Core buckling position measurement for J-PARC RCS cavity

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Abstract

An impedance reduction had been detected in the J-PARC RCS cavity 7 in January 2009. After taking out and opening the cavity tanks, buckling at the inner radius was detected at some of the MA cores. Here we describe the development and application of magnetic sensors, which were expected to detect the buckling of the cores in the stainless steel water tanks without the need for taking out and opening them.

J-PARC RCS空胴のコアの座屈位置の測定

1. Introduction

J-PARC RCS is in the transition from commissioning [1] to production phase and routinely accelerates proton beams to 3 GeV. In RCS currently 11 cavity systems are installed. Each cavity consists of 6 tanks, loaded with 3 MA (magnetic alloy) cores. In January 2009, an impedance reduction in tank 6 of RCS cavity 7 had been detected [2]. In March 2009, this cavity was opened, and 11 of in total 18 cores showed buckling at inner radius.

Taking out from the tunnel and later re-installing a cavity means breaking the vacuum. Such process including alignment takes in the order of 2-3 weeks. From experience with cavity 7, a significant tank impedance change might indicate core buckling. However, a core with modest buckling might not lead to impedance change. Therefore we try to detect core buckling in installed cavities without taking out and opening the water tanks. We developed inductive sensors, which are put between beam pipe and inner cylinder of the cavity tank under test as shown in fig. 1.

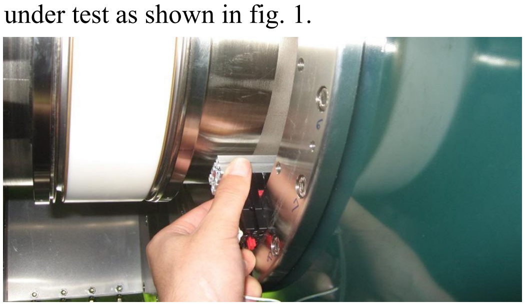

Figure 1: Finemet yoke sensor inserted between beam pipe and cavity tank for buckling check.

The angle and longitudinal position of the sensor are varied to obtain a map of the magnetic permeability environment. The inductance measurement frequency is chosen low enough, in the order of 100 Hz, resulting in a skin depth of 42.7 mm, so that the magnetic field generated by the sensor can go trough the 5 mm thick stainless steel and interact with the MA cores in the tank. Buckling is equivalent to a geometry change in the permeability environment, and the sensor is expected to detect this.

2. Sensor development

An RCS cavity tank loaded with 3 cores of cavity 7, which were affected by buckling was prepared to study if core buckling inside a stainless tank can be detected.

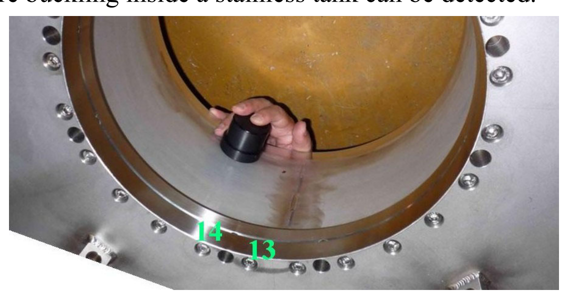

Figure 2: Commercial thickness sensor detects buckling

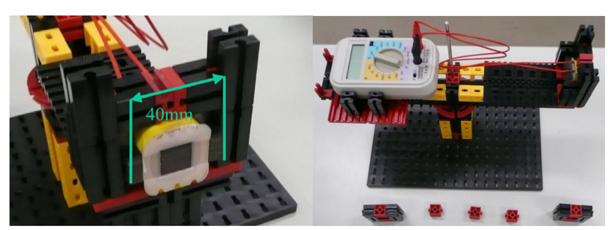

Figure 3: transformer based sensor (left) set-up on rotating support (right)

Using a commercially available sensor [3], figure 2 shows how buckling can be detected through the stainless steel tank. Unfortunately the sensor head for a maximum measurement range of 15 mm, which is sufficient for buckling detection, does not fit into the space between cavity tank and beam pipe. Therefore we tried to develop

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a sensor matched to the narrow available space. The left of figure 3 shows the initial sensor, based on a 100 V transformer, where one side of the yoke is removed. This sensor was put on a weight balanced rotating support with adjustable height (right of figure 3) made by fischer-technik components for rapid prototyping [4] and put into the inner space of the MA loaded tank (figure 4).

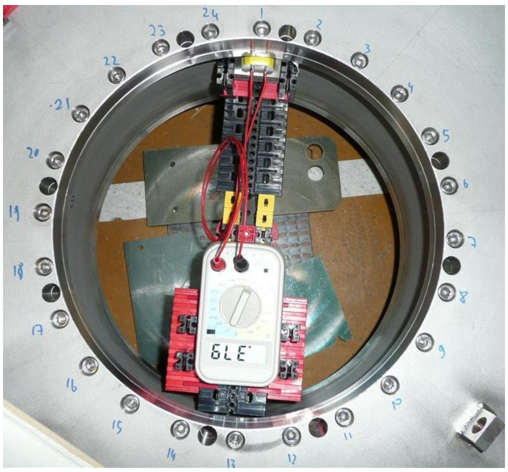

Figure 4: Buckling detection test setup.

Clockwise numbers from 1-24 (15 degree steps) were assigned to the screws of the tank lid to mark the angle. The inductance as function of angle and height in 15 mm steps was measured with an LCR meter at 220 Hz operating frequency. The radar plot of –(inductance) for selected heights (65, 110, 140 mm from below) corresponding approximately to the center height of the Gap core, the center core, and the short side (near lid) ground core, are shown in fig. 5. Buckling points go to the inside.

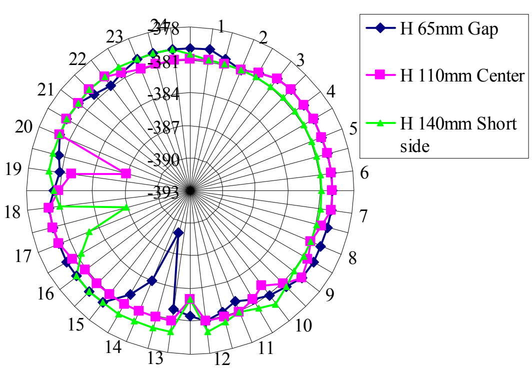

Figure 5: Radar plot of measured inductance [mH].

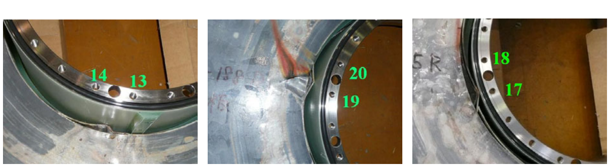

Figure 6: Gap core, center core, and ground side core.

Buckling is expected at pos. 13-14 for the Gap core, at pos. 19-20 for the center core, and at pos. 17-18 for the short side core. This is confirmed in the pictures in fig. 6.

The buckling position is consistent with fig. 2 (Gap core shown). Between pos. 12 and 13, an effect of tank welding is seen. The modified transformer is quite heavy (120 g), and the field distribution with the coil in the center and a gap to the left and right is not optimal. A Poisson 2D-simulation in fig. 7 indicates that the detectable distance can be improved with a U-shaped yoke.

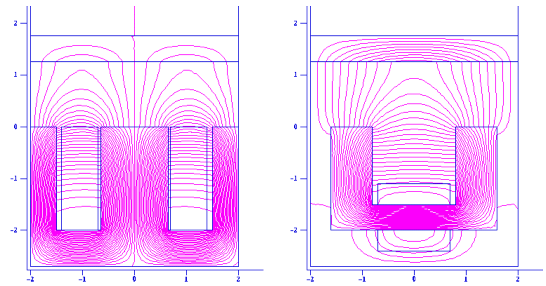

Figure 7: (left) transformer- and (right) U-Shape sensor

A comparable sensor was made by combining 2 yokes and coils from 24 V relays and tried in the buckling test setup, shown in fig. 8. The radar plot is in Fig. 9.

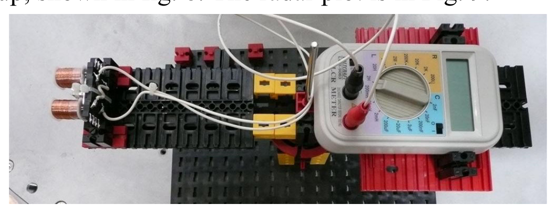

Figure 8: Buckling detection test with relay sensor.

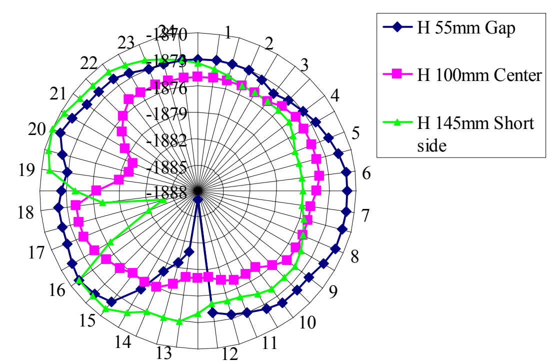

Figure 9: Radar plot of inductance [mH] with relay sensor.

The buckling positions in fig. 5 and fig. 9 are consistent, however the U-shape relay sensor results have a wider peak and show more details due to improved resolution. With this sensor, cavity 4, tank 2, which had shown sudden impedance reduction in June 2009 operation was measured with 15 mm steps for the distance from gap. The results suggested strong buckling around pos. 23 for the gap core. This cavity was opened on 2009/7/1, and buckling was confirmed. However, there might have been discharges, because molten core parts were found sticking to the SUS tank. Therefore the sensor did not detect the buckling, but found a Finemet piece on the SUS tank, which changed the magnetic environment.

3. RCS cavity buckling measurements

3.1 Relay yoke based sensors

To check all 11 cavities in the 2009 summer shutdown, in total 66 tanks with 198 cores, 3 relay based sensors with 61, 108 and 145 mm distance from gap to sensor pole center for gap-, center- and short side- core were prepared (fig. 10 left). Results for cavity 4 are in Table 1.

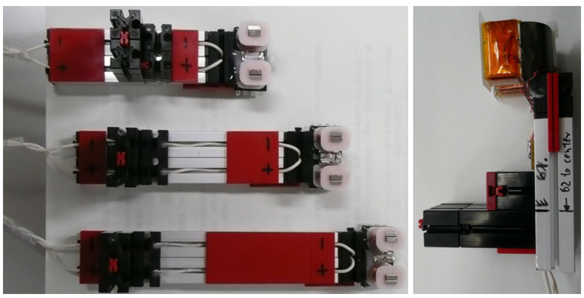

Fig. 10: Relay (left) and Finemet (right) based sensors.

Table 1: Buckling position overview for cavity 4, opened on 2009/7/1. "Exp" means expected.

	Tank 2	Tank 3	Tank 5	Tank 6
Gap core	Big Exp. 23 confirm	Small Exp. 2-3 Is: 13	Small Exp. No Is: 7-8	Big Exp. 20-21 confirm

At cavity 4, the big buckling of gap cores in tank 2 and 6 was detected at the right position. The small buckling of gap cores in tank 3 and 5 was not detected. At tank 5, center core, buckling was expected, but not found after cavity opening. Problems are that the inner tank cylinders are not completely round, but can have a radial variation in the order of ±1-2 mm. Also, we see an effect of welding. The cores can show a radial variation in ±1-2 mm order. Also we found that the coils move a little on the yoke during measurement, affecting the inductance value. Finally guiding the sensor at the inner tank circumference by hand is tough, especially in the upper position.

3.2 Finemet yoke based sensor

Although the moving coil issue was solved, the relay-based sensor performance is limited. Therefore a Finemet cut-core based sensor was prepared (fig. 10 right).

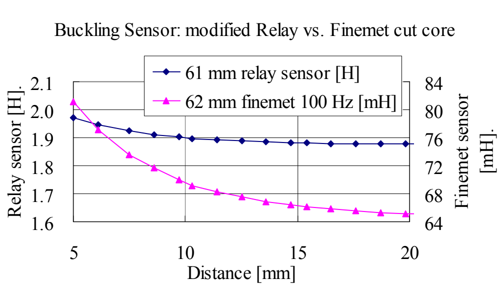

Figure 11: Comparing relay and Finemet based sensor.

Compared to the relay-based sensor the sensitivity defined as relative inductance change per position change is a factor of 4 better (fig. 11). Because the highest risk for buckling is at gap cores, only these positions were re-measured with this sensor.

In cavity 5, opened in July 2009, all 6 gap cores show buckling. The sensor did not detect the small buckling of gap cores in tanks 1, 3, 5, and 6. The bigger buckling in tank 4, and the buckling in tank 2 at position 5 (see fig. 12) was detected. The buckling position was checked by ruler after the tank was disassembled. Figure 12 shows that the angular position of the buckling by measurement with sensor and ruler is consistent.

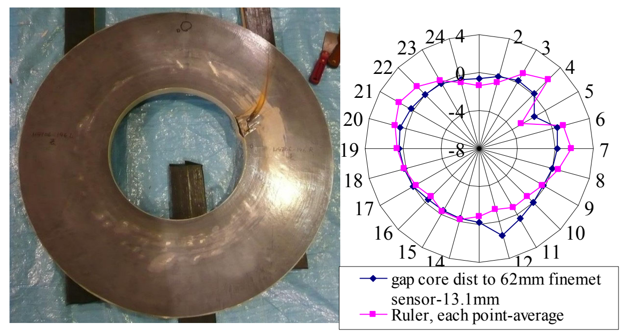

Figure 12: Gap core in tank 2 of cavity 5. Buckling indicated at position 5.

At the end of July 2009 cavity 3 was opened. The small buckling of gap cores in tank 1 and 5 could not be detected. The bigger buckling found at the center core in tank 1 was consistent with data taken by the relay based sensor, however the measured peak was so tiny that it is not regarded as buckling prediction.

4. Summary and outlook

We introduce a method to check MA core buckling in closed cavity tanks. If the buckling is relatively small, less than 1-2 mm, it is masked by geometry variations of tank and core. Bigger, more severe buckling of several mm, especially for gap side cores, can be detected. In the future, we try to improve the detection for example by optimizing the sensor and designing a rotating support.

References

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[3] Explanation of thickness measurement by Sanko-denshi: http://www.sanko-denshi.co.jp/items/ctm.html

[4] http://www.fischertechnik.de/en/index.aspx