# Development and Performance Test of Electro-Magnetic Acoustic Transducer for Reactor Vessel Inspection in PGSFR

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## 1. Introduction

The integrity of the reactor vessel is one of most important issues for safe and reliable operation of a Sodium-cooled Fast Reactor (SFR). To evaluate the integrity of the reactor vessel in PGSFR which is a generation IV nuclear reactor that has been developing at KAERI, the inspection strategy including the volumetric examination for circumferential welds in addition to the continuous monitoring and visual examination (VTM-2) has been established. However, the volumetric examination for the reactor vessel in PGSFR is quite difficult because of the limitation of accessibility and the high temperature condition. There are only 200 mm gap between the reactor vessel and the containment vessel and the temperature of the reactor vessel must not be lower than 200˚C even during the shutdown period. Moreover, the liquid couplant, which is necessary for the contact ultrasonic examination, cannot be employed for the inspection to prevent sodium-water reaction. Therefore, there has been a need for the development of the volumetric inspection sensor which is as small as to be installable in the narrow gap and can be operated without direct contact to the reactor vessel at high temperature.

In this work, a Periodic Permanent Magnet Electro-Magnetic Acoustic Transducer (PPM EMAT) [1, 2] which can be applied to non-contact volumetric examinations at high temperature was developed for in-service inspection of the reactor vessel in PGSFR. And, as the first step for the validity demonstration, the performance of the developed PPM EMAT was investigated through several tests at room temperature.

## 2. Developed PPM EMAT

Figure 1 shows the developed PPM EMAT which has periodically arranged high temperature permanent magnets. The distance ($a$) between two adjacent permanent magnets can be determined by the following equation,

$$a = \frac{c}{2 f \sin\theta} \tag{1}$$

where $c$ is the shear wave velocity in the medium, $f$ is the excitation frequency and $\theta$ is the incident angle (see Fig. 2). From equation (1), one can expect that the incident angle of the ultrasonic wave generated by the developed PPM EMAT can be controlled by adjusting the excitation frequency for a given distance $a$. Since more than two angle beams should be applied for the ultrasonic examination according to the ASME code rules [3], 45˚ and 60 ˚ incident angles were selected for the developed PPM EMAT. To radiate the ultrasonic waves at 45˚ and 60˚ for the selected distance $a$ = 3.13 mm, excitation frequencies were determined to be 700 kHz and 572 kHz, respectively.

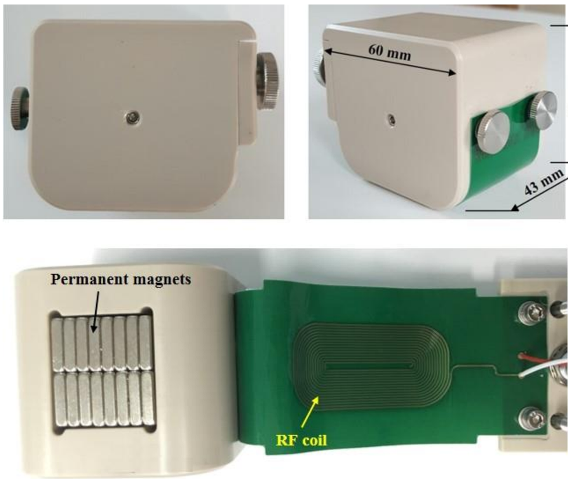


Fig. 1. Developed PPM EMAT.

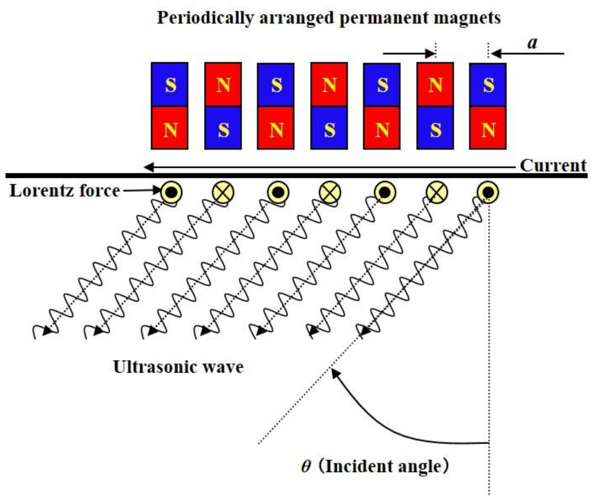


Fig. 2. Working principle of PPM EMAT.

## 3. Performance Tests

To investigate the performance of the developed PPM EMAT, following tests were conducted.

### *3.1 Radiation Pattern Measurement*

The radiation pattern was measured to investigate the incident angle and beam width of the ultrasonic wave generated by the developed PPM EMAT. A half cylinder made of aluminum which has the similar shear wave velocity to that in the PGSFR reactor vessel was employed for the test and radiation patterns in $r$-$\theta$ and $r$-$\gamma$ planes were measured (see Fig. 3).

Figures 3 and 4 show radiation patterns of the developed PPM EMAT measured at 572 kHz and 700 kHz, respectively. The results show that incident angles of ultrasonic waves generated by the developed PPM EMAT have good agreements with those calculated from equation (1). Furthermore, one can also see that the ultrasonic wave generated by the developed PPM EMAT has narrow radiation patterns which might promise more accurate inspection results.

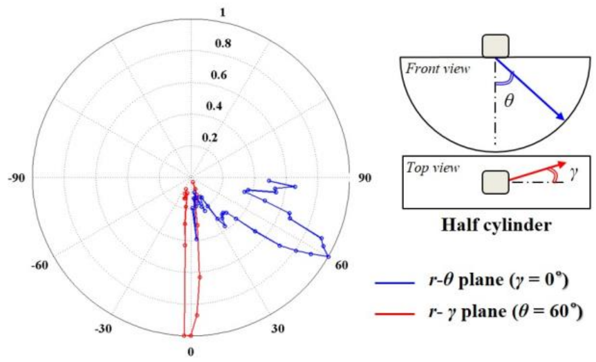


Fig. 3. Radiation patterns of the developed PPM EMAT measured at 572 kHz.

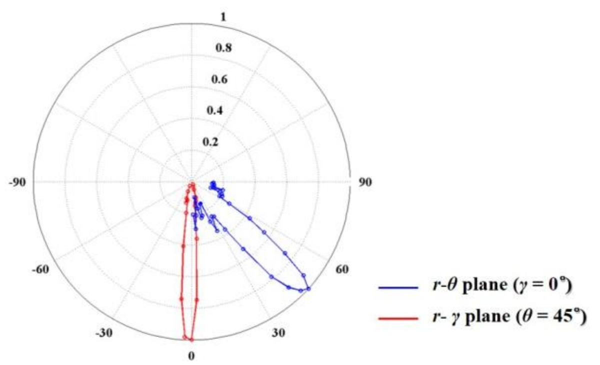


Fig. 4. Radiation patterns of the developed PPM EMAT measured at 700 kHz.

### *3.2 Signal-to-Noise Ratio Measurement*

For more accurate inspection, the inspection sensor should ensure the relatively low noise level compared with any meaningful signal along with the narrow radiation pattern. To investigate this property, the Signal-to-Noise Ratio (SNR) of the developed PPM EMAT was measured.

Figure 5 shows the measured SNR of the developed PPM EMAT. Since the developed PPM EMAT should be applied to the non-contact inspection, the SNR was measured with varying the lift-off from the test medium (stainless steel block) up to 1 mm. From the figure, it can be seen that SNR decreases as the lift-off increases. This is because that magnitudes of magnetic field and eddy current in the test medium decrease as the lift-off increases. However, one can clearly see that the developed PPM EMAT has SNR of over 15dB up to 0.7 mm lift-off.

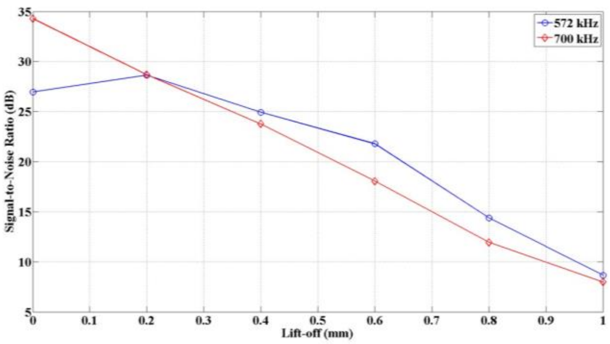


Fig. 5. Measured SNR of the developed PPM EMAT.

### *3.3 Defect Detection Test*

The defect detection test was conducted to evaluate the detectability of the developed PPM EMAT. Two PPM EMATs, one for a transmitter and the other for a receiver, were installed on a 50 mm thick stainless steel (STS316L) block having a slit (width = 0.5 mm, length = 25 mm and depth = 2.5 mm) fabricated at its bottom. Tests were then conducted with lifting up the EMATs from the test block up to 1 mm with a 0.2 mm interval to investigate the effect of the lift-off on the detectability of the developed PPM EMAT.

Test results obtained at 572 kHz (60˚ incidence) and 700 kHz (45˚ incidence) are shown in Figs. 6 and 7, respectively. The results show that the developed PPM EMAT can detect the given defect of which the depth is 5% of the wall thickness up to 0.2 mm lift-off even at 700 kHz. From these results, one can expect that the developed PPM EMAT can be effectively applied to the non-contact inspection of the PGSFR reactor vessel.

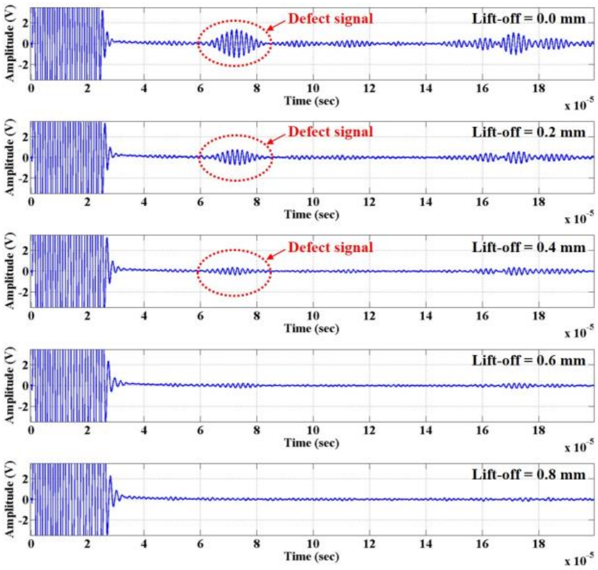


Fig. 6. Defect detection test results obtained at 572 kHz.

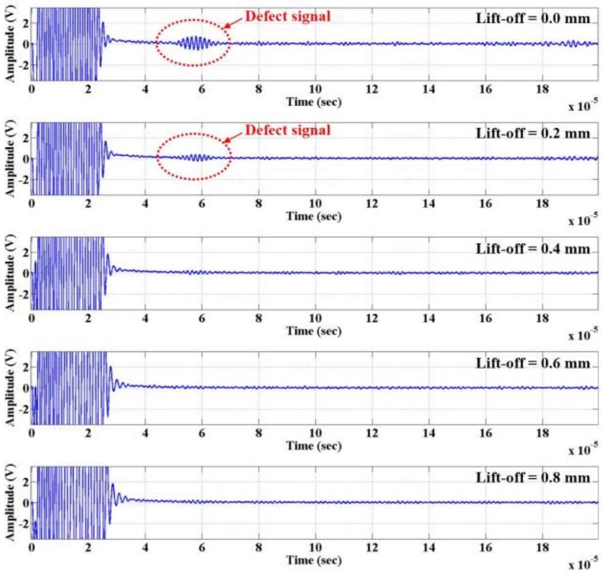


Fig. 7. Defect detection test results obtained at 700 kHz.

## 4. Conclusions

In this work, the PPM EMAT having periodically arranged high temperature permanent magnets was developed for the reactor vessel inspection in PGSFR and its performance was experimentally investigated at room temperature. Through several performance tests, it was demonstrated that the developed PPM EMAT had the narrow radiation pattern and SNR of over 15dB up to 0.7 mm lift-off. Furthermore, it was also verified that the small defect of which the depth was 5% of the wall thickness could be detected by the developed PPM EMAT up to 0.2 mm lift-off. And as the next step for the validity demonstration of the developed PPM EMAT, further investigations on its performance at high temperature over 200˚C will be followed in near future.

## Acknowledgement

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## REFERENCES

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