Discrimination between Carbon Steel Loose Part and Magnetite Scale on Secondary Side of Steam Generator Tubes from MRPC Probe Eddy Current Signals

Deok-Hyun Lee [a*], Myung-Sik Choi [a], Se-Beom Oh [a], and Kyung-Mo Kim [a]
[a]*Nuclear Materials Safety Research Div., Korea Atomic Energy Research Institute, Daedeok-daero 989 Beon-gil, Yuseong-gu, Daejeon, 34057, Korea*
[*]*Corresponding author: dhlee1@kaeri.re.kr*

1. Introduction

The integrity of steam generator tubes in pressurized water reactors are examined periodically by eddy current test methods. The full length of steam generator tubes are screened by using bobbin coil probe and local regions of interest are examined precisely by using motorized rotating pancake coil (MRPC) probe. The alloy 600 tubing material have been replaced with more corrosion resistant alloy 690 tubing material in steam generators of domestic nuclear power plants and degradation mode of mechanical damage other than corrosion are becoming prevalent. Especially, recent domestic and foreign operation experiences show that tube wears by loose parts on the secondary side of steam generators are challenging tube integrity, which lead to leakage of primary coolant and unscheduled shutdown of power plant. Therefore, earlier detection and subsequent retrieval of loose parts during plant outage for maintenance are becoming more important for a preventive measure [1]. On the secondary side of steam generator, corrosion products (magnetite) of carbon steel components deposit locally on the surfaces of tubes and supports, or pile up on the top of tubesheet, and form consolidated bulk shapes similar to solid loose parts. This implies that the eddy current signal from risky loose part could be mistaken for that from harmless corrosion product. In this work, the eddy current signals of MRPC probe from carbon steel loose part and magnetite scale are characterized using steam generator tube mock-up in order that a loose part of concern could be discriminated reliably from magnetite scales in eddy current signal analysis

2. Methods and Results

2.1 Manufacturing of Mock-up

A carbon steel loose part and magnetite scales of two types, flake and adhesive, were manufactured so that they had a bulk shape with same volumetric dimension [2]. The loose part and scales were located on the outer surfaces of alloy 690 steam generator tubes as shown in Fig. 1. The flake type scale simulates the condition where the hard magnetite scale deposited on the tube outer surface has been fallen off but in contact with the tube, and the adhesive type scale simulates the condition where the hard magnetite scale has been deposited tight on the tube outer surface.

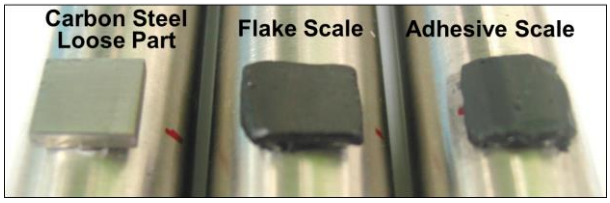

Fig. 1. Mock-ups for carbon steel loose part, flake and adhesive type magnetite scales on steam generator tubes.

2.2 Eddy Current Test

The mock-up tubes were inspected by using a ZETEC MIZ-70 eddy current data acquisition system with a ZRPS-DH3-E00.610 MRPC probe. Multiple test frequencies of 300, 150, 100, 50 and 20 kHz were chosen considering the penetration depth of eddy current field, and the signals from the pancake coil in each test frequency were analyzed. The signals from carbon steel mock-up in each test frequency were calibrated to have a phase angle of 90 degrees and the relative changes of the signal phase angles from scale mock-ups were compared.

2.3 Results and Discussion

Fig. 2 shows the changes of MRPC probe pancake coil signals with test frequency for carbon steel loose part mock-up tube. The amplitude of signal increased drastically with the decrease of test frequency, and the phase angles decreased with lower test frequency.

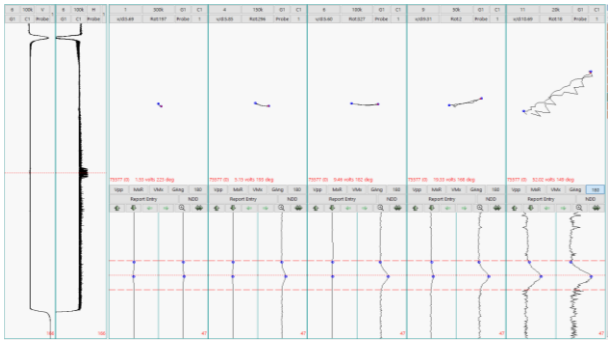

Fig. 2. MRPC probe pancake coil eddy current signal from carbon steel loose part mock-up.

The changes of eddy current signals from magnetite scale mock-ups showed a similar trend with that of carbon steel. Thus, for the obvious and quantitative discriminations of signals, the carbon steel signals in each test frequency were adjusted to a phase angle of 90 degrees as shown in Fig. 3, and the changes of the relative signal phase angles from magnetite scale mock-ups were compared directly.

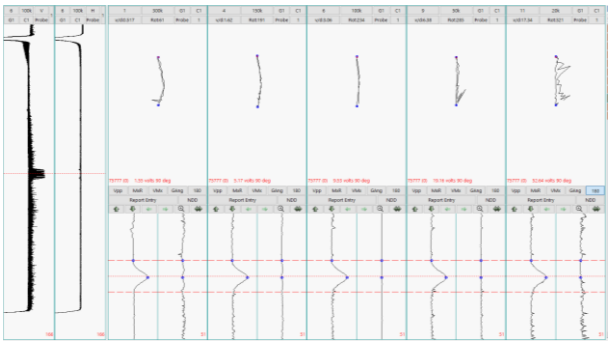

Fig. 3. MRPC probe pancake coil eddy current signal from carbon steel loose part mock-up, phase angles adjusted at 90°.

Fig. 4 shows the changes of eddy current signals with test frequency from the flake type scale mock-up tube. At all frequencies, the phase angles had the values less than 90 degrees, and a similar trend was observed for the adhesive type scale mock-up tube as shown in Fig. 5.

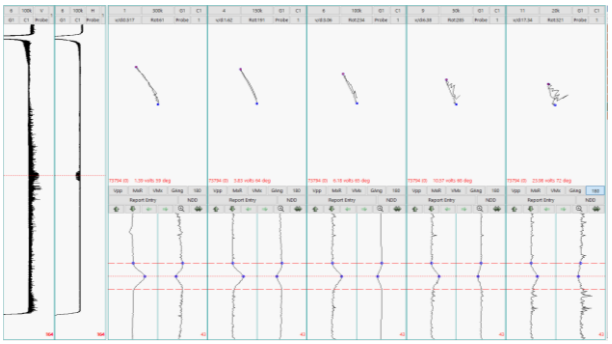

Fig. 4. MRPC probe pancake coil eddy current signal from flake type magnetite scale mock-up.

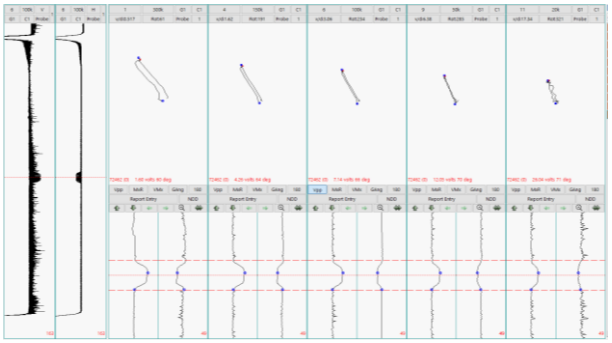

Fig. 5. MRPC probe pancake coil eddy current signal from adhesive type magnetite scale mock-up.

The values of signal phase angle with test frequency were plotted in Fig.6 for a quantitative comparison.

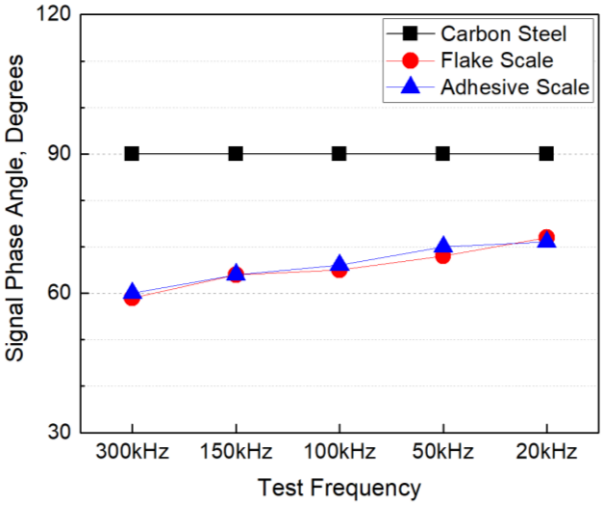

Fig. 6. Changes of relative phase angle in MRPC probe pancake coil eddy current signal with test frequency for carbon steel loose part, flake and adhesive magnetite scales on steam generator tubes.

The phase angles of pancake coil eddy current signals from magnetite scales were consistently low by 20~30 degrees at all test frequencies, as compared with those from carbon steel loose part. The contact condition of magnetite scales on the tube surface had little effect on the phase angle of eddy current signal.

3. Conclusions

A carbon steel loose part and magnetite scales on the surfaces of steam generator tubes could be distinguished by the phase angle of MRPC probe pancake coil signal. The phase angles from magnetite scales showed lower values by 20~30 degrees than those from carbon steel at all test frequency conditions. Thus, a foreign object of carbon steel would be discriminated from magnetite scales by a careful field analysis of phase angles.

ACKNOWLEDGEMENTS

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