*Transactions of the Korean Nuclear Society Autumn Meeting*
*Changwon, Korea, October 24-25, 2024*

# Development of a Composite Sensor Probe for Non-Destructive Evaluation of Rod Cluster Control Assembly

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***Keywords :*** RCCA, Composite sensor, Non-destructive test, Fretting wear, Circumferential cracking

## 1. Introduction

Several non-destructive inspection systems have been developed and used to inspect a Rod Cluster Control Assembly (RCCA), such as the encircling bobbin probe and the multi-array pancake coil probe system. The encircling bobbin probe uses an absolute or differential bobbin coil as a sensor by measuring the total magnetic flux density that changes around the control rod when there is a defect. The spatial resolution is limited to the circular area in the circumferential direction where the coil is wound, so the resolution is low, and the encircling bobbin probe has the disadvantage that it is difficult to detect cracks in the circumferential direction.

Therefore, the existing inspection system has limitations in detecting defect sizes and quantitative evaluation, and simultaneous inspection is not possible.

This study aims to develop a composite sensor that integrates three sensors: a bobbin coil, a multi-array pancake coil, and annular-array magnetic sensors (15 channel hall sensor) to detect various types of wear and crack defects in the RCCA at once.

A verification test of the present composite sensor probe is carried out on the artificial defects of the same RCCA control rod used in currently operating Westinghouse nuclear power plants in Korea.

## 2. Research Background

### *2.1 Non-Destructive Evaluation for RCCA*

The Rod Cluster Control Assembly (RCCA) is used to control the rapid reactivity change in the reactor core of Westinghouse PWR operating in Korea and to shut down the reactor in the event of an accident. As shown in Fig. 1, RCCA is usually composed of a bundle of 16 (14×14), 20 (16×16), or 24 (17×17) control rods tied by a structure of the spider. The control rod located in the core contains a neutron absorber composed of Ag (80%)-In (15%)-Cd (5%), and the outside is surrounded by a stainless steel cladding tube to prevent corrosion and cracking [1].

Therefore, fretting wear [2] may occur in the cladding tube by contact with the guide cards due to vibration caused by the coolant flow in the vessel. In addition, in order to control or stop the reactivity of the core, sliding wear as the RCCA descends or rises, as well as end plug welding by Intergranular Stress Corrosion Cracking (IGSCC) may occur [3].

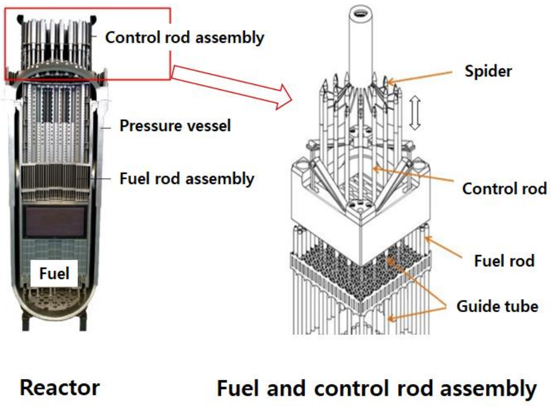



Fig. 1. Rod Cluster Control Assembly (RCCA) in the reactor vessel.

### *2.2 Status of the previous test methods for the RCCA*

In the existing technology (Fig. 2), different non-destructive testing methods are sequentially used for detecting the location and the type of the defects in the RCCA.

1) First, for the entire RCCA, an encircling bobbin coil probe is used to detect the average wear amount (volume defect) on the outer surface of the cladding tube and the abnormal signal from the welding region of the end tip.

At this time, if abnormal signs appear for volume defects, the following additional inspection is performed on the corresponding control rod.

2) Through the profilometry inspection, the amount of local wear in the circumferential direction of the cladding tube is measured to check whether the cladding tube is penetrated.

In addition, if an abnormal signal is detected in the welding region of the end tip as a result of the encircling bobbin coil test, the following inspection will be performed on the RCCA.

3) Through multi-array pancake coil inspection, cracking defects in the welding region are detected and the circumferential length of a crack is measured.

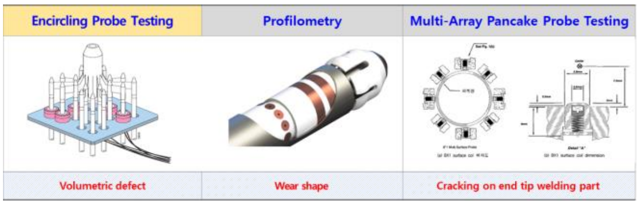



Fig. 2. Previous test methods for the inspection of RCCA.

In order to detect the defects by the existing RCCA inspection methodology, an abnormal indication is detected in the eddy current sensor by the bobbin coil probe, and this indication must be re-examined by replacing it with a multi-array pancake eddy current sensor. For this, additional work was required, such as lifting the inspection body from the nuclear fuel storage tank, replacing the eddy current sensor, and performing calibration.

Therefore, the existing technology inspects several control rods constituting the RCCA one by one, and the inspection speed is very slow due to the replacement of the probe/inspection equipment, which also leads to an increase in radiation exposure for the inspector.

In addition, while the bobbin probe is sensitive to detecting longitudinal defects of rod shape of the objects, there is a problem that is insensitive to detecting circumferential defects. Even in the case of multi-array pancake coils that measure circumferential cracks, spatial resolution is low, and only encircling bobbin coil inspection is performed for practical inspection.

In order to replace the existing RCCA inspection ECT sensors, a control rod assembly inspection device was designed to detect wear and crack defects in one inspection by arranging magnetic sensors in an annular array (patent document 0001), but to detect longitudinal defects and cracks in the end-tip welds, bobbin coil eddy current inspection or multi-array pancake coil inspection must be accompanied.

Although probes equipped with bobbin coils and annular-array magnetic sensors together were designed (patent documents 0002 and 0003), these technologies are limited to the probes that can penetrate the inside of the heat exchanger tubes and inspect them, and a separate probe is required for pancake coil inspection.

Therefore, in this study, to solve the existing problems, three types of bobbin coils, multi-array pancake coils, and annular-array magnetic sensors were combined in one probe so that these inspection methods could be performed simultaneously, and a rod bunddle-level inspection method was developed instead of the current one-rod-level inspection.

## 3. Development of Composite Sensor Probe

### *3.1 Configuration of the composite sensor probe*

The Rod Cluster Control Assembly (RCCA) is used

In this study, we developed a composite sensor that integrates three sensors: a bobbin coil, a multi-array pancake coil, and annular-array magnetic sensors (15 channel hall sensor). Figure 3 shows them composed of one probe (composite sensor probe) [4]. A pancake coil is installed at the front of the probe head, magnetic sensors in an annular arrangement in the middle, and a bobbin coil is installed at the last. The annular-array magnetic sensors are surrounded by the exciting coil that generates an electromagnetic field around the defect.

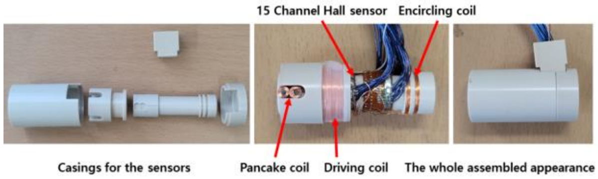
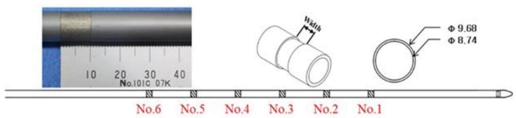


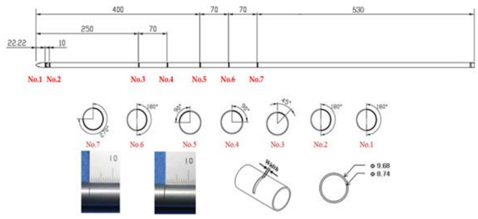

Fig. 3. Composite sensor probe integrated with 3 types of sensors.

### *3.2 Multiple inspection frequencies optimized for each sensor type*

In order to test this composite sensor inspection device, defect specimens that artificially simulate the RCCA defects was manufactured. As an example, various types of defect simulation specimens were manufactured as shown in Fig. 4, and the detection results of the defect signals are illustrated in Fig. 5 through testing of the composite sensor inspection device.




(a) Short-Circumferential Groove (SCG)



(b) Partial-Circumferential Crack (PCC)

Fig. 4. Artificial test specimens for RCCA.

There are three types of sensors in the composite sensor probe, and Fig. 5 shows that the inspection frequency suitable for the annular-array magnetic sensors and the pancake coil is different. In Fig. 5, it is easy to detect a defect signal in a relatively low frequency (10 kHz) range for an annular-array magnetic sensor, while the detection signal is clearer in a relatively high frequency (150 kHz) range for a pancake coil.

Therefore, there are multiple inspection frequency generators to input inspection frequencies optimized for three different sensors in the composite sensor probe. The defects are detected by separate signals with frequencies optimized for each different type of sensors.

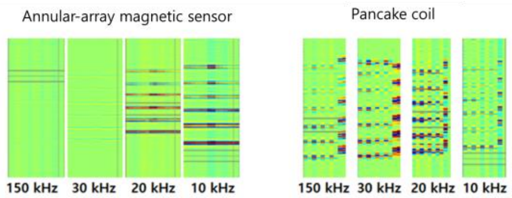
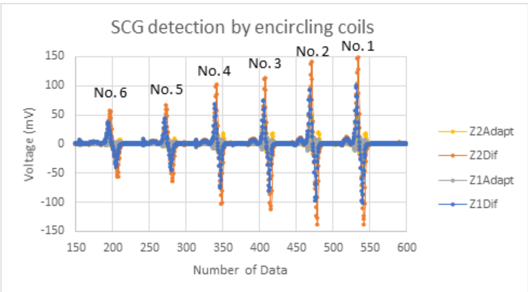


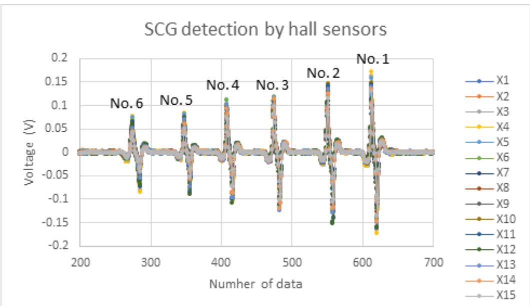

Fig. 5. Comparison of sensor signals according to input frequency change.

### *3.3 Example of test results*

Figure 6 shows the test results for the case of SCG test specimen (as shown in Fig. 4) using the encircling bobbin coil and the annular-array magnetic sensor (15 channel hall sensor). It shows that defect measurement is possible in all SCG regions with 10% or more of wall thickness, and the presence or absence of defect in the test region could be confirmed.




(a) Encircling bobbin coil




(b) Annular-array magnetic sensor

Fig. 6. Measurement results for SCG.

## 4. Conclusions

In this study three types of bobbin coils, multi-array pancake coils, and annular magnetic sensors are integrated into a single probe to detect various types of wear and crack defects in the RCCA at once.

In addition, using this inspection method, the inspection time can be drastically shortened by performing the inspection by a rod bundle rather than by one rod.

The effects of the present technology are specifically described as follows.

1. Through the bobbin coil sensor constituting the composite sensor, it is possible to easily detect longitudinal defects of rod shape objects, and it is possible to identify the locations where volumetric defects occur and provide a reference point for determining signals of other sensors.
2. The annular-array magnetic sensor constituting the composite sensor can compensate for the shortcomings of spatial resolution of the existing multi-array pancakes and facilitate the detection of cracks in the circumferential direction.
3. Through the pancake coil constituting the composite sensor, it is possible to usefully detect cracks in the end tip welds of the control rod.
4. Inspection frequencies optimized for each of the three different sensors constituting the composite sensor will simultaneously input so that each sensor may optimally detect defects in the future work.

## ACKNOWLEDGMENTS

This work was supported by the Technology development Program (No. RS-2023-00225436) funded by the Ministry of SMEs and Startups (MSS, Korea).

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