Simulations and Measurements of Sodium Effect on the ECT Signal for SG Tubes of FBR

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The present paper estimates using numerical simulations the eddy current effect of the sodium layer located outside of steam generator tubes of fast breeder reactors. Variations in the outside tube defect signal are computed by finite element simulations. The numerical model of sodium layer is based on the experimental determination of the sodium layer using a test tank sodium experiment.

Keywords: Steam Generator, Fast Breeder Reactor, Eddy Current, Sodium

1. Introduction

In fast breeder reactors with sodium coolant, the integrity of steam generator (SG) tubes plays an important role in the reactor safety. These tubes are bundled in a cylindrical vessel with sodium located outside of the tube and water flowing inside of it. Due to the high chemical reactivity of sodium with water, penetration of SG tubes wall have to be avoided by all means and therefore, earlier defect detection before wall penetration during the in-service inspection (ISI) is required to increase the safety of SG tube component. Eddy current technique (ECT) is used to inspect the SG tubes [1], after sodium from the vessel is drained and the SG tubes are cooled down to the room temperature. After draining and cooling, there is a thin sodium layer adhering to the outer surface of SG tubes. Due to the high electrical conductivity of sodium layer, the eddy current signal will be modified. In the present paper, the authors investigate the effect of sodium on several types of outer tube defects with variable depths and widths using numerical finite element simulations. The numerical model of sodium is build after validation of experimental results using a test sodium tank experiment. The phase-amplitude diagram is constructed for defects with depths up to half of the tube wall thickness and 15 mm wide.

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2. Results from a Test Sodium Tank Experiment

A small test sodium cylindrical tank, 2.2 m high and 0.6 m in diameter was filled with sodium at 500 degrees (see Fig. 1).

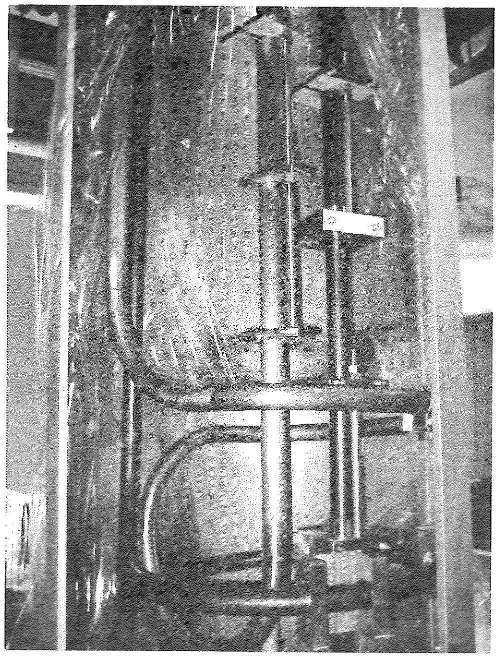

Fig 1. View of the test sodium tank

Two SG tubes, one made of austenitic stainless steel (the Superheater tube) and the other made of Cr-Mo alloy (the Evaporator tube), were introduced in the tank and kept for more than two hours, in order to have a good wetting phenomenon (see Fig 2). After draining and cooling of the sodium from tank, the eddy current effect from an artificial defect (outer groove, 10 mm wide and 20% from tube wall thickness) was measured in order to evaluate the sodium effect. In addition, after performing the experimental measurements, the sodium deposits located on the outside tube surface were measured and weighted to evaluate the sizes of sodium layer thickness. It was found out that for the Superheater tube the sodium layer thickness is between 2 and 6 μm, while inside of defect the sodium deposit thickness was 40 μm. The thickness of sodium deposit was greater for the evaporator tubes (up to 50 μm) with a 50 μm sodium layer located inside of the defect.

A view of the sodium deposits on the evaporator and Superheater tubes are shown in Fig. 3 and 4.

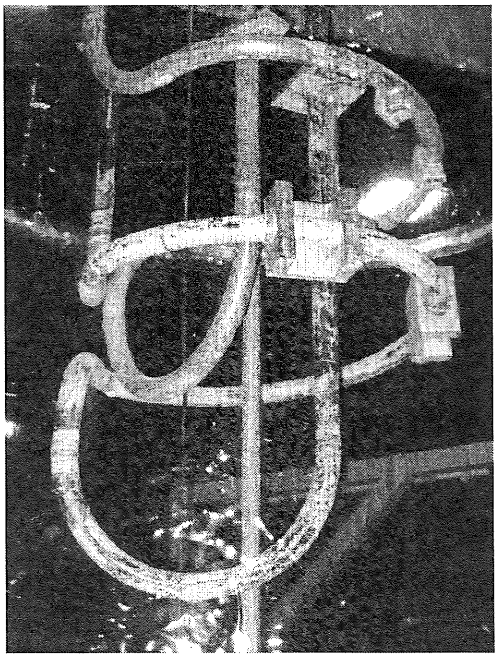

Fig 2. View of adhesion of sodium to the SG tubes

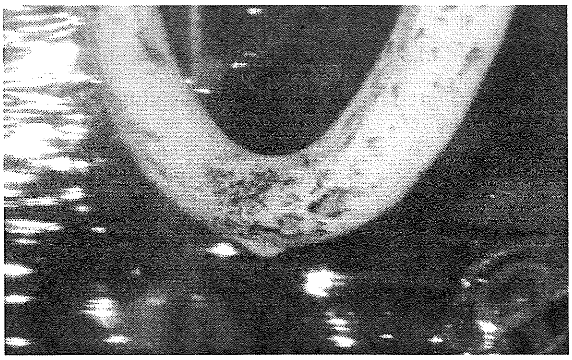

Fig 3. Sodium structures on the Evaporator tubes

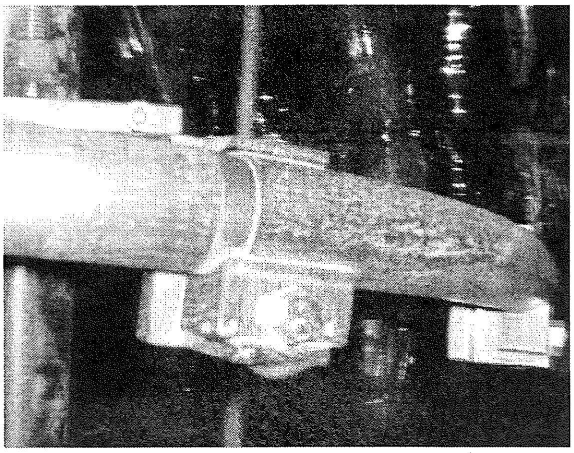

Fig 4. Sodium structures on the Superheater tubes near the helical support

3 Numerical Model to Simulate Sodium ECT Signal

Numerical simulations were conducted using a two-dimensional axisymmetric finite element code [2] which can model the electromagnetic interaction between electromagnetic field produced by the ECT coils system and ferromagnetic/austenitic SG steel tube and calculate the electromagnetic disturbance due to a defect in the tube.

The presence of sodium layer on the outer tube surface modifies the electromagnetic signal during eddy current measurements due to the sodium high electrical conductivity (23.8x10^6 S/m). Based on the experimental measurements of the sodium layer thickness it was constructed a model of the ECT detection system that was validated with the outer groove signal (see Fig 5-7) in both absence or presence of sodium and under a tube SP [3].

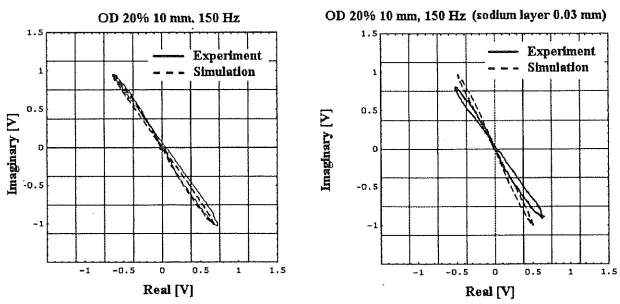

Fig 5. Simulations and measurements of ECT signal for outer groove evaporator

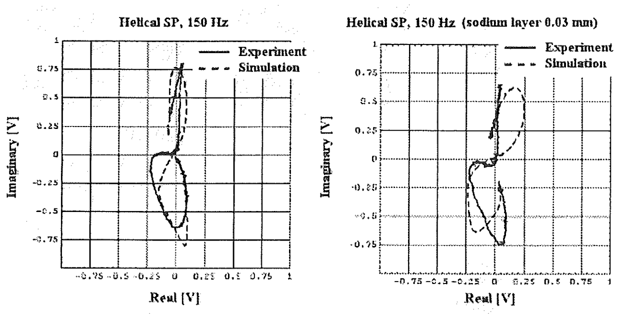

Fig 6. Simulations and measurements of ECT signal for helical SP of evaporator

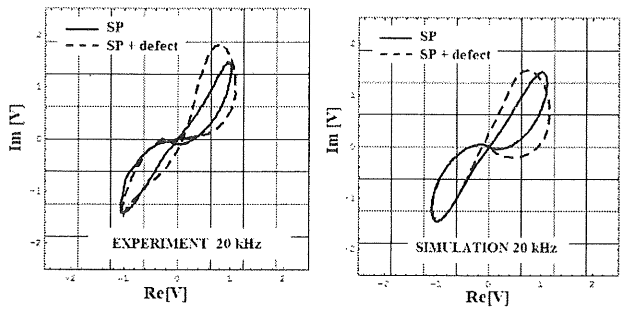

Fig 7. Simulations and measurements of ECT signal for outer groove under straight SP of Superheater in the presence of sodium layer

In a previous paper was also confirmed by matching numerical simulations with experimental measurements that the sodium layer thickness adhering to the Evaporator tubes is 50 μm [4]. However, it was not evaluated the thickness of the sodium layer for Superheater tubes.

In the present analysis, the numerical model was relatively well confirmed by the experimental measurements in various situations for both Superheater and Evaporator, using axisymmetric FEM simulations, as: a) defect on the free tube area; b) defect under helical or straight tube SP ; c) absence or presence of a thin sodium layer.

3. Estimation of phase-amplitude defect signal due to variation of sodium layer thickness

Despite the small values of the sodium layer thickness, their variations can influence the defect signal. However, experimental measurements can be performed only in a limited number of cases, raising the question of the extrapolation of the results to other types of defects with variable depths and widths.

Based on the numerical electromagnetic model validated in both situations with sodium/without sodium layer, it were performed finite element simulations for outer circumferential defects with depths up to 50% from the tube wall thickness and length ranging from 0.25 to 15 mm.

In the model it was consider that the thickness of sodium layer can varies between 20 and 50 μm for the evaporator tubes and between 2 and 6 μm for the Superheater tubes respectively. Due to the variable sodium layer thickness, the signal from an outer defect on the SG tube will change in amplitude and phase, depending also as how much sodium will fill the defect.

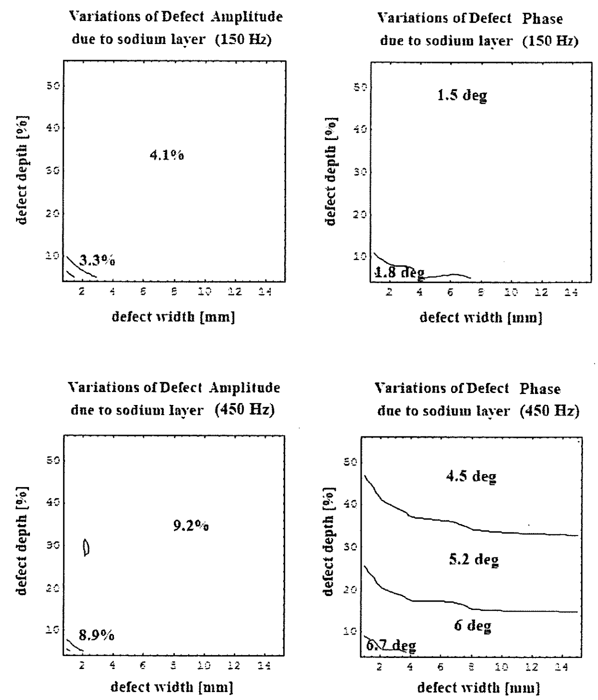

Fig 8. Amplitude and phase of defect signal in evaporator tube covered by a thin 20-50 μm sodium layer

In Fig. 8 is shown the variations in the defect signal amplitude and phase when the sodium layer thickness adhering to Evaporator change from 20 to 50 μm. The error in the phase and amplitude signal increases as the frequency of excitation system is increasing from 150 to 450 Hz. It can also be observed that there is a small variation in both amplitude and phase change for different types of defect, so it can be assumed that phase and amplitude change constantly for all defects.

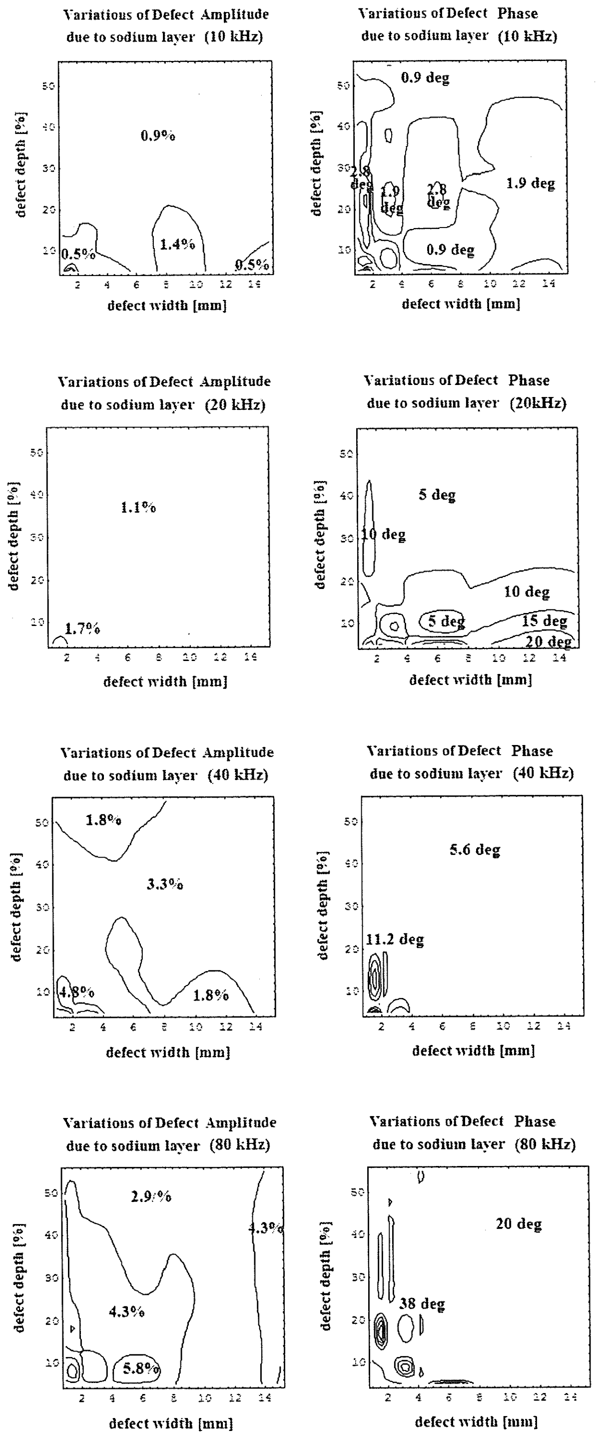

Fig 9. Amplitude and phase of defect signal in Superheater tube covered by a thin 2-6 μm sodium layer

Fig. 9 shows the variation in phase and amplitude of signal for defects in Superheater tubes at 10, 20, 40 and 80 kHz frequencies. The phase of the defect signal is more sensitive to the variations in the sodium layer thickness at higher frequencies.

5. Conclusion

Numerical ECT simulations of the defect signal in the absence/presence of sodium layer on the outer SG tube surface were confirmed by the experiment measurements in various situations, validating the numerical electromagnetic model of problem. The ECT signal from outer defects change due variations in sodium layer thickness. It was found, using FEM simulations, that phase of signal in Superheater tubes can change between 5 and 25 degrees for various sodium layer thicknesses. The amplitude and phase of defects in Evaporator tubes remain relatively constant for all class of defects and increase at higher inspection frequency.

References

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