NEW CUTTING SCHEME OF MAGNETIC ALLOY CORES FOR J-PARC SYNCHROTRONS

Masahito Yoshii, Shozo Anami, Yoshisato Funahashi, Eizi Ezura, Keigo Hara, Chihiro Ohmori#, Akira Takagi, Makoto Toda, Kenji Ueno, KEK, Ibaraki, Japan
Masahiro Nomura, Fumihiko Tamura, Masanobu Yamamoto, Alexander Schnase, Katsushi Hasegawa, JAEA/J-PARC, Ibaraki, Japan
Tamaki Yoshioka, Yuichi Morita, IHEP, Univ. of Tokyo, Hongo, Tokyo, Japan

Abstract

A cut core configuration is adopted for the magnetic alloy cavities of J-PARC Main Ring to lower the R/Q to combat beam loading. The cut core surface is treated by "Diamond Polishing" which improves surface quality, therefore reducing the local temperature rise due to RF losses in operation. Long-term high-power tests have been performed for the J-PARC MR RF systems. The mechanisms of local heating, the cutting scheme, and the manufacturing method are presented.

INTRODUCTION

Magnetic alloy cores [1] are used for the J-PARC synchrotron RF cavities to satisfy the required field gradient for rapid acceleration [2,3]. Magnetic alloy ribbons of 18 µm thickness are wound and form large size cores (~ 80 cm) for RF cavities. To improve performance at high frequencies by reducing eddy-currents, one side of the ribbon is coated with silica of 2 µm thickness.

However, the bare Q-value of the material is about 0.6 and the wake voltage at the acceleration gap will be large when a high intensity bunched beam circulates. To reduce the beam loading effects, a solution is the cut core configuration [4], where each toroidal core is split into two pieces with the effective core inductance controlled by changing the cut core gap height.

Such cut cores are commercially used for transformers to avoid magnetic field saturation. The materials have a very large permeability at low frequency and degradation easily occurs by a small amount of DC current. The cutting method uses a grind stone cutter followed by etching to produce the cores. By cut core gaps of few ten µm for 10 cm cores, the effective permeability at low frequency is reduced and field saturation avoided. However, the diameter of commercially available cut core was limited up to 30 cm.

CUTTING METHODS

Three different cutting methods have been developed to produce cut cores for J-PARC. "Diamond Polishing", which is the most recent one, will be used for mass production.

Water Jet

The first MA cut cores for a synchrotron have been produced in 2000. Water jet cutting was used because it does not affect the cores and cavity shunt impedances. The stream of high-pressure water with abrasive garnet powder inside removes a few mm of the MA core and the flatness of the surface is 0.5-1.0 mm. Figure 1 shows the cut surface.

When high power RF was applied to the core, local temperature rise was observed near the cut core gap. The locations and temperatures depend on each core. Especially, local heating is clearly observed when the cut gap is less than a few mm as shown in Fig. 2. It can be explained that the rough cut surfaces disturb the magnetic field between two halves and the insulation between ribbons was partially destroyed by the water jet.

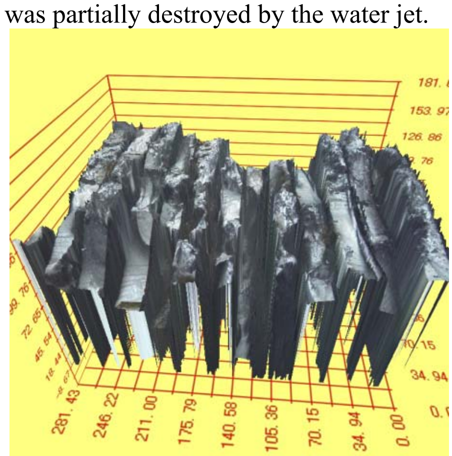

Figure 1: Three-dimensional microscopic view of the surface by water jet. Each ribbon was split and removed by high-pressure water.

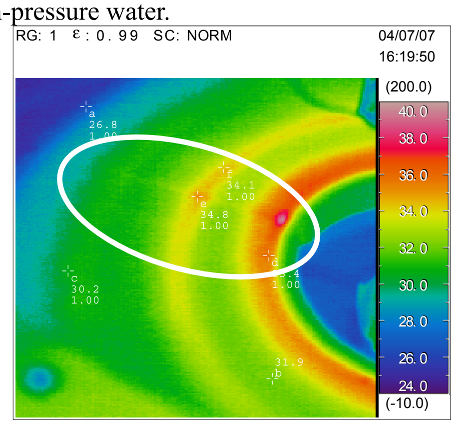

Figure 2: An infrared camera measured the MA core temperature. A white circle indicates the cut core gap. Hot spots were observed.

#chihiro.ohmori@kek.jp

Grind Stone Cutting and Etching

In 2005, a cutting scheme using grind stone and etching [5] was tested. The method has been already used for commercially available MA cores. The flatness of the cut core surface is 10 µm locally and 0.5 mm for the whole cut surface. The cut surface is shown in Fig. 3. When high power RF was applied, the cut surface did not show a local temperature rise as confirmed by Fig. 4. However, this scheme has a disadvantage: some acid remains in between the MA ribbons. Usually, the acid is dried and removed at 150 deg. C in oven in case of commercially available cut cores. However, the large size cores for J-PARC need a waterproof coating and cannot stand this temperature. A drying process at 120 deg. C was not very efficient and takes a few days.

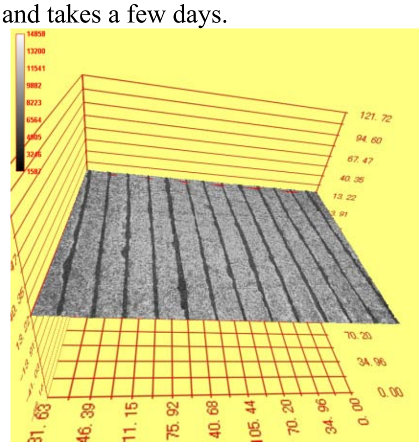

Figure 3: 3D-microscopic view of the surface made by grind stone cutting. The MA ribbons are clearly separated by silica and epoxy resin. Thanks to etching, the surface has only a small roughness.

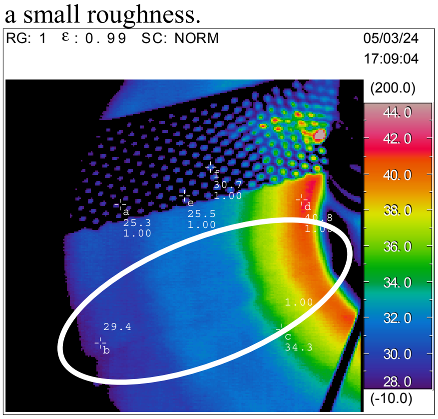

Figure 4: MA core temperature. The cut core gap is surrounded by a white circle. No hot spot was observed.

Diamond Polishing

This year, a new scheme for cut cores called "Diamond Polishing" was introduced. The cut core surfaces made by water jet were polished with very fine diamond powder. Neither oil nor acid is used. Figure 5 shows the surface. The flatness is a few µm locally and 0.2 mm for the whole cut surface. The polished surfaces were tested with high power RF, shown in Fig. 6. Two of 6 cores did not show any hot spots. Three cores showed small hot spots around the polished surfaces. One core showed a hot spot where polishing was not enough. After re-polishing, these hot spots became smaller or disappeared. An advantage of this scheme is the simple production process with less risk of scratches and damages on the cores.

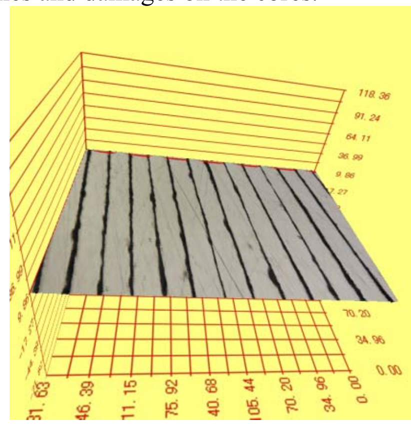

Figure 5: 3D-microscopic view of a "Diamond Polished" surface. The flatness is better than by other methods.

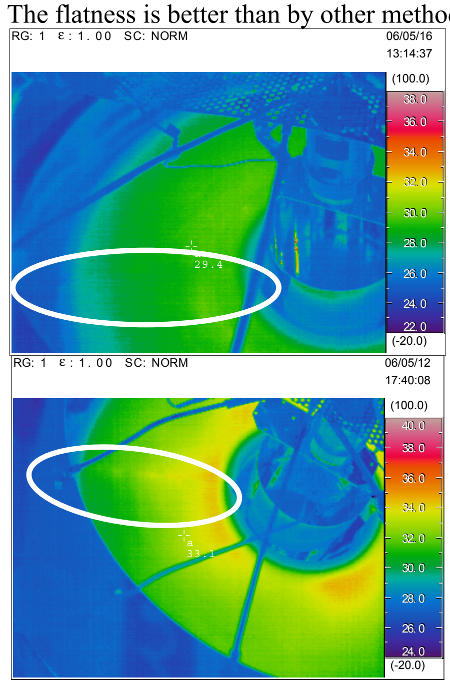

Figure. 6: MA core surface temperature. The cut core gap is surrounded by white circles. Two of 6 cores did not show hot spots (top). Others showed hot spots (bottom).

HIGH POWER TESTS

Requirements

The J-PARC MR has been designed as a 50 GeV synchrotron. However, the ring will operate up to 40 GeV during Phase I. Because of different acceleration gradient, the requirements on the RF cavities for DAY-1 operation differ from the original ones as shown in Table 1.

Table 1

Energy	Intensity	Requirements	
		Power dissipation	Q-value
40 GeV	few 100 kW	30 kW/gap	>0.6
40 GeV	600 kW	30 kW/gap	> 10
50 GeV	750 kW	70 kW/gap	> 10

Corrosion and Coatings

To handle the large power dissipation in MA cores, shown in Table 1, direct water-cooling was adopted. The cores are stacked in water tanks and surrounded by demineralised water as shown in Fig. 7. The cooling efficiency of the scheme is good, however corrosion was observed because MA contains iron. Figures 7 and 8 show the core surfaces before and after high power test. The cut surface shows corrosions in short term. Although the core surface was covered by corrosion, the core impedance has not changed. These cores are still available to be used for high power operation.

Figure 7: MA core without coating.

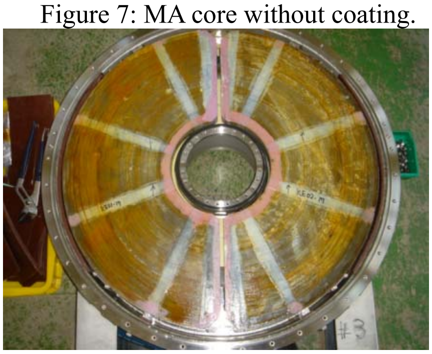

Figure 8: MA core without coating after high power test. The core was used from 2003 on and tested for about 800 hours, in total.

Figure 9: Cut surface after a few 10 hours high power test. The surfaces were not covered by coating and the dissolved oxygen was not controled.

High Power Tests for Full Coated Cores

To avoid such corrosion, epoxy coating was applied. Cut cores made by water jet and grindstone with full coating were tested under operational conditions. In case of cut cores made by water jet, the coating was damaged in short time. The cores made by grindstone could survive longer than the ones made by water jet. However, some coatings on cut surfaces show partial color changes along scratches which were probably made during the processes of cleaning of acid, drying and coating on the cut surface. In case of full-coated cores made by grindstone cut, the performance of cavity will not satisfy the 50 GeV operation requirements.

High Power Tests for Diamond Polished Cut Cores

In case of diamond polishing, it is difficult to coat the cut surface because of its mirror like quality. Instead of coating, it is planned to use demineralised water with low dissolved oxygen. In the test system, the dissolved oxygen is 0.26 ppm, which is 30-times less than before. High power tests with 50 GeV MR operational requirements have been performed for 300 hours. The core surfaces are shown in Figs. 10. Although the cut surfaces are not covered, the corrosions are much less than that in case of high dissolved oxygen (see Fig. 9). The test will run until 1000 hours.

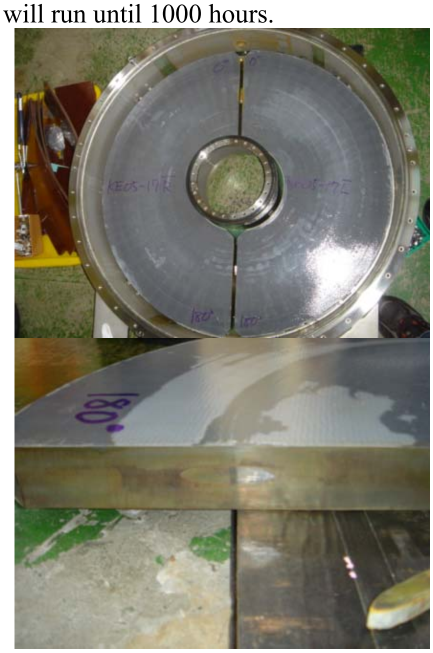

Figure 10: MA cores using Diamond Polishing. 98% of the core surface is covered by epoxy coating (top). After 300 hours high power test, the corrosion on cut surface (bottom) is restricted.

REFERENCES

[1] M. Fujieda et al., “Studies of Magnetic Cores for JHF synchrotrons”, Proc. of PAC 1997.

[2] Y. Mori et al., “A New Type of Cavity for High Intensity Proton Synchrotron using High Permeability Magnetic Alloy”, Proc. of EPAC 1998.

[3] C. Ohmori et al., ”High Field Gradient Cavities loaded with MA for Synchrotrons”, Proc. of PAC 1999.

[4] M. Yoshii et al., “MA RF Cavity for the KEK 12 GeV PS”, Proc. of EPAC 2000.

[5] C. Ohmori et al., “High Field Gradient Cavity for J-PARC 3 GeV RCS”, Proc. of EPAC 2002.