INFLUENCE OF CORE WINDING TENSION AND RIBBON QUALITY ON THE MA CORE RF CHARACTERISTICS

M. Nomura*, A. Schnase, T. Shimada, F. Tamura, and M. Yamamoto
JAEA/J-PARC, Tokai-mura, Ibaraki, Japan
K. Hara, K Hasegawa, C. Ohmori, M. Toda, and M. Yoshii
KEK/J-PARC, Tsukuba, Ibaraki, Japan

Abstract

During the development of Magnetic Alloy (MA) cores for RF cavities in J-PARC synchrotrons, we found that the core shunt impedance was increased by lowering the core winding tension to improve the electrical insulation between MA ribbon layers. The lower winding tension reduced the core filling factor. The core shunt impedance might be reduced according to the core filling factor reduction. We study the influence of improving the electrical insulation and lowering the core winding tension on the core shunt impedance. The increasing of the core shunt impedance was not realized by the improvement of the electrical insulation. The reason why the core shunt impedance was increased might be that the lower winding tension keeps enough spaces between the ribbon layers, and thereby it prevents the ribbons from the damage caused by tightening.

INTRODUCTION

J-PARC 3 GeV Rapid Cycling Synchrotron (RCS) and Main Ring (MR) employ RF cavities loaded with MA cores to generate a high field gradient. During the development of MA cores for RCS RF cavities, we improved the electrical insulation between MA ribbon layers by changing the core winding methods and lowering the winding tension. After the improvement of electrical insulation by lowering the winding tension, we found that the core shunt impedance was increased. The core shunt impedance is a key parameter to achieve the high field gradient. We discuss the reason why the core shunt impedance was increased.

INCREASING THE CORE SHUNT IMPEDANCE

We briefly describe the MA cores and RF cavities. The MA cores are produced by a winding process using amorphous ribbons with about 18 μm thickness and 35 mm width and they are annealed at a temperature of more than 500 degrees Celsius to have the desired magnetic properties. In order to create sufficient electrical insulation, a coating of S_iO_2 with in average 2 μm thickness was put on one side of the ribbons. The inner and outer diameters of MA cores for RCS are 375 and 850 mm, respectively. The weight is about 100 kg. The RF cavity consists of six water tanks that employ three MA cores each and it has three accelerating gaps. The fundamental RCS frequency (h = 2) is 0.938 to 1.67 MHz.

During the development of MA cores for RCS, we improved the electrical insulation between ribbon layers by changing the winding method and lowering the winding tension. We employ the vertical winding method from the beginning to core production number 165 and we changed the winding method from the vertical winding to the horizontal one from the core production number 166. From the core production number 187, we reduced the winding tension to keep enough spaces between ribbon layers.

We evaluated the electrical insulation between ribbon layers by the DC resistance between the core inner and outer radius. We call it the radial resistance. When the core has no electrical insulation break, the radial resistance is proportional to the ribbon length. If the core has electrical insulation breaks, the radial resistance is reduced by the short circuits between the ribbon layers [1].

The relationship between the electrical insulation of MA cores for RCS and the core manufacturing process is shown in Fig. 1. Figure. 1 shows that the radial resistance is increased drastically by lowering the winding tension.

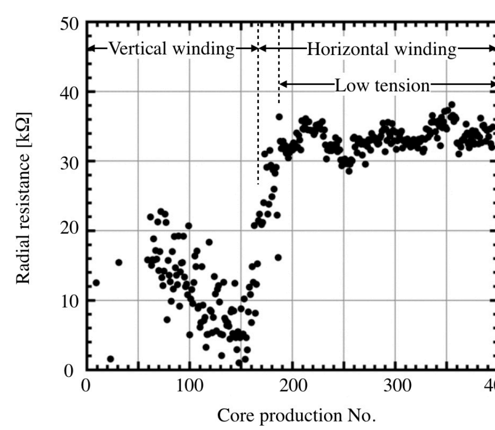

Figure 1: Radial resistance vs. core production number. The radial resistance means the DC resistance between the inner and outer core radius.

The lower winding tension reduced the core filling factor that is defined as the volume ratio of ribbons and core geometrical dimensions. The relationship between the filling factor and the core manufacturing process is shown in Fig. 2. The filling factors are reduced from the core production number 187 by lowering the winding tension.

*masahiro.nomura@j-parc.jp

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We show the core shunt impedance at 1 MHz in Fig. 3. The core shunt impedance might be reduced according to the core filling factor reduction. Figure 3 shows that the shunt impedance was increased after the improving of electrical insulation by lowering the winding tension.

Figure 3 shows that the MA cores from core production number 247 to 329 have a lower shunt impedance. This lower shunt impedance might be influenced by the ribbon thickness, ribbon resistivity, and so on. The detail is now under consideration.

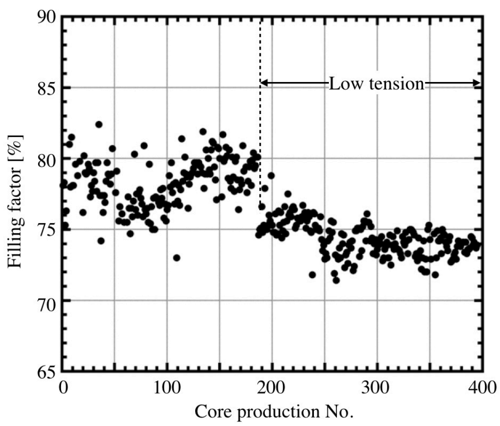

Figure 2: Filling factor vs. core production number.

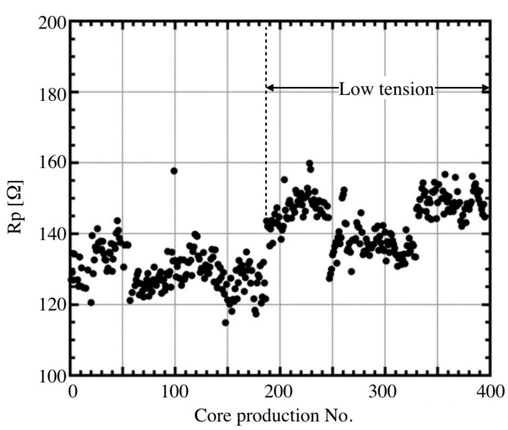

Figure 3: Core shunt impedance at 1 MHz vs. core production number.

RELATION BETWEEN ELECTRICAL INSULATION AND CORE SHUNT IMPEDANCE

The core shunt impedance was increased by lowering the core winding tension to improve the electrical insulation. The core shunt impedance is a key parameter to achieve the high field gradient. In this section, we discuss the influence of the electrical insulation breaks on the core shunt impedance.

When the ribbon contacts electrically with the other ribbons through the electrical insulation breaks, the eddy current in the ribbon is increased. In the high frequency region, the influence of eddy current is significant because it increases according to the frequency. The permeability is reduced by the magnetic field that is generated by the eddy current.

The relation between the complex permeability μ_s and the core shunt impedance R_p is expressed by

$$\mu_s = \mu_s^{'} - i\mu_s^{''}, \qquad (1)$$

$$R_p = \left(\frac{\mu_s^{'2} + \mu_s^{''2}}{\mu_s^{'2}}\right)\mu_0 t \ln\left(\frac{r_2}{r_1}\right), \qquad (2)$$

where μ_0 represents the permeability in vacuum, t represents the ribbon width, and r_1 and r_2 show the core inner and outer radius, respectively. From eq. (2), the core shunt impedance R_p is reduced by the reduction of the permeability μ_s'. In sum, the electrical insulation breaks have a possibility to reduce the core shunt impedance R_p.

The radial resistance dependency of core shunt impedance is shown in Fig. 4. Figure 4 shows that the core shunt impedance does not change until the radial resistance of 30 kΩ. This means that the core shunt impedance is not reduced by the electrical insulation breaks. The core shunt impedance is increased drastically from the radial resistance of 30 kΩ. The MA cores with more than 30 kΩ are produced with the lower winding tension.

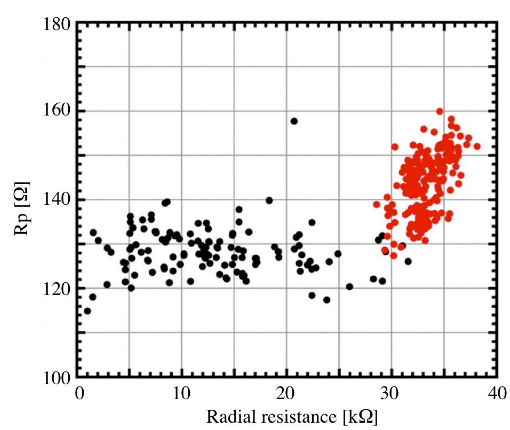

Figure 4: Radial resistance dependency of core shunt impedance R_p at 1 MHz. The black and red dots represent the high winding tension core and low winding tension core, respectively.

The MA core with the low radial resistance has many electrical insulation breaks and those points are thought to be scattered around. They don't lay on a line in the radial direction, and hence they don't make a large electrical loop where the magnetic flux density passes through. In this case, the electrical insulation breaks don't reduce the core shunt impedance significantly.

STRENGTH OF CORE WINDING TENSION AFFECTS PERMEABILITY

In this section we discuss the influence of the winding tension on the core shunt impedance. The relationship between filling factor and the core shunt impedance is shown in Fig. 5. Figure 5 shows that the core shunt impedance is increased by lowering the winding tension despite of low filling factor. The relationship between the filling factor and $\tan\delta$ at 1 MHz is shown in Fig. 6. The $\tan\delta$ is expressed by

$$\tan\delta = \frac{1}{Q} = \frac{\mu_s''}{\mu_s'} . \qquad (3)$$

It is clear from Fig. 6 that the $\tan\delta$ is not affected by both the filling factor and the winding tension. This means that the ratio of μ_s' to μ_s'' is not changed by the changing of the winding tension. The relationship between the $\tan\delta$ and permeability μ_s' at 1 MHz is shown in Fig.7. Figure 7 shows that the permeability μ_s' is reduced by the high winding tension. From Fig. 6 and Fig. 7, it is understood that the μ_s' and μ_s'' are reduced at the same rate by the high winding tension. We thought that a part of the ribbons might be damaged by tightening, and thereby both the μ_s' and μ_s'' are reduced at the same rate. In other words, the reason why the core shunt impedance was increased might be that the lowering winding tension keeps enough spaces between the ribbon layers, and thereby it prevents the ribbons from the damage caused by tightening.

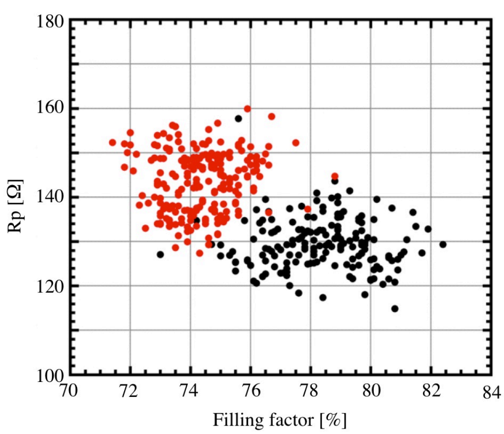

Figure 5: Relationship between filling factor and the core shunt impedance R_p at 1 MHz. The black and red dots represent the high winding tension core and low winding tension core, respectively.

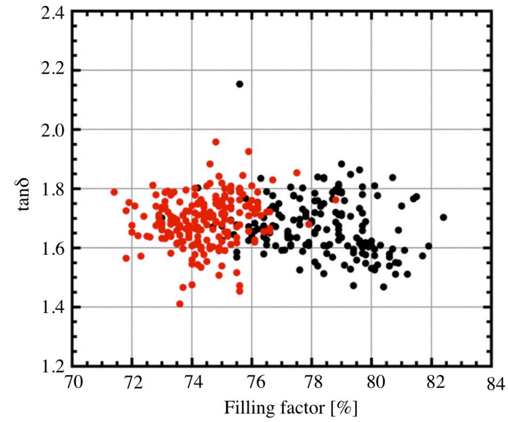

Figure 6: Relationship between filling factor and $\tan\delta$ at 1 MHz.

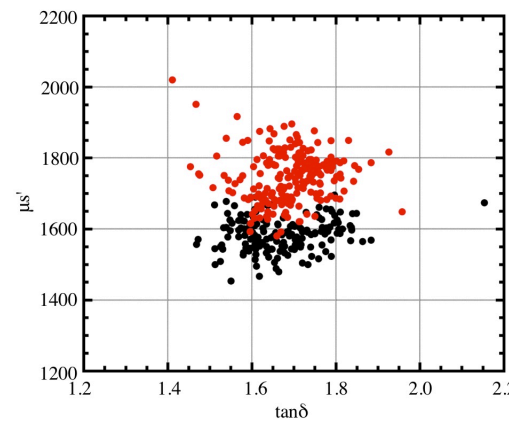

Figure 7: Relationship between $\tan\delta$ and μ_s' at 1 MHz.

SUMMARY

During the development of MA cores, we found that the core shunt impedance was increased by lowering the core winding tension to improve the electrical insulation between ribbon layers. The increasing of the core shunt impedance was not realized by the improvement of the electrical insulation. The reason why the core shunt impedance was increased might be that the lowering winding tension keeps enough spaces between ribbon layers and prevents the ribbons from the damage caused by tightening.

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[1] M. Nomura *et al.*, Nuclear Instruments and Methods in Physics Research A 668 (2012) p 83–87.