Proximity Measurement of Remote Tubes from within Fuel Channels of CANDU® Reactors

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Outline

- Background
- Motivation
- Experimental setup
- Results
- Discussion
- Conclusion

Reactor Geometry

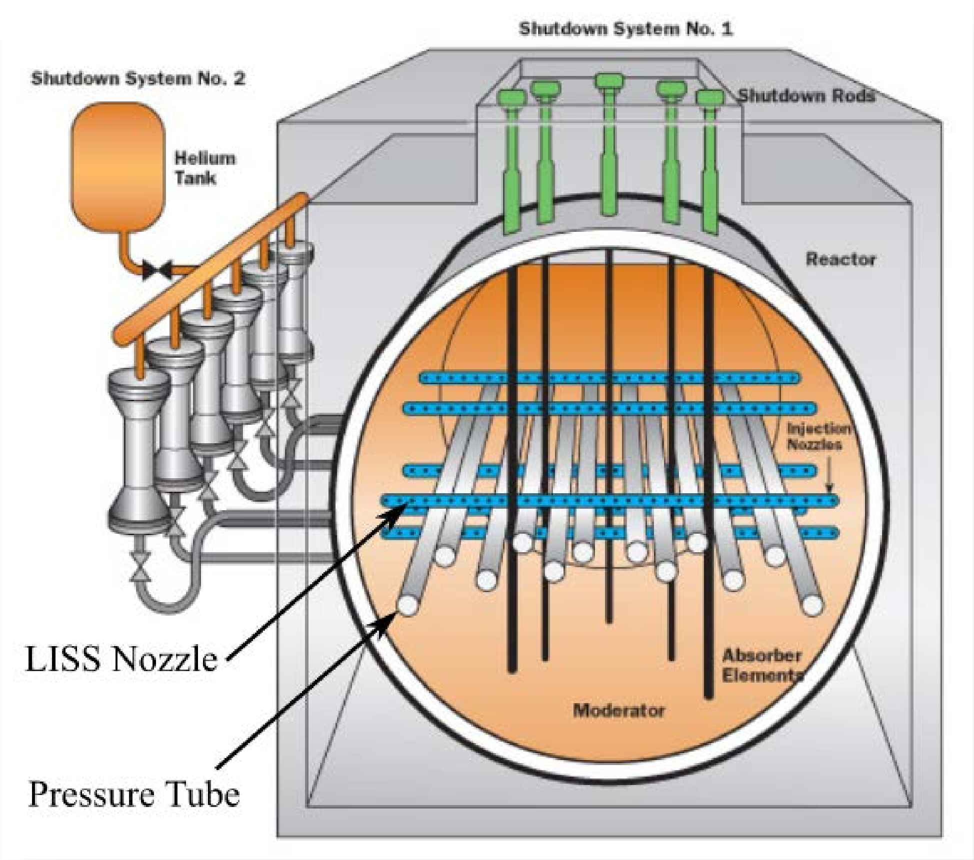


Figure 1. Diagram of interior of CANDU reactor [1].

Reactor Geometry

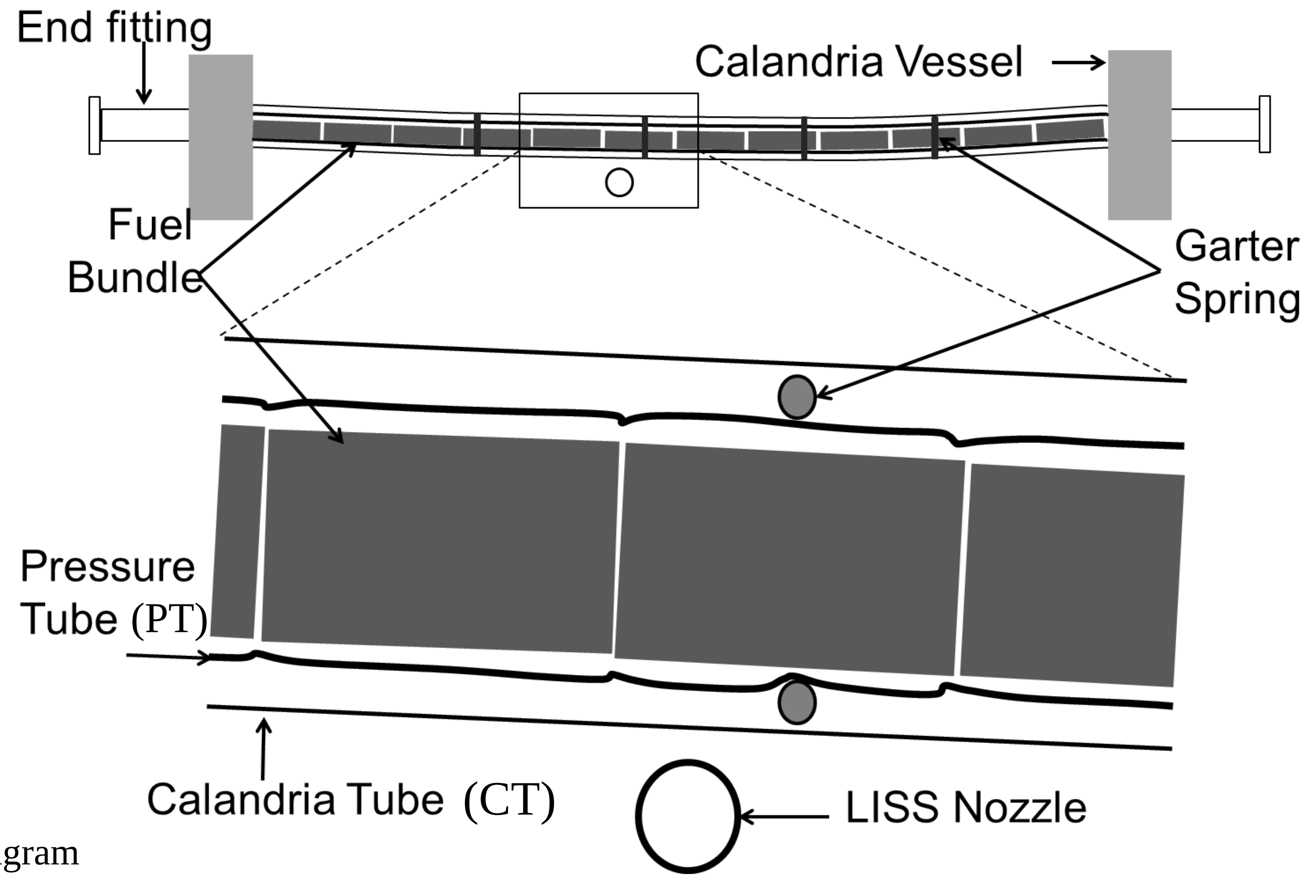


Figure 2. Diagram of interior of CANDU fuel channel.

LISS - Liquid Injection Shutdown System

Reactor Geometry

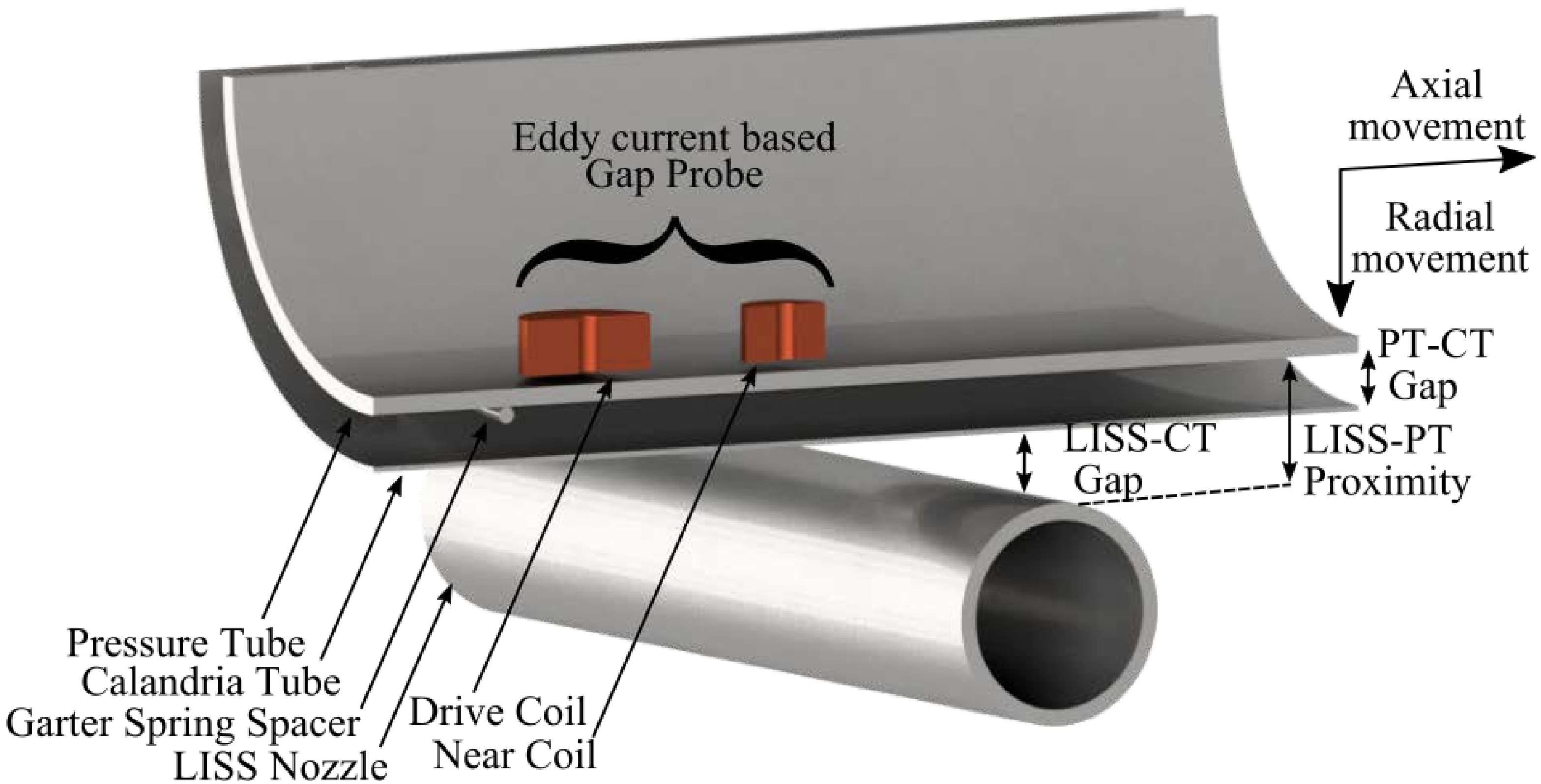
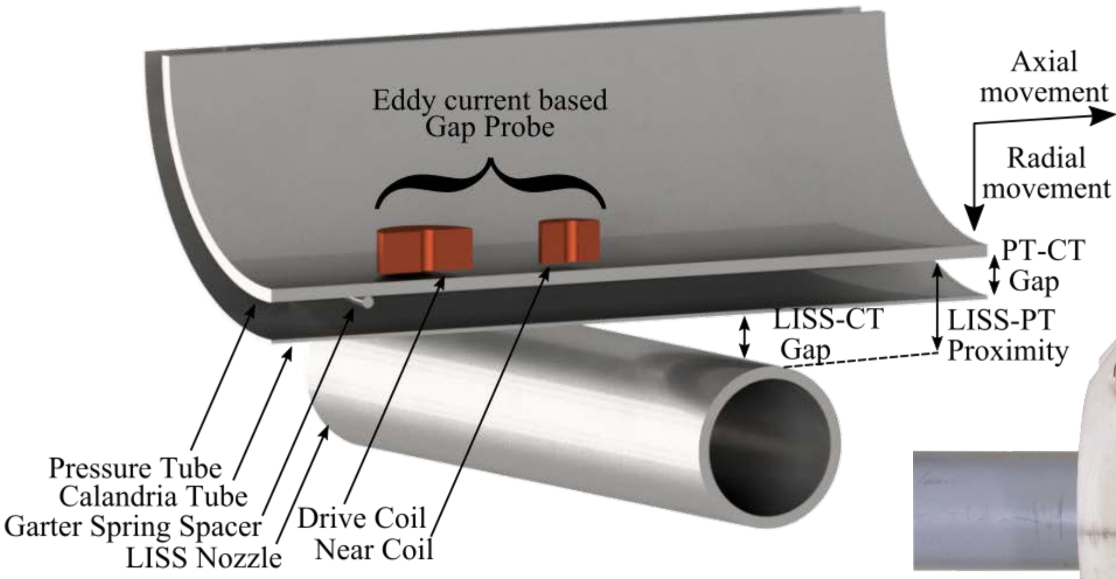


Figure 3. Quarter section of fuel channel with LISS and coils.

Reactor Geometry



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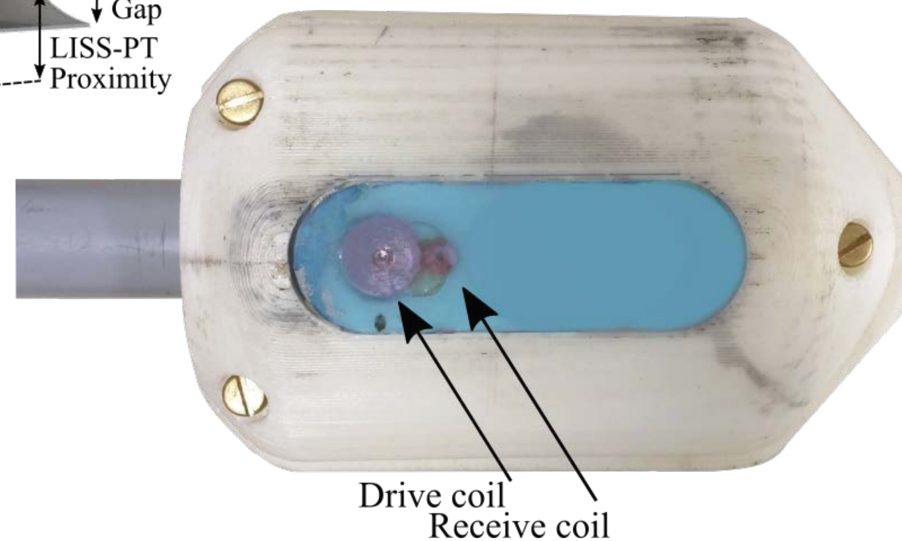


Figure 4. Gap probe used in research setting.

Why measure LISS-PT proximity?

- Cannot have Pressure tube and Calandria tube contact; leads to hydrogen ingress and possible cracking.
- Cannot measure PT-CT gap near LISS nozzles; linear approximation is required in this area

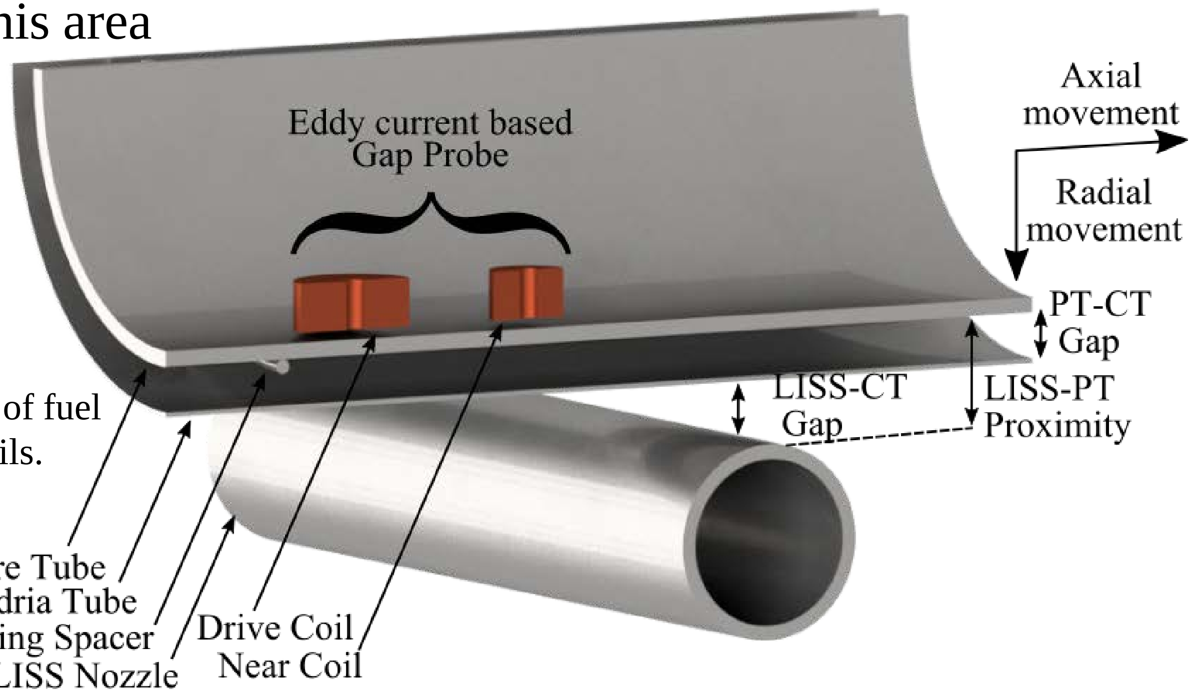
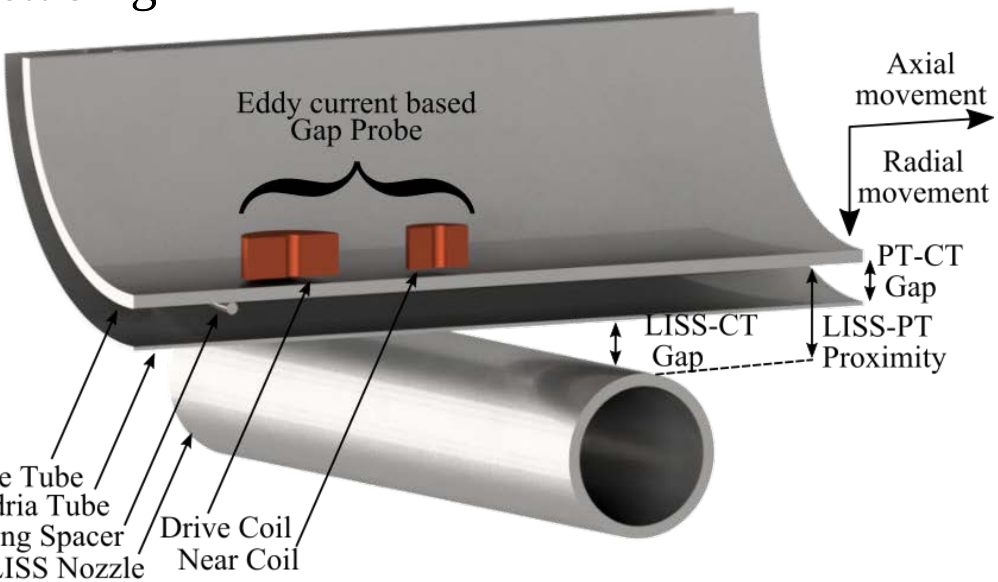


Figure 3. Quarter section of fuel channel with LISS and coils.

Motivation

- Proximity of LISS nozzles compromises PT to CT gap measurement up to ~80 mm along channel
- LISS-CT contact results in retubing
- Cost of optical inspections [2] on order of ~$1 million
- Method could examine historical PT-CT gap scans to examine LISS approach to CT



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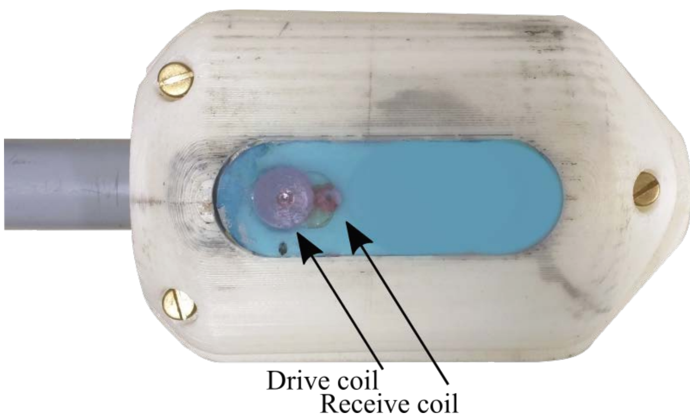
Eddy Current Measurements

- Time harmonic magnetic fields generated by drive coil and sample are recorded by the receive coil [3]
- Changes in sensor response with position contains information about proximity and properties of nearby conduction materials



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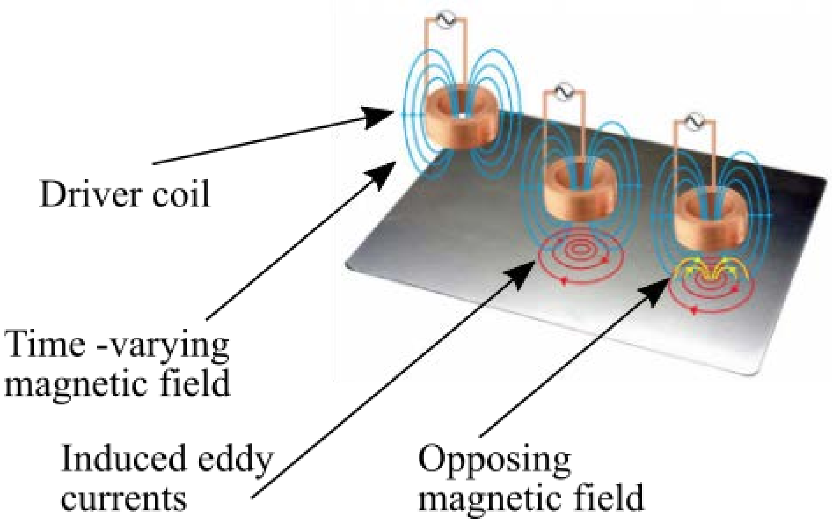
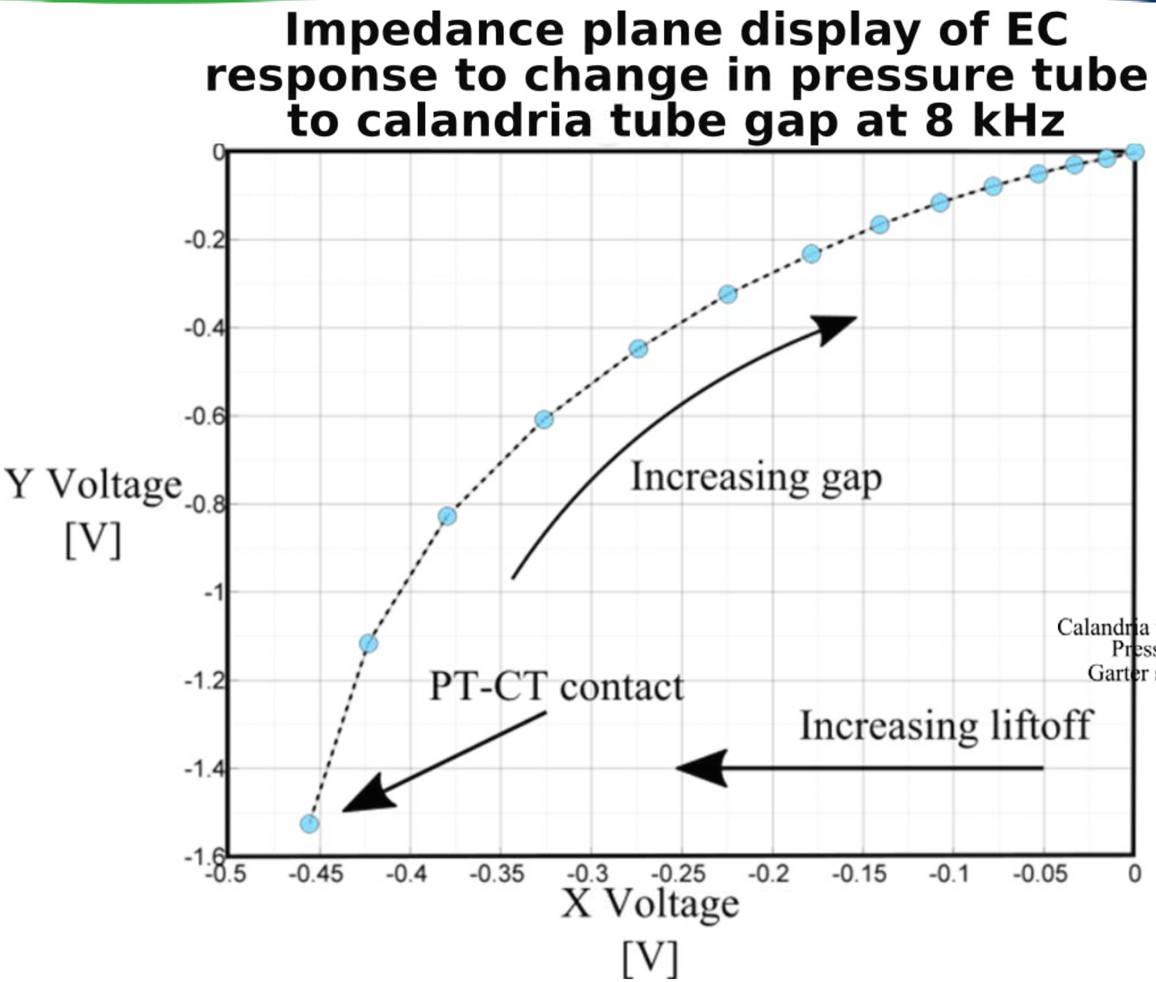


Figure 5. Illustration of eddy currents induced in conductor [4].

Gap Scan



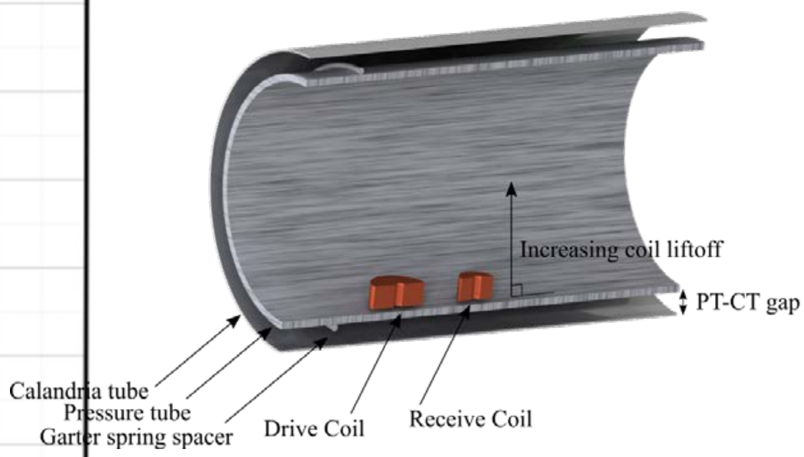
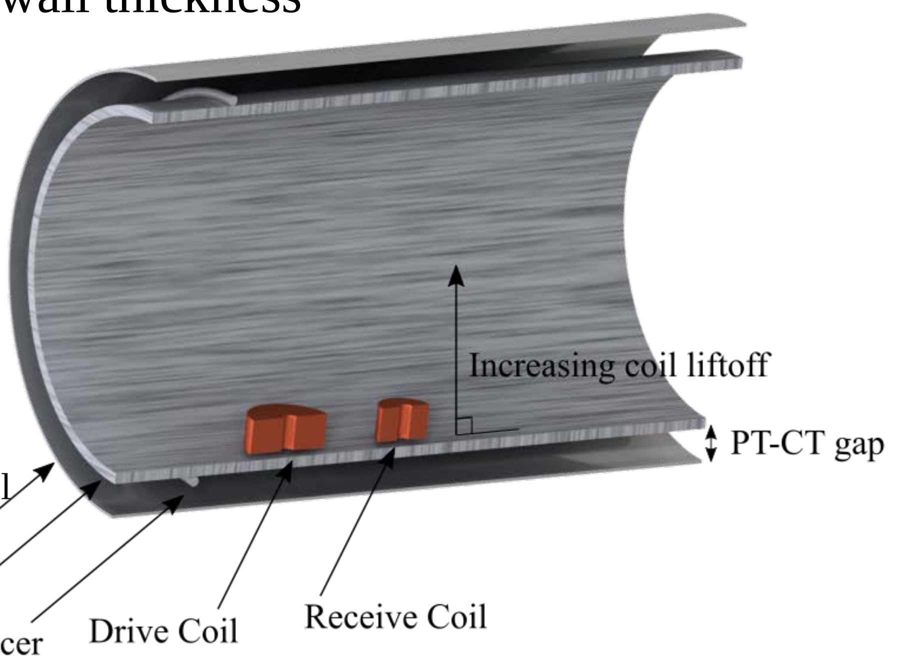


Figure 6. Half section of fuel channel with coils.

Essential Parameters

- Parameters that varied during scan may produce error in gap measurement and possibly hinder intended target accuracy [5]
- PT resistivity, probe liftoff, PT wall thickness
- Manufacturing process and non-uniform diametral creep



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Experimental setup

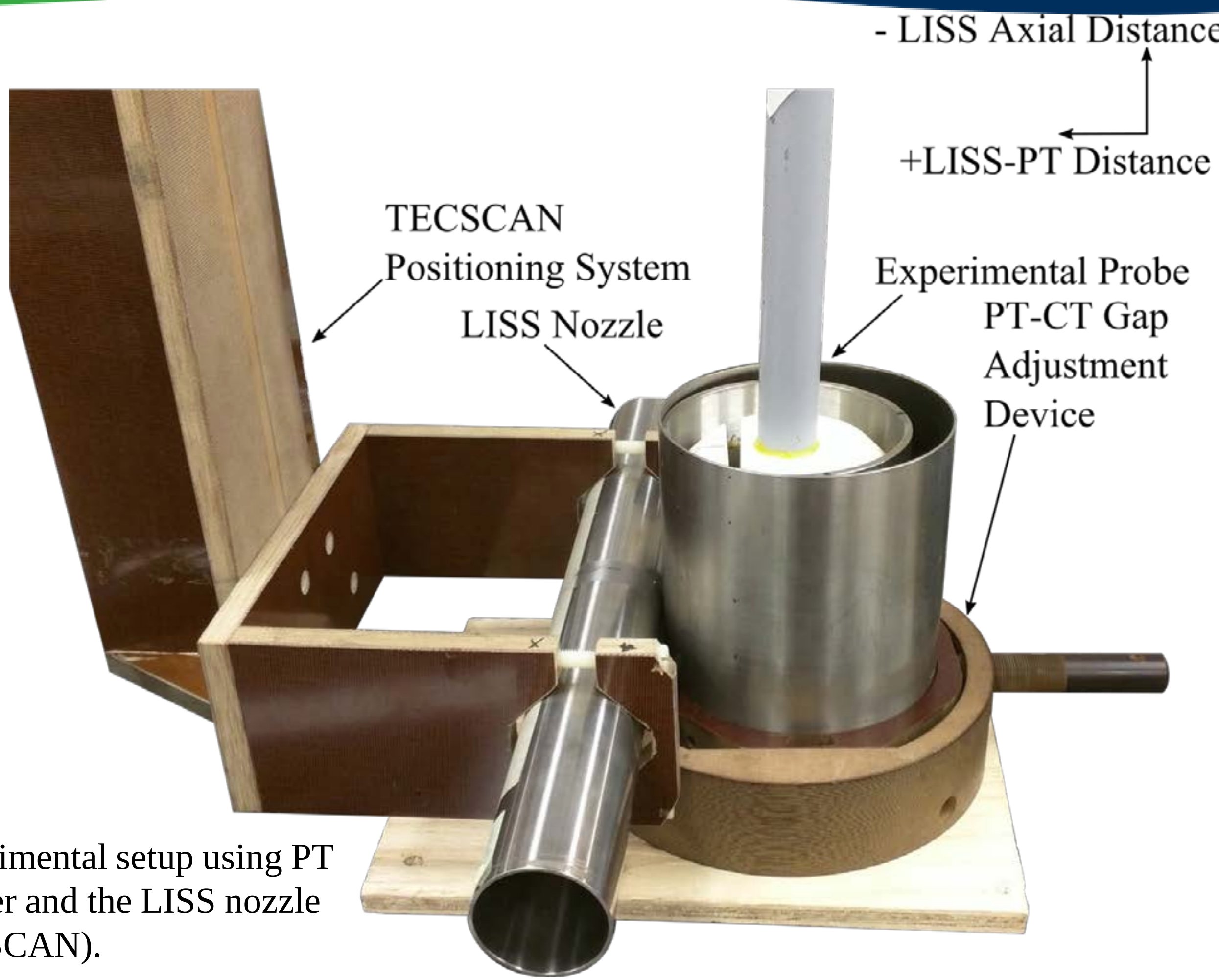
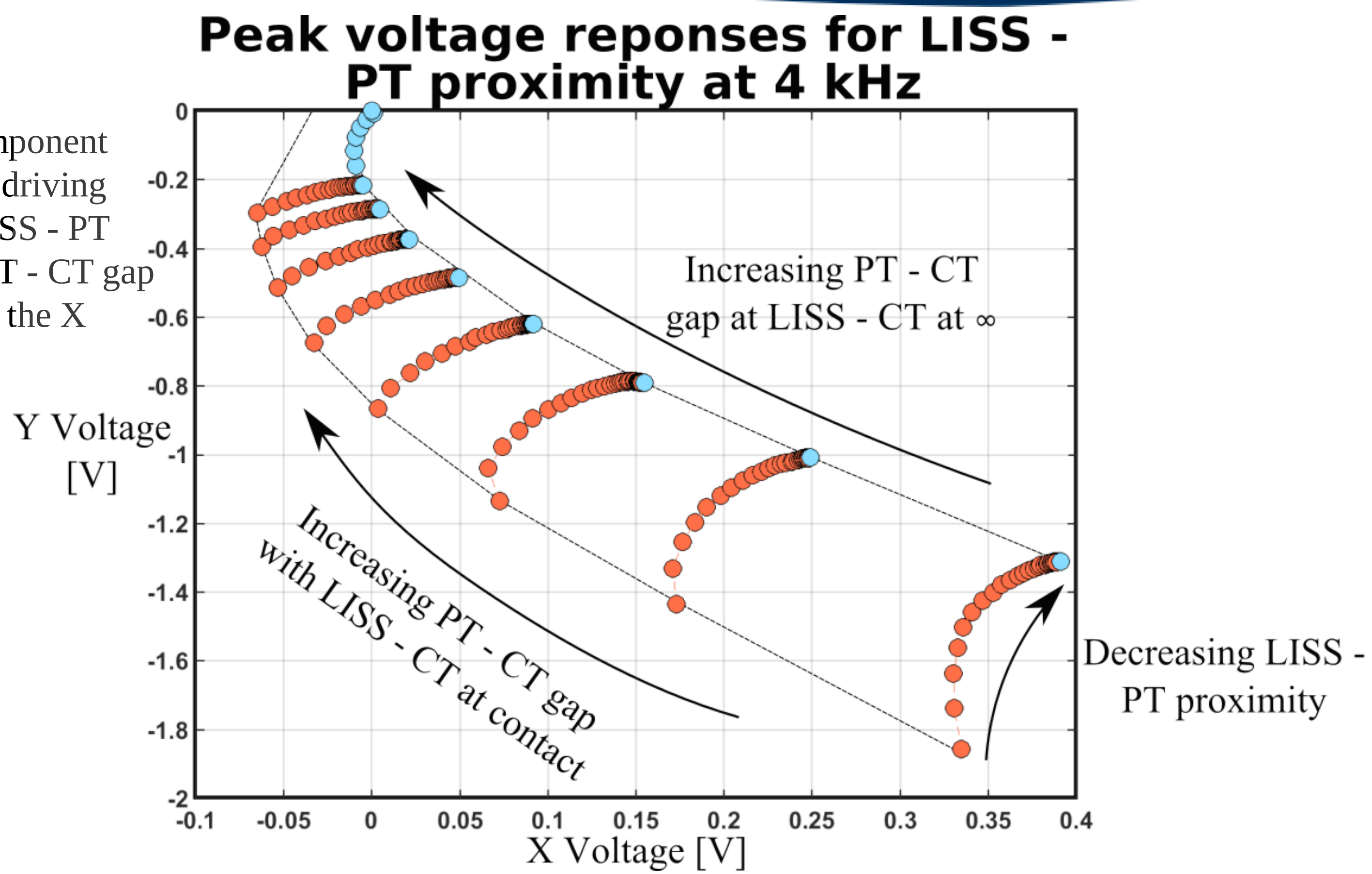


Figure 7. Experimental setup using PT - CT gap adjuster and the LISS nozzle 3D robot (TECSCAN).

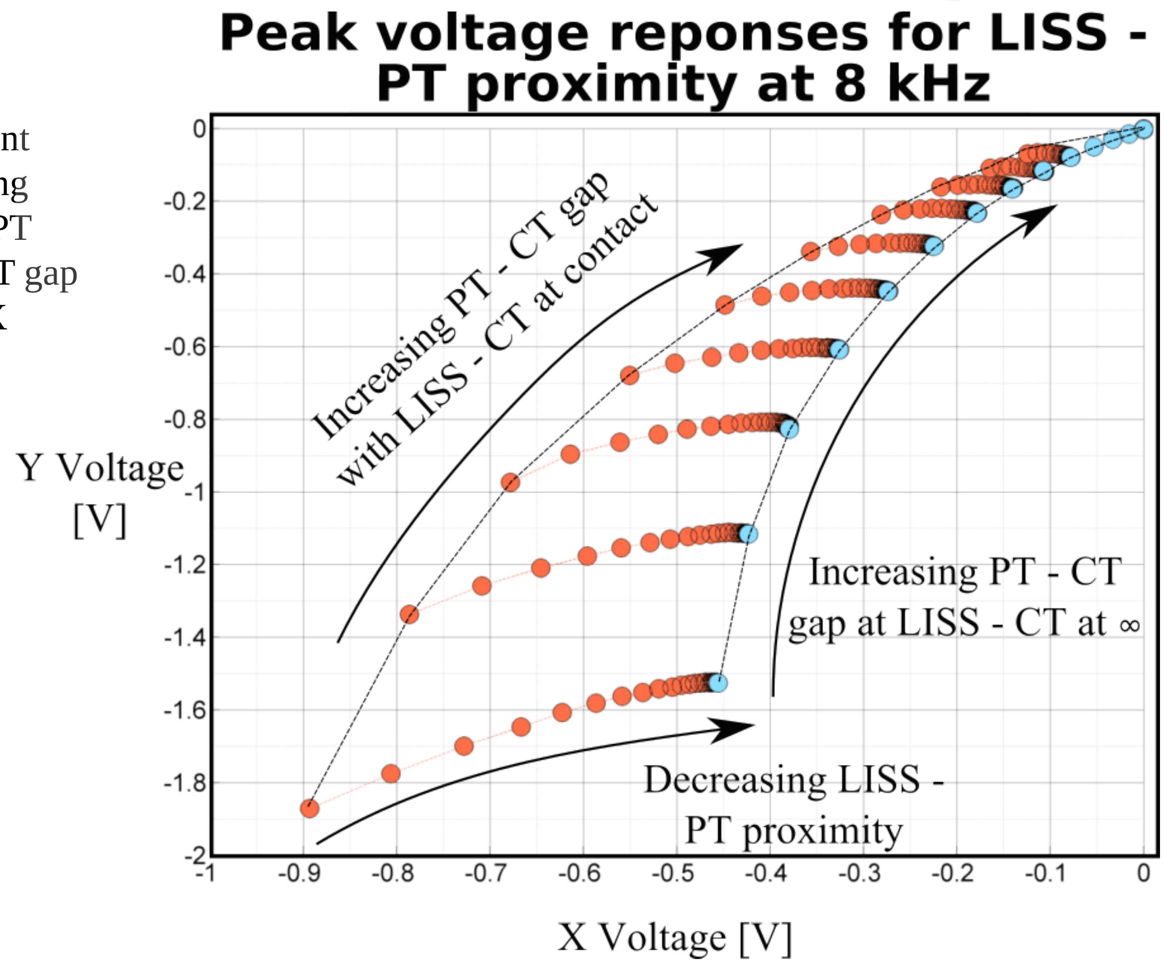
Impedance Plane

Figure 8. X and Y component voltages for the 4 kHz driving frequency. Note the LISS - PT movement at a fixed PT - CT gap (strips of points) is in the X direction.



Impedance Plane

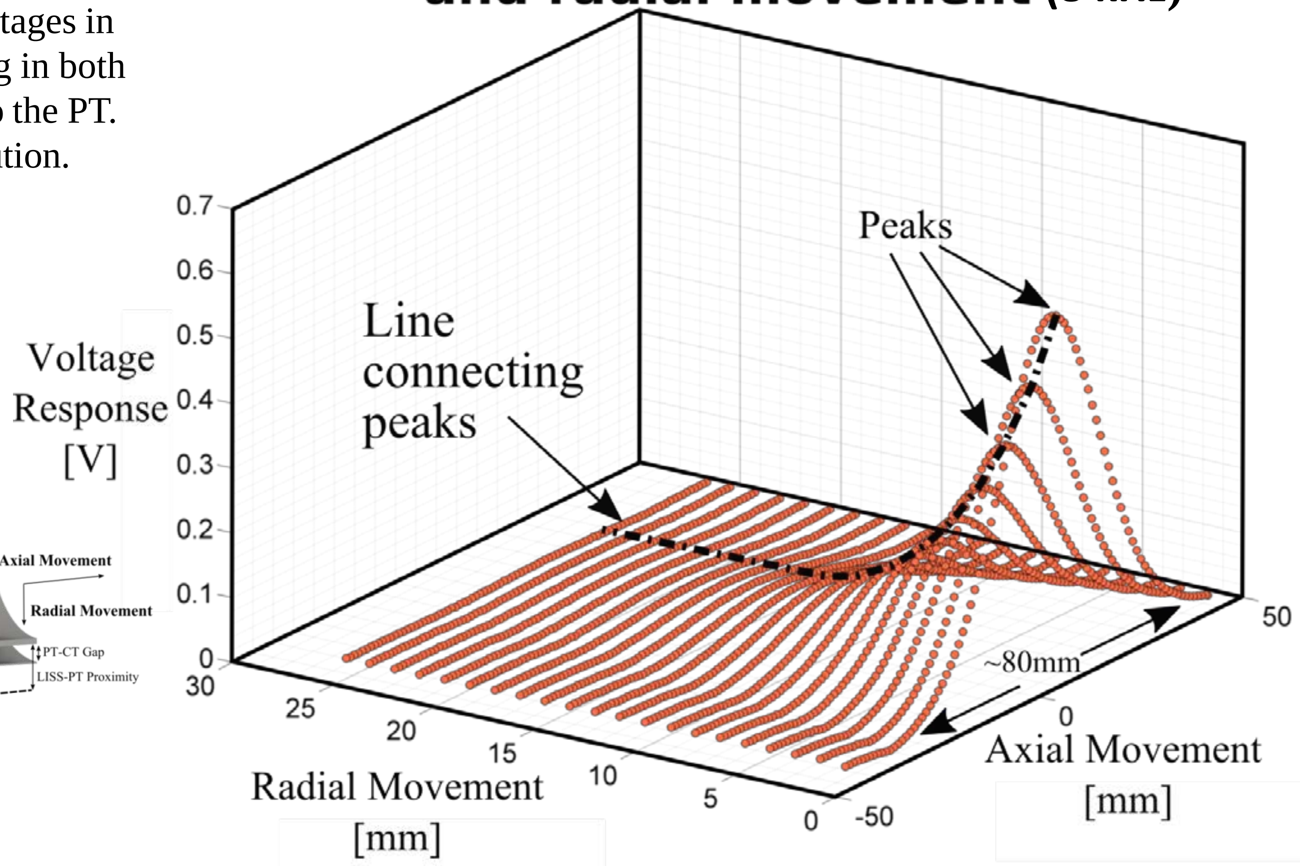
Figure 9. X and Y component voltages for the 8 kHz driving frequency. Note the LISS - PT movement at a fixed PT - CT gap (strips of points) is in the X direction.

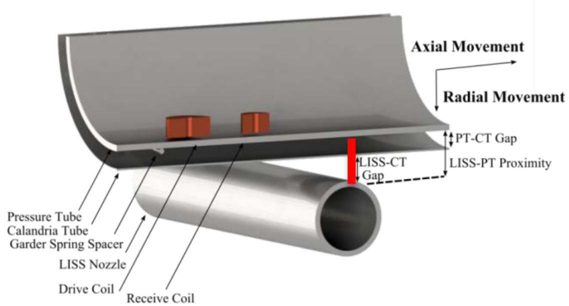


Voltage Response

Figure 10. Eddy current voltages in response to the LISS moving in both radial and axial directions to the PT. Note the peak in the distribution.

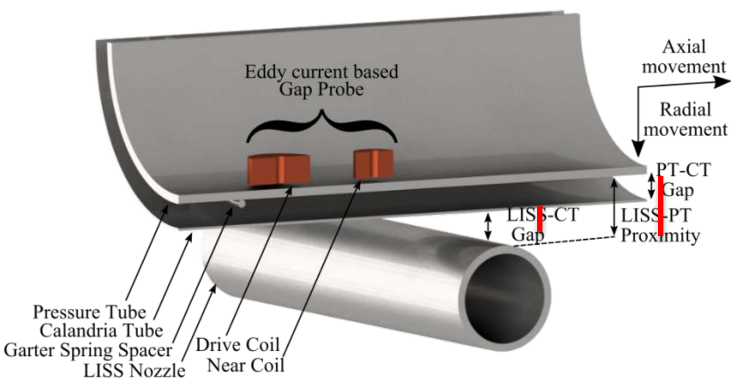
Eddy current response to LISS axial and radial movement (8 kHz)



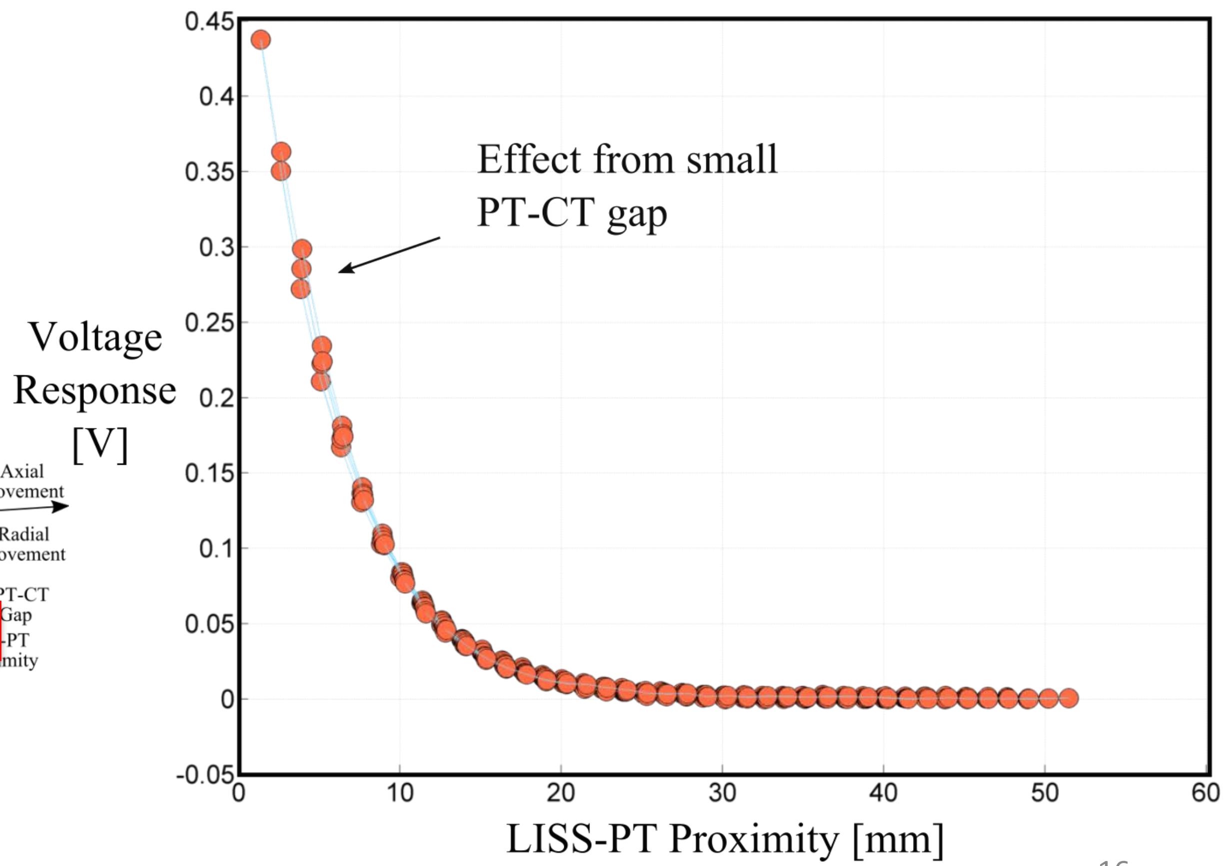


Results

Figure 11. Voltage responses from LISS-PT proximity for multiple PT-CT gaps. Note that plot is of multiple voltage vs LISS-PT proximity curves for fixed PT-CT gap and are overlapping.

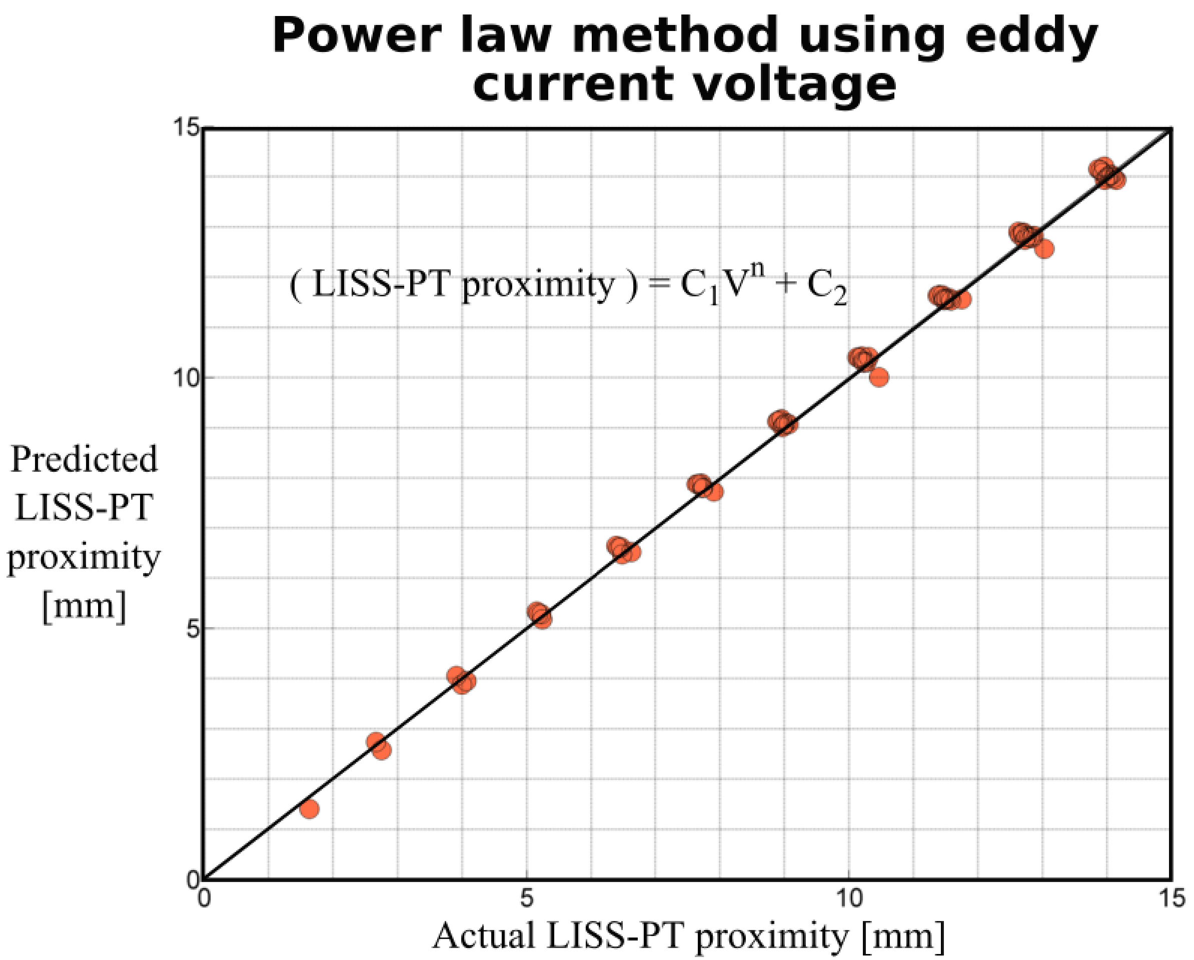


Peak voltage reponses vs LISS - PT proximity at 8 kHz



Analysis

Figure 12. Method predicts LISS - PT proximity out to 15 mm with ±0.3mm (2σ) accuracy and out to 25 mm with ±0.9mm (2σ) accuracy under variable gap conditions, but with PT resistivity, PT wall thickness, and probe liftoff held constant.

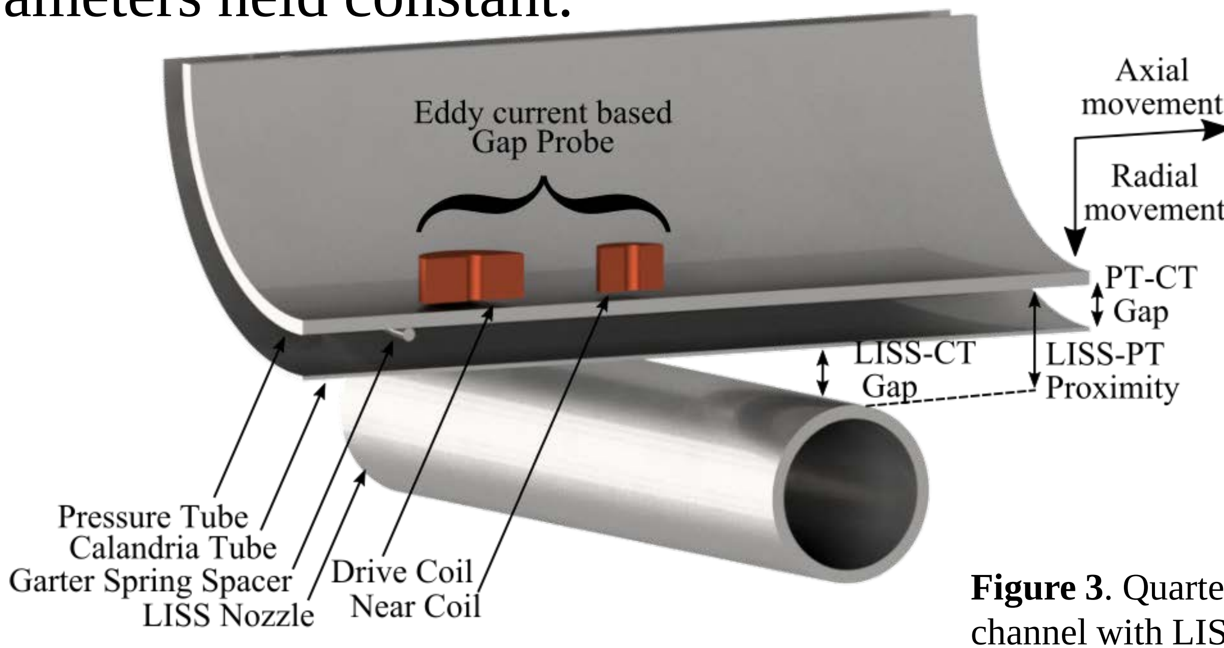


Discussion

- EC measurements were only done for one nominal PT wall thickness and resistivity with probe at fixed lift-off.
- Examination of response to LISS-nozzle proximity under variation of PT wall thickness and resistivity, and probe lift off, as might occur under in-reactor conditions, is required to establish overall system accuracy.
- Method for calibration of response to LISS-nozzle proximity also needs to be developed.
- Method could be used to extract LISS-nozzle movement over time from historical PT - CT gap scans.

Conclusion

- Method predicts LISS - PT proximity out to 15 mm with ±0.3 mm (2σ) accuracy and out to 25 mm with ±0.9 mm (2σ) accuracy under varying gap, but with additional essential parameters held constant.



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Acknowledgements

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Thank-you

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June 2017

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Questions?

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