# THERMAL DEFORMATION OF MAGNETIC ALLOY CORES FOR J-PARC RCS RF CAVITIES

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*Abstract*

Magnetic alloy-loaded (MA) cavities have been installed in J-PARC RCS (Rapid Cycling Synchrotron). In total, 198 MA cores are used. Several MA cores have shown the buckling during two years operation [1]. To find the mechanism how the buckling happened, we heated up MA cores in the air by 500 kHz RF and measured the thermal deformation. It was found that the deformations depend on the production procedures of cores.

## INTRODUCTION

To measure temperature and deformation of the cores in operation is essential for investigation into the buckling process. However, it is difficult because the cores are water-cooled in tanks in operation. So we heated up the cores in air by RF and measured the thermal deformation.

## MEASUREMENT

Since the high electromagnetic field is generated around the core in RF operation in air, we used mechanical sensors to measure the displacement and a non-contact sensor to measure the temperature of the cores.

Figure 1 shows a set up of RF heating and measuring deformation of a core. We put the core on an FRP plate for electrical and thermal isolation and reduction in friction against a base plate. We excited the core by a one-turn coil with 500 kHz CW RF generated by a solid state amplifier and measured the deformation using 6 dial gauges inside of the core and 6 dial gauges outside.

Figure 2 shows an example of measured core deformation. The red lines are the design inner and outer diameters of the core. The blue arrows are measured displacements. The two blue closed lines are made by the cubic spline method.

Figure 3 shows an example of measured surface temperature of a core using an infrared thermo camera. The magnetic flux density is proportional to 1/r; therefore, heat loss is proportional to $1/r^2$, where r is the radius from the core center. Points a and b show the temperature at the inside of the core, points c and d show the outside one and point e shows the floor temperature.

We kept the constant temperature of the core by controlling the RF feed power monitoring the temperature of the inner core surface, for example, the points a and b in Figure 3 during testing.

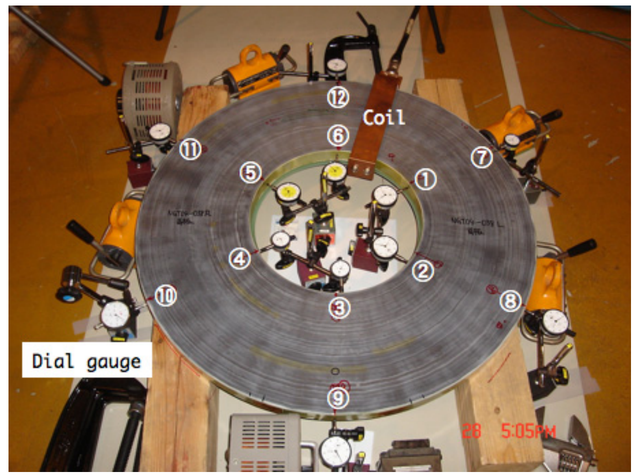


Figure 1: Setup of RF heating and measuring deformation of a core. Encircled numbers are the position of the dial gauges.

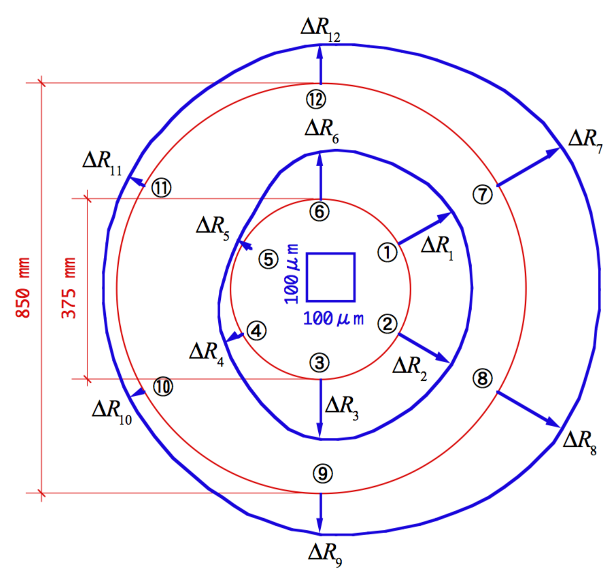


Figure 2: An example of measured core deformation. Two red circles are the design value. Two blue curves are the core deformation scaled by factor 1000.

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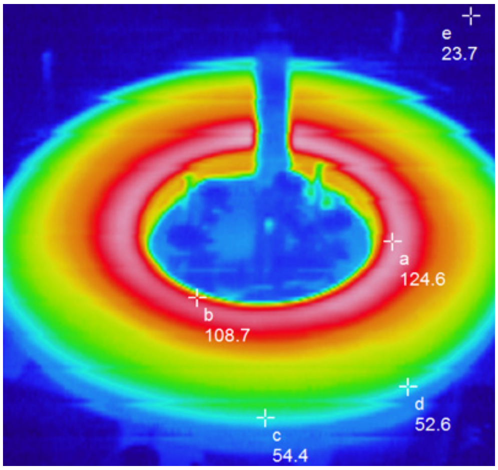


Figure 3: An example of measured surface temperature of a core. A blue band crossing the core is the copper coil. The temperature at the points a ~ e are shown.

Table 1: Experimental conditions.

| case | core No. | production methods of cores | | | inner surface temperature & holding time |
|---|---|---|---|---|---|
| | | silica coating | low viscosity resin | high viscosity resin | |
| 1 | NGT06-204 | No | Yes | No | ~80 °C * 8 hours |
| 2 | | | | | ~100 °C * 8 hours |
| 3 | | | | | ~120 °C * 8 hours |
| 4 | NGT05-168 | Yes | Yes | 180 um Glass Cloth | ~80 °C * 8 hours |
| 5 | | | | | ~100 °C * 8 hours |
| 6 | | | | | ~120 °C * 8 hours |
| 7 | NGT04-038 | Yes | No | 50 um Glass Cloth | ~80 °C * 8 hours |
| 8 | | | | | ~100 °C * 8 hours |
| 9 | | | | | ~120 °C * 8 hours |
| 10 | NGT09-291 | Yes | No | 50 um Glass Cloth | ~120 °C * 8 hours |
| 11 | NGT09-292 | Yes | No | 50 um Glass Cloth | ~120 °C * 8 hours |
| 12 | NGT09-293 | Yes | No | 50 um Glass Cloth | ~120 °C * 8 hours |
| 13 | NGT09-294 | Yes | No | 50 um Glass Cloth | ~120 °C * 8 hours |

## RESULTS AND DISCUSSION

Table 1 shows the list of the experimental conditions. We tested seven cores made by three different production procedures. NGT06-204, 05-168 and 04-038 are made by different production procedures. NGT09-291 ~ 09-294 are made by the same production procedure. These four cores are candidates to replace the current cores which had shown buckling in accelerator operation. In the cases 1 ~ 9, we measured the deformation of the cores at the inner surface temperature: 80, 100 and 120 °C for each core. In the cases 10 ~ 13, we measured the deformation at 120 °C. In all cases we held the core temperature constant for 8 hours.

Only in the case 6, a buckling occurred immediately after the inner surface temperature rose over 120 °C. See Figure 4.

A stress is calculated from the expansions at the inner and outer radius of the core. See Figure 5.

$$\sigma = \varepsilon E = \frac{\Delta L_{outer} - \Delta L_{inner}}{L_{inner}} E \qquad (1)$$

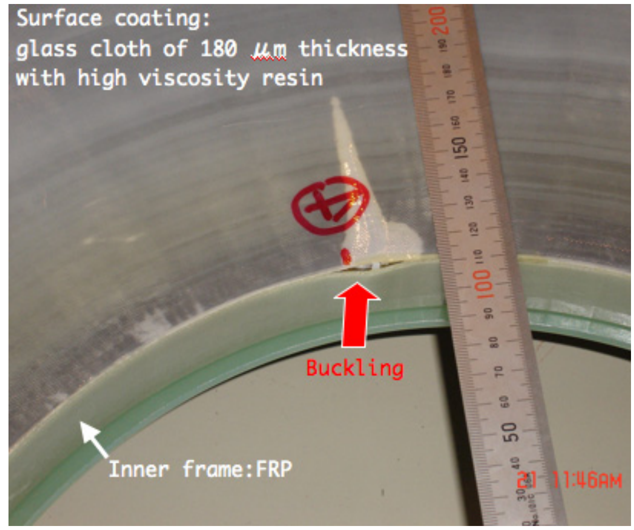


Figure 4: Buckling of NGT05-168 in the case 6.

where $\sigma$ is the stress, $\varepsilon$ is the strain, $E$ is the Young's modulus, $L_{inner}$ is the inner circumference of the core, $\Delta L_{outer}$ and $\Delta L_{inner}$ are the expansions at the inner and outer radius of the core, respectively. The expansions are calculated from the measured displacements.

$$\Delta L_{inner} = 2\pi \frac{1}{6} \sum_{i=1}^{6} \Delta R_i$$
$$\Delta L_{outer} = 2\pi \frac{1}{6} \sum_{i=7}^{12} \Delta R_i \qquad (2)$$

where $\Delta R_i$ is the measured displacement. The suffix $i$ indicates the position of the dial gauge in Figure 1 or Figure 2. The components of the global translation of the core are canceled by taking an average of $\Delta R_i$ in Equation (2). We calculated the stress in each case assuming $E = 200$ G.

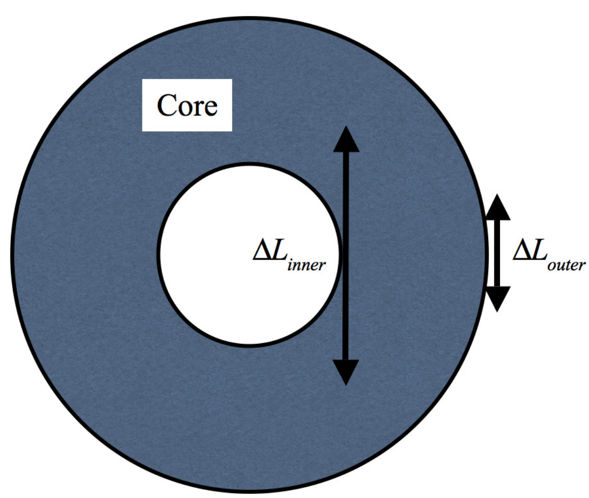


Figure 5: Expansions at inner and outer radius of core.

Figure 6 shows the stress at the inner radius of the core depending on the temperature and the production procedure in the cases 1 ~ 9. The stress increases as the temperature goes up as long as no buckling occurs. When a buckling occurred the stress decreases. This means that the buckling releases the stress.

It looks like that the stress increase is higher when the thickness of glass cloth is higher or immersion of low-viscosity epoxy resin is carried out.

Figure 7 shows the stress depending on core differences although the cores are made by the same production procedure, in the cases 10 ~ 13. The average value of the stress of four cores is 81 MPa. The variation of the stress for each core is caused by measurement errors and individual differences of the cores.

## CONCLUSION

The first measurement of thermal deformation of magnetic alloy cores has been done. We examined the thermal stress and its dependence on temperature and production procedures.

To measure the deformation of cores by RF heating in air is useful to collect the information about the thermal stress of the cores.

We plan to test more various cores in order to clear the relation between the thermal stress and the production procedure, especially immersion of low-viscosity epoxy resin.

## REFERENCES

[1] M. Nomura et al., "Condition of MA cores in the RF cavities of J-PARC synchrotrons after several years of operation", Proc. of IPAC2010.

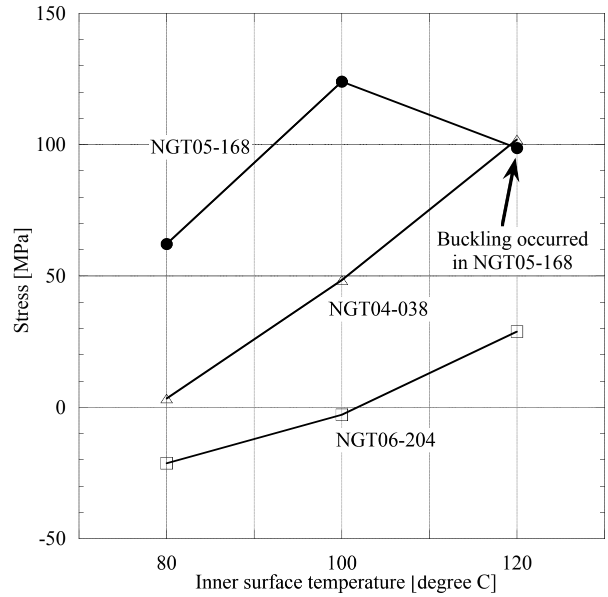


Figure 6: Stress at the inner radius of the cores depends on the temperature and the production procedure.

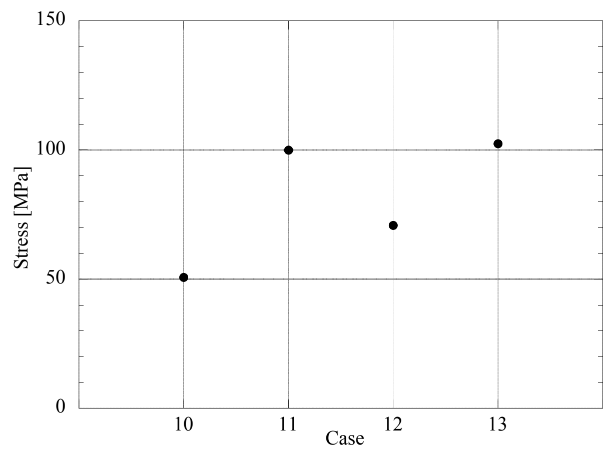


Figure 7: Stress of the different cores made by the same production procedure.