

# SIMULATION OF MAGNETIC ALLOY LOADED RF CAVITY AND HOM ANALYSIS

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## Abstract

The RF cavity using Magnetic Alloy (MA) cores has been developed for achieving the high field gradient in J-PARC. For reducing the beam loading effects, the Q-value of the RF cavities in the Main Ring (MR) is controlled by using the cut-core configuration. In order to check the effect of HOMs between the cut-core gap, a simulation method of MA cores was studied and electromagnetic fields of excitation modes have been calculated by HFSS. We present the details of the simulation method of MA cores and the HOM analysis of the cavity with the cut-cores.

## INTRODUCTION

We have been developing the RF cavity using MA cores for achieving the high field gradient instead of the ferrite-loaded cavity. MA cores have higher magnetic permeability compared with ferrite cores and a wide frequency band because of the low Q-value of approximately  $\approx 0.6$ . By using the wide frequency band characteristic, the RF cavities in the rapid cycling synchrotron (RCS) of J-PARC are exciting the fundamental and the second harmonic RF signals at each single cavity [1]. The Q-value of these cavities is in the order of  $\approx 2$ . On the other hand, the RF cavities in MR of J-PARC have the Q-value of 26 in order to decrease the periodic-transient beam-loading effects. The Q-value is adjusted from 0.6 to 26 by the cut-core technique [2]. Higher Order Mode, HOM, is an issue to disturb the high intensity beam acceleration. However, the electromagnetic analysis of the RF cavity loaded with MA cores could not calculate this because of the complex structure of MA cores.

In this article we describe the simulation method of MA cores and the HOM analysis of the RF cavity using the uncut-cores, cut-cores, and MA cores.

## ELECTROMAGNETIC FIELD ANALYSIS OF MA CORES

The MA cores are produced by a winding process using MA ribbons, whose size is about 35 mm width and 18  $\mu\text{m}$  thickness, with a  $\text{SiO}_2$  coating of about 2  $\mu\text{m}$  thickness on one side of the ribbon. The size of an MA core is inner/outer diameter of 375/850 mm in RCS and 245/800 mm in MR. It is difficult to calculate the MA cores by using a real structure. Therefore we need simplify the structure of MA cores.

A single layer inside MA cores can be described by a CR parallel equivalent circuit, where C is a capacitive property along the radius direction and R is a conductive property along the circumferential direction. In case of the minimum radius of 122.5 mm in MR cores, dominant signal propagation path is the capacitive property along the radius direction above 300 kHz. Therefore MA cores are described by layer structures instead of winding structures.

Then, we describe the layer structures of MA cores by macro mediums in a cylindrical coordinate system. Microscopic structures of the MA cores are constructed by layers of metallic foils and insulation layers of  $\text{SiO}_2$  and are very small compared with the wavelength. In addition, electric field components of excited modes are restricted to the radial component ( $E_r$ ) for metallic layer structures. Consequently, MA cores are described by anisotropic mediums, where the components are equivalent permittivity (permeability) in radial direction and metallic property in circumferential (beam axis) direction.

In this simulation, excitation modes are calculated by the Eigenmode solver of HFSS. The simulation geometry is as shown in Fig. 1. The inside components of the cavity are only cores and water for simplified calculation. If necessary, capacitors for adjusting the resonance frequency are described by changing the permittivity of ceramics in the acceleration gap. For example,  $\epsilon_r \sim 2800$  corresponds to a capacitance of 1764 pF.

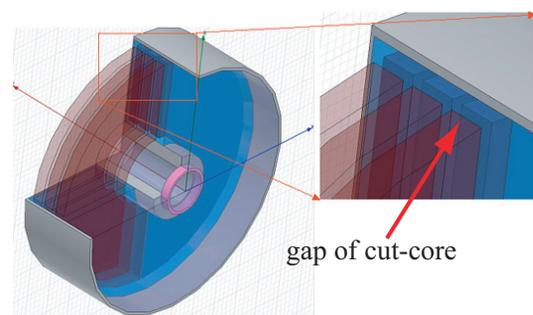


Figure 1: Simulation geometry with Cut-cores in HFSS. The inside components of the cavity are only cores and water. Capacitors for adjusting the resonance frequency are described by changing the permittivity of ceramics in the acceleration gap.

## HOM ANALYSIS

First, we have investigated the excitation modes of the cavity with uncut- or cut-cores of isotropic medium like a

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Table 1: The simulation results of the Eigenmode solver in a cavity with uncut-cores or cut-cores. Excitation modes of the cavity with cut-cores are arranged in the same order as modes of the cavity with uncut-cores.

Mode	Gap 0 mm	Mode	Gap 10 mm
1	0.826 MHz	1	2.713 MHz
2	5.616 MHz	3	5.906 MHz
3	5.896 MHz	2	5.882 MHz
4	5.897 MHz	5	6.690 MHz
5	6.653 MHz	4	6.637 MHz
6	6.654 MHz	7	7.742 MHz
7	7.295 MHz		
8	7.704 MHz	6	7.682 MHz
9	7.707 MHz		

ferrite core. The parameters of this calculation are cores ( $\epsilon_r \sim 12, \mu_r \sim 1000$ ), acceleration gap ceramics ( $\epsilon_r \sim 1000$ ) and water ( $\epsilon_r \sim 81$ ).

The simulation results of the Eigenmode solver are summarized in Table 1. Mode 1 is a dominant mode (TEM) and modes higher than Mode 2 are TM modes. Excitation modes of the cavity with cut-cores are arranged in the same order as modes of the cavity with uncut-cores.

Resonance frequency shifts by changing the gap distance between cut-cores are as shown in Fig. 2. The Resonance frequency of the dominant mode ( Mode 1) changes by varying the gap distance because Mode 1 is a TEM mode and magnetic fields cross the gap between cut-cores. However, the resonance frequencies of the HOMs don't change because the magnetic field exists only inside the cores and does not cross the cut-core gap. Consequently, new HOMs are not excited in the cavity loaded with cut-cores.

Second, we have investigated the excitation modes of the cavity with cut-cores of isotropic medium or anisotropic medium cut-cores. Simulation parameters of anisotropic medium cores are  $\epsilon_r(r, \phi, z) \sim (12, 1, 1)$  and  $\mu_r(r, \phi, z) \sim$

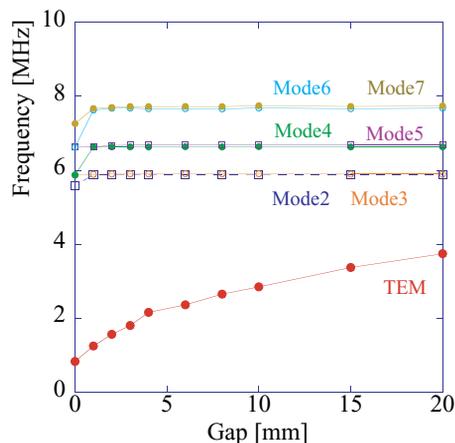


Figure 2: The simulation results of the resonance frequency shift by changing the gap distance of cut-cores.

Table 2: The simulation results of Eigenmode solver in a cavity loaded with cut-cores of isotropic (ferrite) or anisotropic (MA) mediums. Excitation mode of the cavity with MA cores has only dominant mode.

Mode	ferrite core	Mode	MA core
1	2.713 MHz	1	2.841 MHz
2	5.882 MHz		
3	5.906 MHz		
4	6.637 MHz		
5	6.690 MHz		

(4, 1000, 1000). Simulation results are as shown in Table 2. The excitation mode of the cavity with anisotropic medium cores is only the dominant mode and HOMs are not excited. In addition, when simulation parameters are defined by using the value of actual MA cores and capacitance, the calculated frequency of the dominant mode is 1.881 MHz. Figure 3 shows the result of an impedance measurement of a single gap cavity with MA cut-cores. We find that the simulation results are consistent with the measurement results.

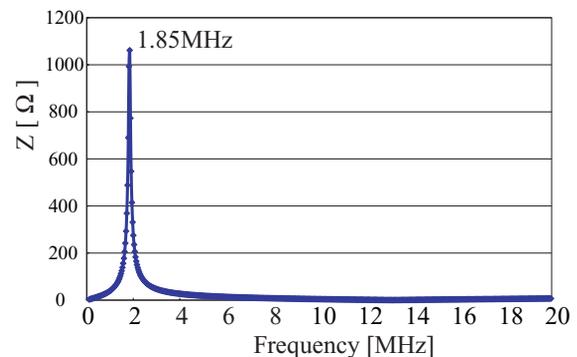


Figure 3: Impedance measurement of a single gap of a MR RF cavity loaded with MA cut-cores.

## SUMMARY

We simplified the structure of MA cores by the anisotropic medium model and calculated the electromagnetic fields of the RF cavity with uncut-cores or cut-cores. Simulation results are consistent with the measurement results and we found that HOMs are not excited by using the cut-cores. The dominant mode is an ordinary TEM one.

## REFERENCES

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