Characteristics of Eddy Current Signals from Magnetite Scale and Carbon Steel Loose Part on Secondary Side of Steam Generator Tubes

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1. Introduction

The integrity of steam generator tubes in pressurized water reactors are periodically inspected by eddy current test methods. The dominant degradation mode was corrosion for steam generators with alloy 600 tubing materials. The new or replaced steam generators have more corrosion resistant tubing materials of alloy 690 and degradation modes other than corrosion are becoming prevalent. In addition to wears due to the contacts of tube to support structure and the tube to tube, wears by foreign objects on the secondary side of steam generators challenge tube integrity which can lead to primary to secondary leakage of coolant and unexpected outage of power plant. Therefore, earlier detection of foreign objects by eddy current technique is becoming more important for a preventive measure [1]. On the secondary side of steam generator, corrosion products of carbon steel components (magnetite) are deposited on the surfaces of tubes and supports, or piled up on the top of tubesheet, and thus a foreign object of concern should be discriminated reliably from magnetite scales in eddy current signal analysis. In this work, the characteristics of eddy current signals from magnetite scale and carbon steel loose part are investigated using steam generator tube mock-up, and signal analysis techniques for the discrimination are discussed.

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 the same volumetric dimension of width 10mm, length 10mm and thickness 2mm. The carbon steel loose part was machined from SA-106 Gr.B pipe, and the scales were compacted by mixing magnetite powder with small amount of curing glue. Considering the size of particles present in steam generator systems ranges from 0.1 to 10 ㎛ [2], the magnetite power with particle size less than 5 ㎛ was used. The loose part and scales were attached on the outer surfaces of alloy 690 steam generator tubes as shown in Fig. 1. The flake scale mock-up simulates the condition where the hard scale deposited on the tube outer surface has been fallen off but in contact with the tube, and the adhesive scale mock-up simulates the condition where the hard scale has been deposited tight on the tube outer surface.

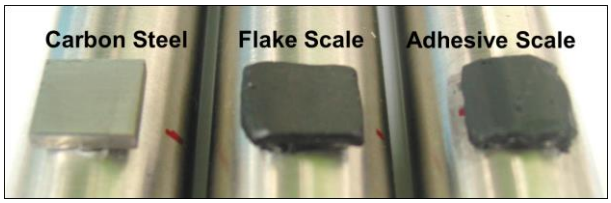

Fig. 1. Mock-ups for carbon steel loose part, flake and adhesive magnetite scales on steam generator tubes.

2.2 Eddy Current Test

The mock-up tubes were inspected with a ZETEC M-ULC bobbin coil probe and MIZ-70 eddy current data acquisition system. Multiple test frequencies of 300, 150, 100, 50 and 20 kHz were applied considering the penetration depth of eddy current field, and the signals from the absolute mode in each test frequency were analyzed.

2.3 Results and Discussion

Fig. 2 shows the changes of eddy current signals with test frequency for each mock-up tube. The amplitude of signal increased drastically with the decrease of test frequency. For visual comparison of Lissajous graphs, the span at the test frequency of 100, 50 and 20 kHz were zoomed down to 1/2, 1/8 and 1/16, respectively.

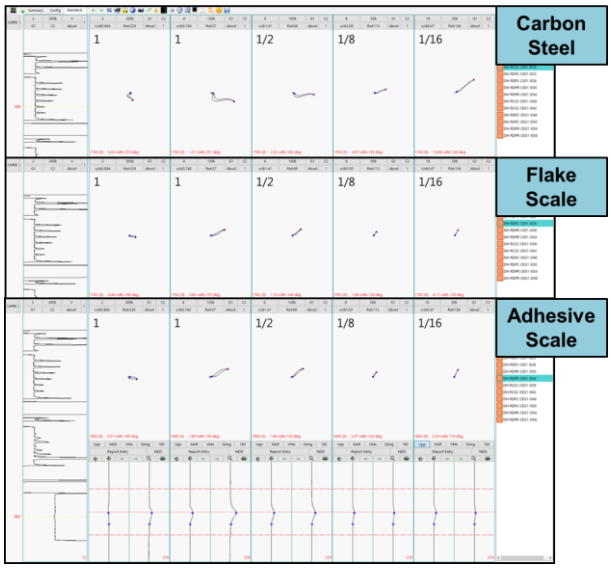

Fig. 2. Eddy current signals from carbon steel loose part, flake and adhesive magnetite scales on steam generator tubes.

At the high test frequency of 300 kHz, the signals of interest were too small to be detected, reflecting the short penetration depth of eddy current field. However, the signals below 150 kHz showed a meaningful trend in the amplitude and phase angle for the carbon steel and scales of interest. Therefore, the values of signal amplitude and phase angle with test frequency were plotted as shown in Fig. 3.

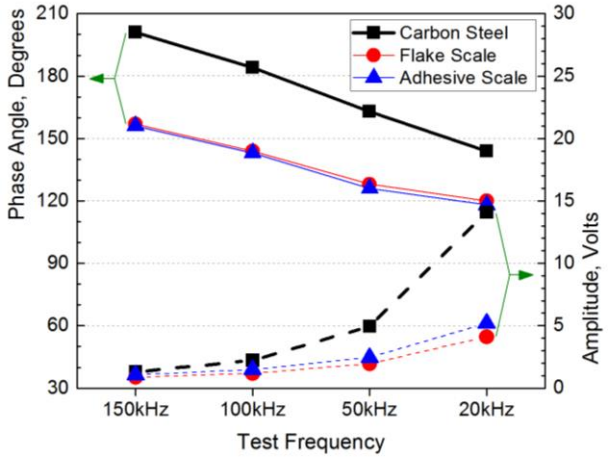

Fig. 3. Changes of eddy current signal amplitude and phase angle with test frequency for carbon steel loose part, flake and adhesive magnetite scales on steam generator tubes.

The amplitude of signal from carbon steel loose part increased remarkably with the decrease of test frequency from 150 to 20 kHz, but those from magnetite scales showed gradual increases. Also, the phase angle of signal from carbon steel loose part ranged from about 200 to 150 degrees, and those from magnetite scales showed relatively smaller values ranged from about 150 to 120 degrees. The flake and adhesive scale showed little difference in amplitude and phase angle values with the test frequency, but just the adhesive scale showed a slightly larger amplitude and smaller phase angle value, compared with the flake scale.

In order to simulate the condition of loose part or scales located on the tube within the intersection of support structure, the mock-up tubes were assembled with an eggcrate tube support of type 409 stainless steel, and the characteristics of eddy current signal were examined. Very large eddy current signals (~60 volts at 20 kHz) introduced by the support masked a much small signal from loose part and scales, and made it hard to detect the signals from loose part or scales. Only the detection of carbon steel loose part and scale was restrictively possible, depending upon their relative location within the geometry of support structure. Fig. 4 shows an example where the carbon steel loose part and scales are located at a quarter (1/4) of lengthwise span of support. The red lines in graphs show the signal components from loose part and scales, and these results imply that a careful scrutiny into the minor change of Lissajous shape is required to detect the loose part and scales within the support.

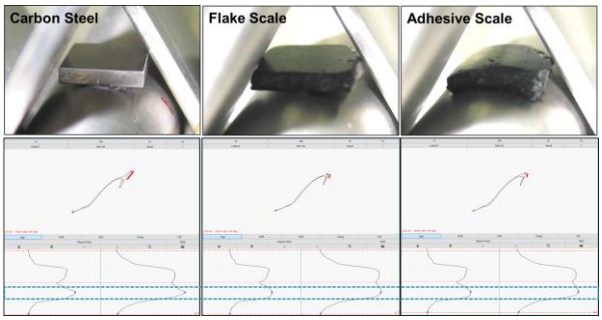

Fig. 4. Eddy current signals at 20 kHz for carbon steel loose part, flake and adhesive magnetite scales located at a quarter of lengthwise span of eggcrate support.

3. Conclusions

A carbon steel loose part and magnetite scales on the free span of the steam generator tubes showed different characteristics in the changes of eddy current signal amplitude and the ranges of signal phase angle with test frequency of bobbin coil probe. Thus, a foreign object of carbon steel would be discriminated from magnetite scales by a careful signal analysis. However, only the detection of carbon steel loose part or scale was restrictively possible within the intersection of support structure, depending upon their relative location.

ACKNOWLEDGEMENTS

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