Prototype probe development for Liquid Injection Shutdown System Tube Gap Detection by Remote Field Pulsed Eddy current technique

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Abstract: In 540 MWe PHWR reactors, there are horizontally placed Liquid Injection Shutdown System (LISS) tubes for injecting poison into the moderator to clamp down the nuclear power under trip conditions. The gap between the coolant channel and the LISS tube is critical. Electromagnetic technique only appears to be feasible for the inspection. Remote Pulsed Eddy Current technique is proposed for the measurement. The remote field originates from the exciter coil kept in the bore of the pressure tube. The search coil is used at this location to pickup the prominent Remote Field. The pick up signal is further digitally signal processed to gather information on the gap between LISS tube and calandria tube. COMSOL software was used to map the poynting vector to gauge the re-entry location of the remote field. Further it was also simulated to know the order of the voltage to be picked by the pick up coil.

Keywords: PHWR, Remote Field, Pulsed Eddy Current, Poynting vector

1. Introduction

Pressurised Heavy Water Reactors play a prominent role in contributing power for the Nuclear Energy Programme in India. In 540 MWe PHWR reactors, there are horizontally placed Liquid Injection Shutdown System (LISS) tubes for injecting poison into the moderator to clamp down the nuclear power under trip conditions. The schematic of reactor core is shown in figure 1. The Horizontally placed LISS pipes are placed perpendicular to the horizontal Coolant Channels in the inter lattice positions. The schematic of coolant channel is shown in Figure 2. The gap between the coolant channel and the LISS tube is critical considering the possibility of fretting damage in the event of closing of the gap. The Coolant channels consists of two co-axial tubes called Pressure tube (inner) and Calandria Tube (outer). The gap between LISS tube and calandria tube cannot be measured directly as the whole core of the reactor is enclosed in a vessel called Calandria vessel. Only easy access to the core is through the bore of the pressure tube for employing any inspection technique for measuring the gap and the probing medium has to penetrate the pressure tube and calandria tube barriers. Electromagnetic technique only appears to be feasible for the inspection.

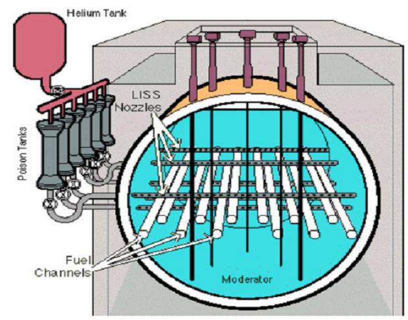

Figure 1: Schematic of Reactor Core

Remote Pulsed Eddy Current technique is proposed for the measurement. The remote field originates from the exciter coil kept in the bore of the pressure tube and propagates through the outside metallic barriers and makes a re-entry inside the pressure tube approximately at a distance of 2 diameters of pressure tube. The search coil is used at this location to pickup the prominent Remote Field. The pick up signal is further digitally signal processed to gather

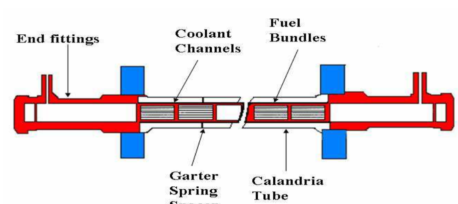

Figure 2: Schematic of coolant channel

information on the gap between LISS tube and calandria tube.

COMSOL software was used to map the poynting vector to gauge the re-entry location of the remote field. Further it was also simulated to know the order of the voltage to be picked by the pick up coil.

2. Design Philosophy

The Remote field detection is based on the fact when a coil placed inside a tube is excited, it generates direct field and remote field. Direct Field which emanates within near vicinity in the tube. Remote field emanates from the coil penetrates the metallic barriers and traverses in

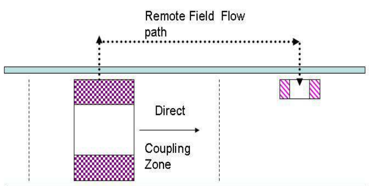

Figure 3. Flow of Remote Field

axial direction and makes a re-entry into the tubes. Figure 3 shows flow direction of remote field. The sensor consists of transmitter coil and receiver coil placed 1 Diameter to 2 Diameter distance part. The transmitter coil which is located in the coolant channel is excited with Pulsed current source. The receiver coil is used to pick up the remote field which links with LISS tube. The schematic of sensor is shown in Figure 4.

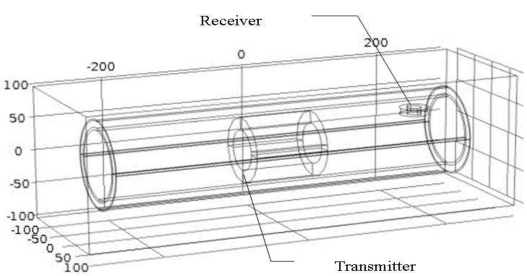

Figure 4. Schematic of Sensor

The picture of prototype sensor is shown in Figure 5.

Figure 5. Picture of prototype sensor.

3. Remote Field Mapping

The Poynting Vector gives an inference on the Electromagnetic Energy flow in the vicinity of the sensor. The remote field emerges from the transmitter and penetrates the metallic tubes of coolant channel and traverses in axial direction (outside the coolant channel) and makes a re-entry into the metallic tubes at distance of 1D to 2D from the transmitter. The re-entry point can be inferred from the Poynting Vector Field at location where the Poynting vector makes a reversal of the direction. The Poynting Vector mapping is shown in Figure 6.

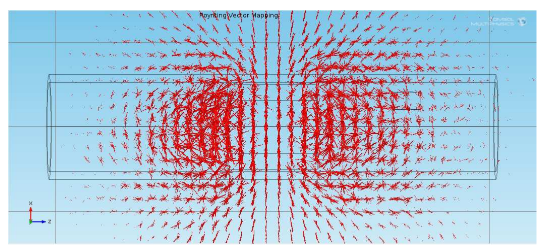

Figure 6. Poynting Vector Mapping

4. Electromagnetic Analysis

The transmitter coil and receiver coil was modeled using COMSOL 4.2 software. The magnetic flux density generated by transmitter coil and Electric Field around the vicinity of receiver coil surface is shown in Figure 7. The voltage induced in single turn of the receiver coil is shown in Figure 8. The transmitter coil was excited with pulsed voltage source and plots were simulated for different instance of time. The voltage was derived by integration of electric field over one turn.

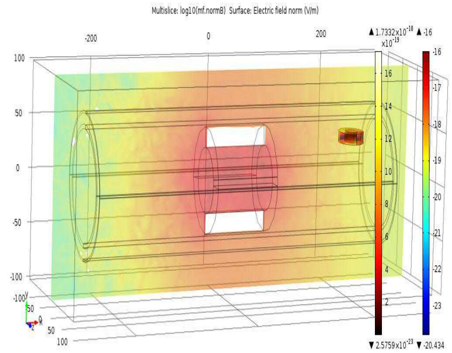

Figure 7. Magnetic Flux density Distribution and Electric Field Distribution

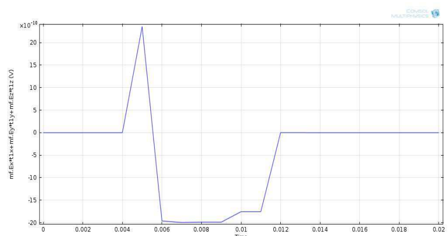

Figure 8. Voltage induced in single turn coil.

5. Preliminary Results

The pick up signals are signal conditioned and acquired in High speed Data acquisition system. Time-Frequency analysis is carried out and Time Frequency zones are identified which are sensitive to the variation of gap between the LISS tube and the Calandria tube of the Coolant Channel. The preliminary results are obtained by varying gap between LISS tube and Coolant channel in mock-up setup. The Time-Frequency analysis is carried out and amplitude values are sampled at specific Time Frequency zone (49 Hz and 0.00635s). The Time Frequency Analysis is for 0mm gap , 25mm gap and 45mm gap is shown in Figure 9, Figure 10 and Figure 11. Trails are being carried out to establish the consistency. The experimental mock-up setup is shown in Figure 12.

6. Conclusion

The LISS tube gap detection prototype sensor based on Remote Field Pulsed Eddy Current Technique appears to be promising method. The Pulsed Eddy Current technique is a broad band technique and when applied in remote field mode has capability to detect LISS tube through the metallic tube barriers of the coolant channel. The distance between the Transmitter coil and Receiver coil can be optimized by mapping the Poynting vector and identifying the zone where reversal of vector direction takes place. The Coil pickup voltage was simulated for one turn of coil. Preliminary Time frequency analysis of the signals show some specific zone sensitive to gap variation between LISS tube and the Coolant channel. Exhaustive trails are being carried out to establish the technique.

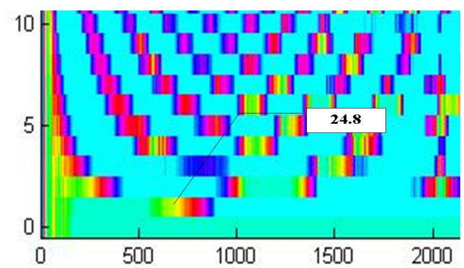

Figure 9. Time Frequency Analysis for 0mm gap.

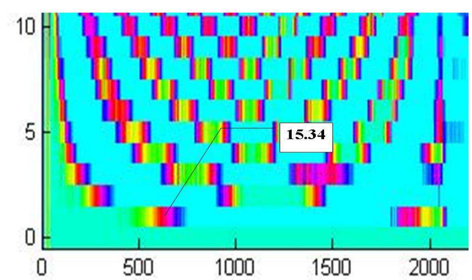

Figure 10. Time Frequency Analysis for 25mm gap.

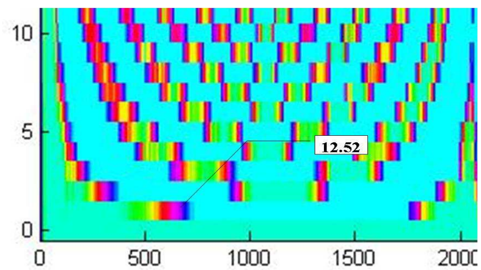

Figure 11. Time Frequency Analysis for 45mm gap.

Figure 12. Experimental setup for LISS tube measurement

7. References

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