were no significant changes of the measured parameters during operation. After long run operation, two of the water vessels showed a large impedance reduction of 7 % and another a small impedance reduction of 3 %, and then we found damaged cores in each water vessel. The position of them was also nearest to the accelerating gap.

Recently, the 3rd RCS cavity was tested; the operation time also amounted to 300 hours. There were no significant changes of the measured parameters during operation. After long run operation, four water vessels had no change, but two water vessels showed very small impedance reduction of 1.7 % at the first high power input; we found very small damage spots on the core surface. The core was placed nearest to the accelerating gap and also placed middle position in the water vessel. We also saw this kind of small spots in the 1st and 2nd cavity.

Impedance reduction and MA ribbon resistance

After the long run operation of the 2nd cavity, we checked the measurement data of the water vessel impedance carefully; then we noticed when the water was poured in the vessel some water vessels already showed lower impedance *before* high power input. Figure 2 shows the impedance measurement results of the water vessels of the 2nd cavity. The water vessels No. 1, 5, 6 have almost same impedance, but No. 2, 3, 4 have lower impedance before power input although we equalized the impedance of each water vessel by shuffling the cores. The same situation happened in the 3rd cavity, but the reduction was smaller than the 2nd cavity case.

We check the cores one by one for the shuffling when we received the manufactured cores. However, the impedance reduction can not be seen at that one by one check, we can see it after assembling the cavity. Then, the core may suffer damage after high power input in the water vessel, which shows the impedance reduction before high power input.

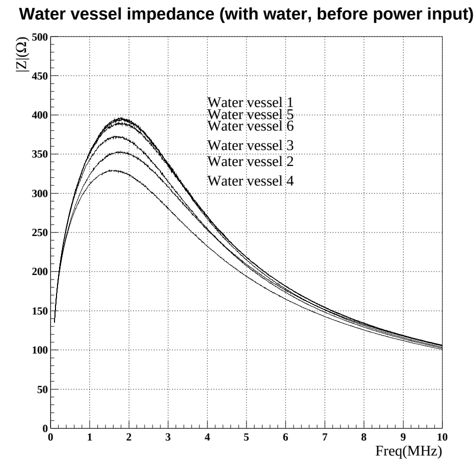

Figure 2: The magnitude of the impedance $|Z|$ of the cores stacked in the water vessel.

We consider the reason why we cannot notice the impedance reduction at one by one check. Assuming that an resistance R_r on the core exists as shown in Fig. 3, some cores have high resistance and the others have low resistance. Then, the measured impedance Z at the resonant frequency becomes $Z = \frac{R_{\text{core}} \cdot R_r}{R_{\text{core}} + R_r}$. However, the resistance R_r is much larger than the core shunt impedance R_{core}, the difference of the measured Z between high R_r cores and low R_r ones is very small, therefore it is very difficult to notice.

When the cores are stacked in the water vessel, then the equivalent shunt impedance R_e as shown in Fig 4 becomes larger and is getting closer to the resistance R_r. Then, the measured impedance Z at the resonant frequency becomes $Z = \frac{R_e \cdot R_r}{R_e + R_r}$. The difference becomes larger compared to the one by one check and we notice it.

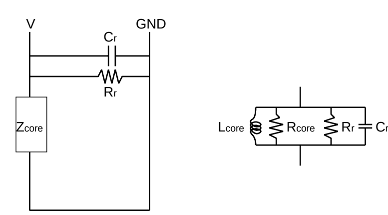

Figure 3: The one by one measurement of the core.

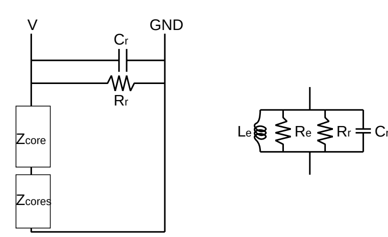

Figure 4: The measurement with the core stack.

We think this kind of the resistance R_r on the core is related to the DC resistance of the core ribbon. If the electric isolation between the layers of the core ribbon is not so perfect, the DC resistance becomes lower.

MA core manufacturing and treatment

We notice that the core winding process affects the core ribbon resistance. There are two types of core winding processes, one is so called 'vertical winding' and another is 'horizontal winding'. From the measurement data of the core ribbon resistance, it is found that the horizontal winding is better than the vertical one. We should use the horizontal wound one nearest to the accelerating gap.

The other thing related to the ribbon resistance, sometimes we find the area where the ribbon has been struck to make the core surface flat or has been scratched by something. We think in that area the insulation among the ribbons is affected, and such core shows the low ribbon resistance locally.

MA core coating and impregnation

The MA core is coated by epoxy to be water proof. Some types of coating scheme have been developed. We test two types of coating schemes for the RCS cavity.

One type is that the core is coated only by the high viscosity epoxy. For the other type, the core is first impregnated by low viscosity epoxy and afterward coated with high viscosity epoxy. In this type, the coating is thicker than the former type. This type has been used for the MR cavity since last year, and is recently used for the RCS cavity. This coated and impregnated core has the advantage that there is no pin hole where the water goes through, and the mechanical strength of the core becomes high.

Recently, we install the coated and impregnated cores in the 3rd cavity, then the result of the 300 hours long run test is good. There is no damage and no corrosion on the cores.

HIGH POWER TEST ROAD MAP

We have to check all of the cores to be installed in the RCS cavity. Each cavity should be run up to 300 hours because the problem at the initial stage usually happens until 50 hours and after that the condition seems to be stable. We think 300 hours are enough time to check. we will put the core having the good ribbon resistance at the accelerating gap side and the cores with low ribbon resistance should be placed at the short side of the water vessel. Then, we have to check the validity of the core selection scheme by performing the high power test.

Furthermore, we plan to perform a 1000 hours long run test to have more confidence for the core, which is made in horizontal winding process and impregnated. We expect that such cores have good ribbon resistance and we do not see any corrosion.

SUMMARY

We have been constructing the J-PARC RCS cavities. The high power tests were performed for three of them up to 300 hours and some cores had damage. We find the impedance reduction is related to the damage, and this happens at the core with low ribbon resistance. The cores made in the horizontal winding process show improved ribbon resistance, and impregnated and coated cores have good water proof. We will test this type of cores up to 1000 hours.

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