Analysis of an Eddy Current Flow Meter for Lead Cooled Nuclear Reactors

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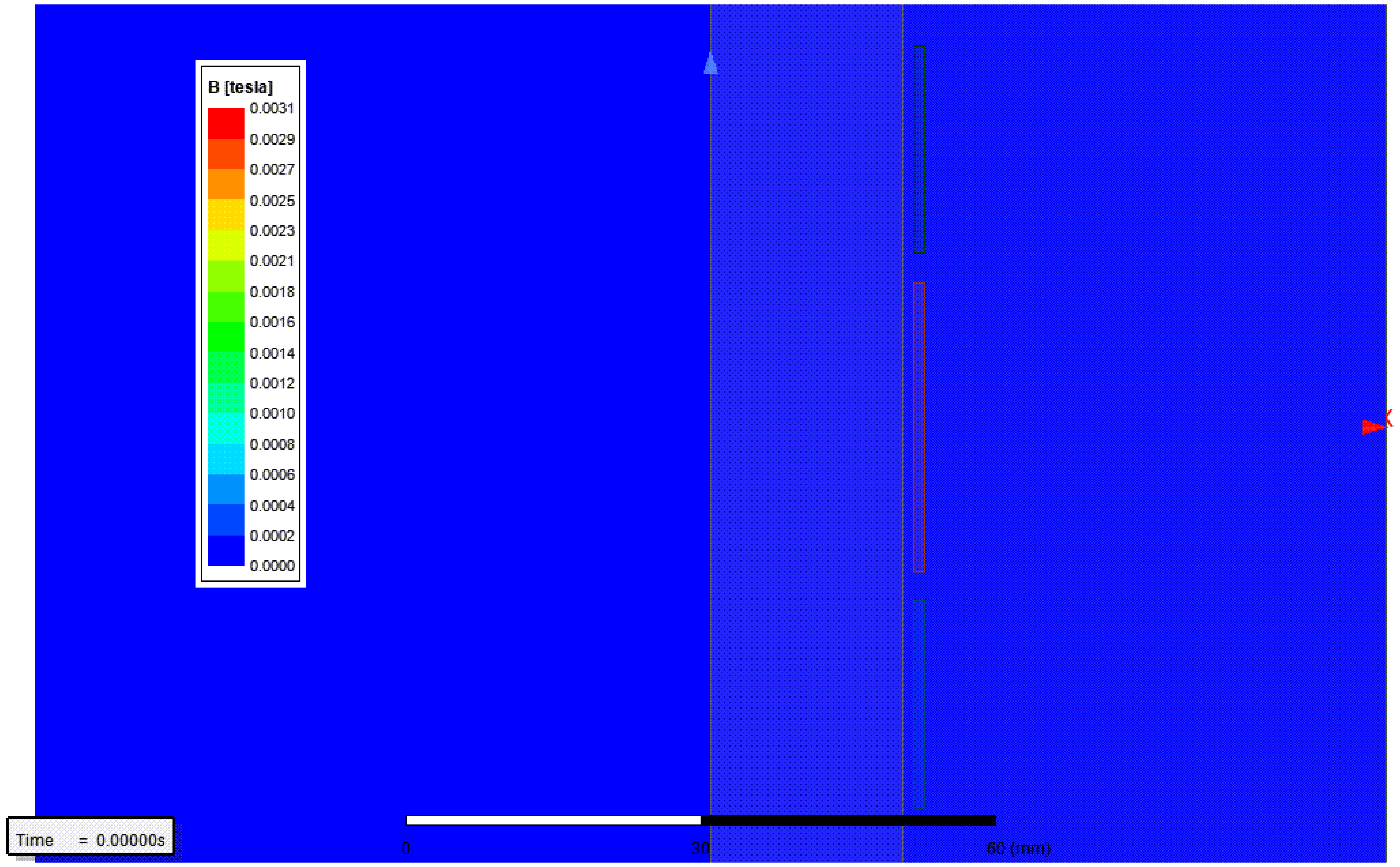

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INTRODUCTION

Eddy current Flow meters (ECFMs) are constructed of three coils mounted coaxially on a bobbin. The primary coil is excited by an Alternating Current (AC) power source which then excites two additional secondary coils via mutual inductance. As a conductive fluid flows within the ECFM's magnetic field it will induce eddy currents that will alter the output voltage of the secondary coils. The induced voltage difference between the secondary coils will be proportional to the conductive fluids velocity. Therefore, an ECFM can be used to detect a flow conditions of conductive materials such as liquid lead. Additionally, when an external ECFM design is utilized the sensor will not have direct contact with the flowing medium. Therefore withstanding harsh environments, which makes the ECFM optimal for nuclear applications.

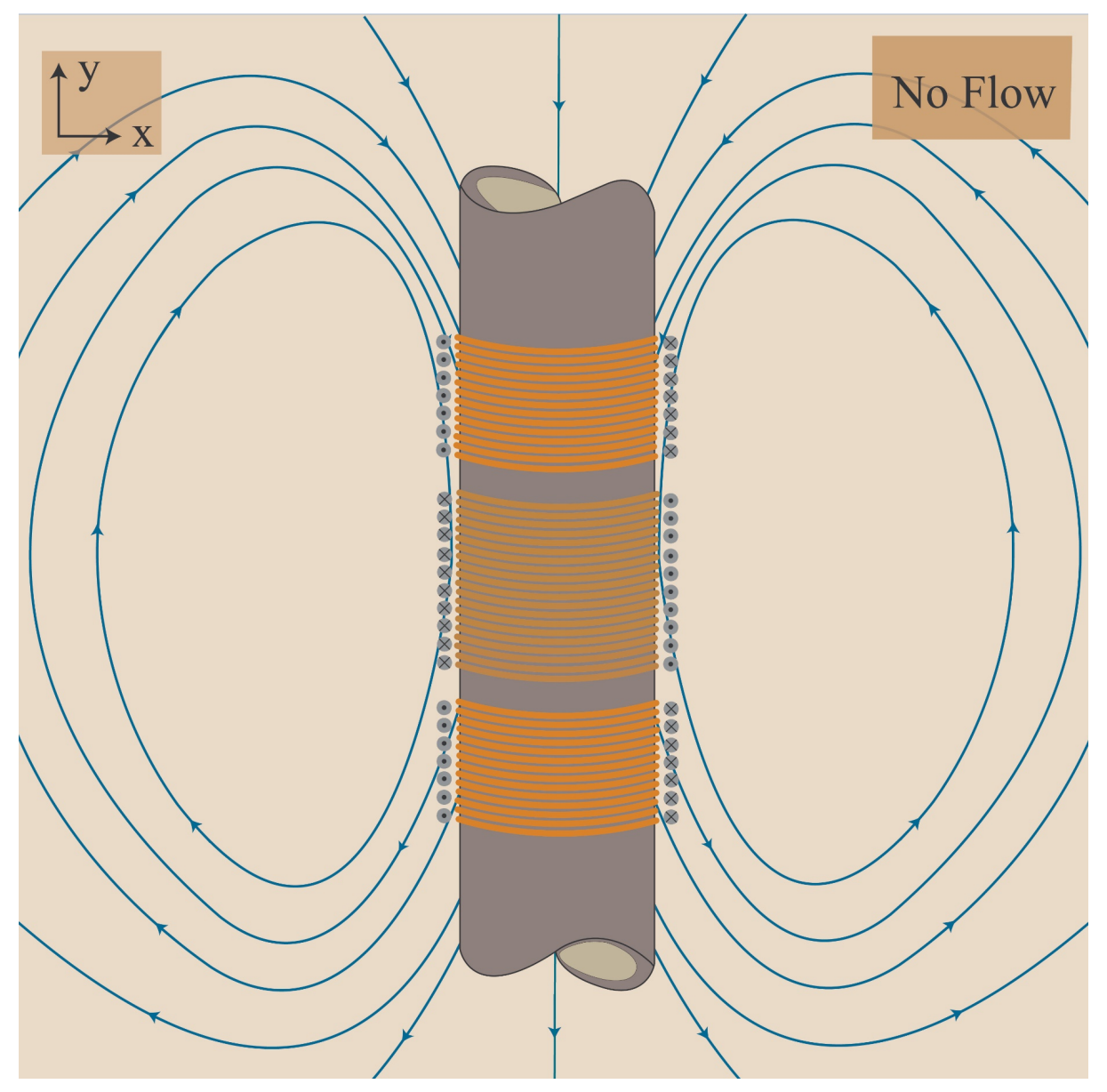

Fig. 1. ECFM magnetic field lines under no flow condition.

- No eddy currents when there is no fluid flowing
- Secondary coils excited by mutual inductance with primary coil
- Magnetic field is symmetric which ensures that both secondary coils are excited to the same voltage
- Sensor output is equal to the difference in voltage of the two secondary coils

- Eddy currents induced by the conductive fluid moving through a magnetic field
- Eddy currents educed magnetic field opposes direction of flow
- Eddy currents and shift in magnetic field create a difference in the induced voltage of secondary coils
- The difference in secondary coil voltage is then proportional to fluid velocity

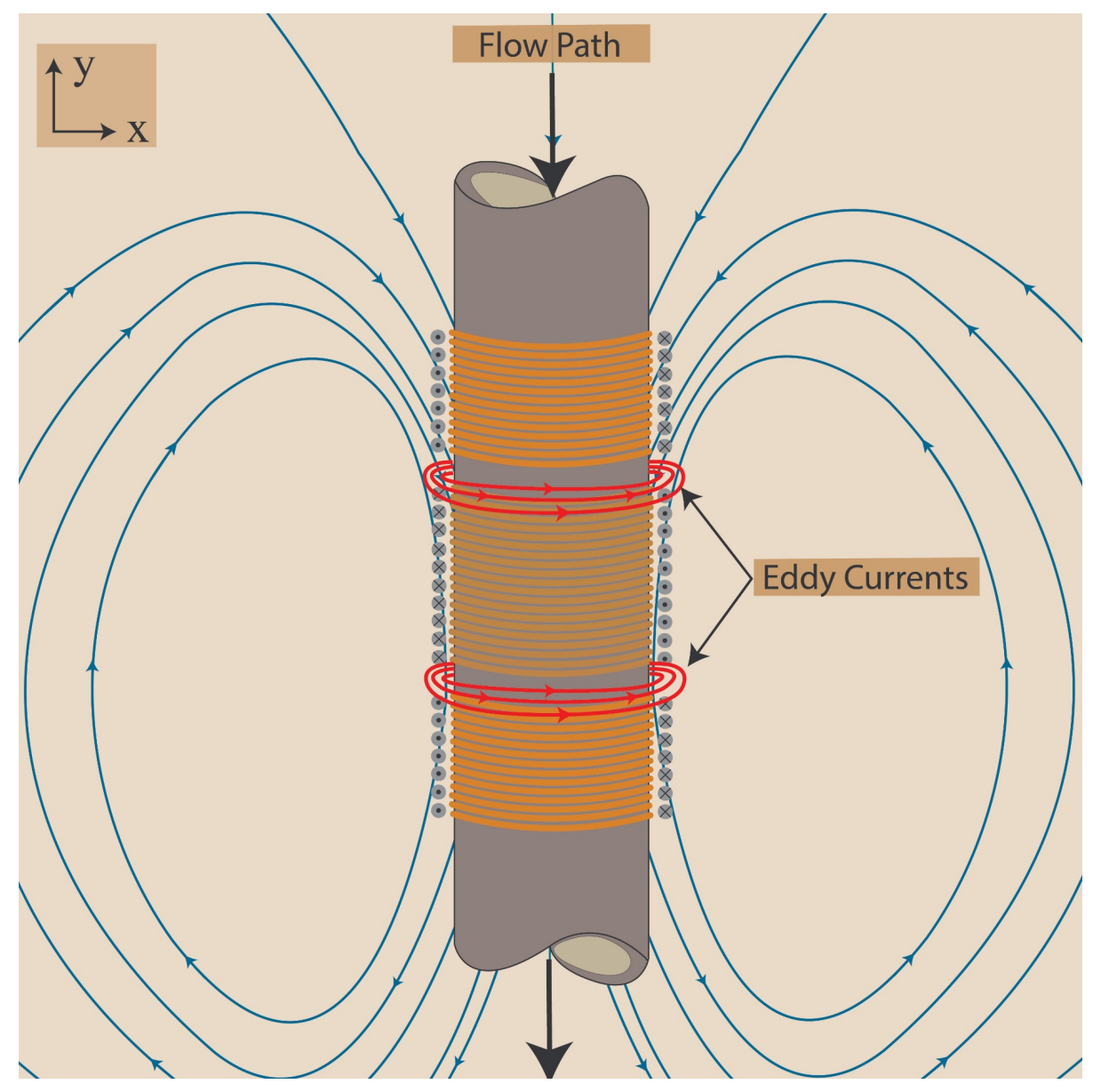

Fig. 2. ECFM magnetic field lines under flow conditions. Note the shift in magnetic field and induced eddy currents.

EXPERIMENT

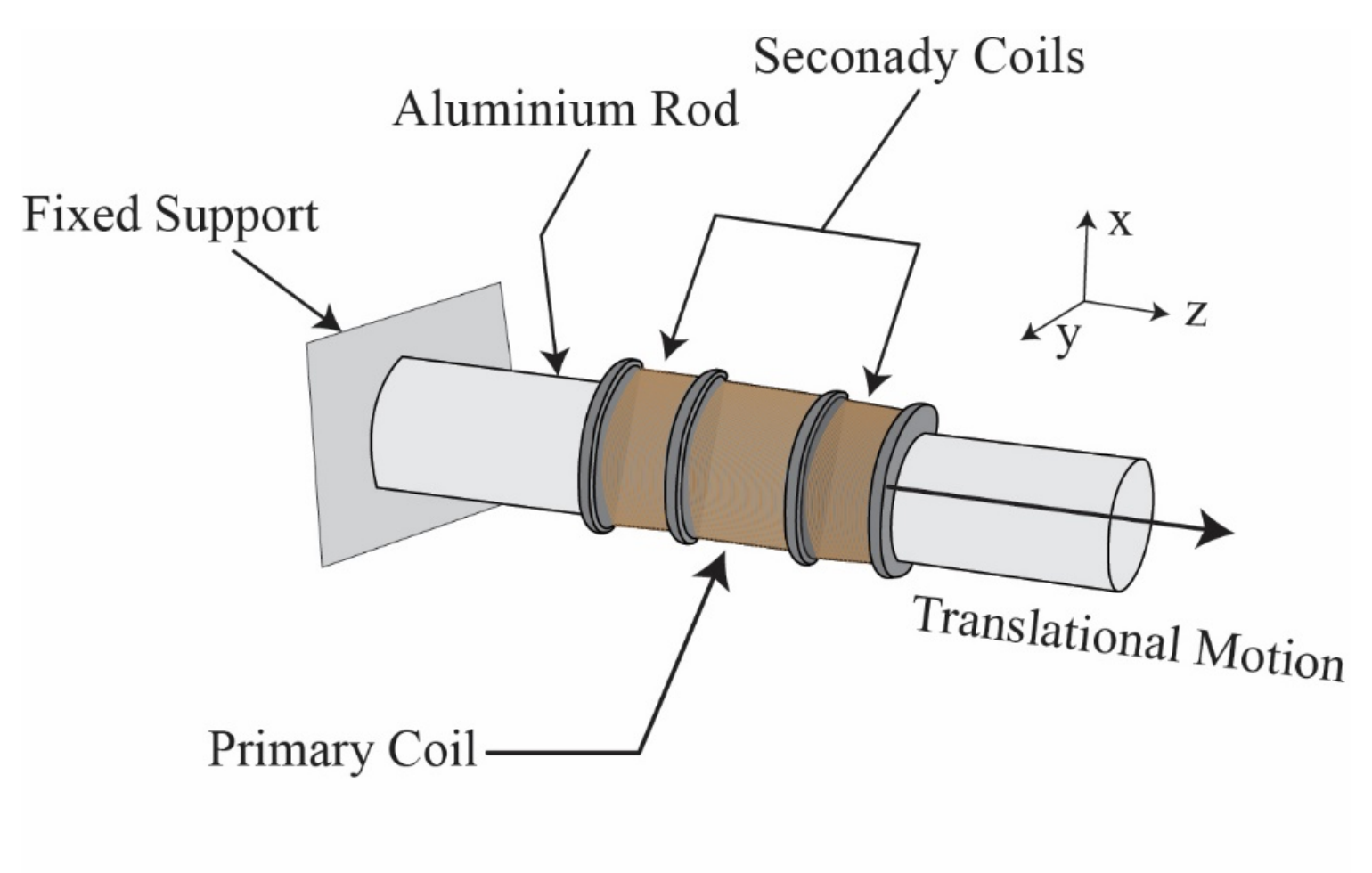

Fig. 3. Drawing of prototype ECFM dry test experiment. Note that the aluminum rod is held static while the ECFM is driven transitionally by a stepper motor.

- Dry testing through motion of ECFM over stationary aluminum rod
- ECFM driven by fixed speed by stepper motor
- Aluminum used to simulate magnetic properties of lead
- Prototype ECFM hand wound on 3D printed bobbin

- Primary coil excited by 500 Hz 2.618 Vrms AC source
- Secondary coil signals output to NI9202 DAQ for filtering and analog to digital conversation in LABVIEW
- Final data used to validate ANSYS Maxwell simulation

SIMULATION

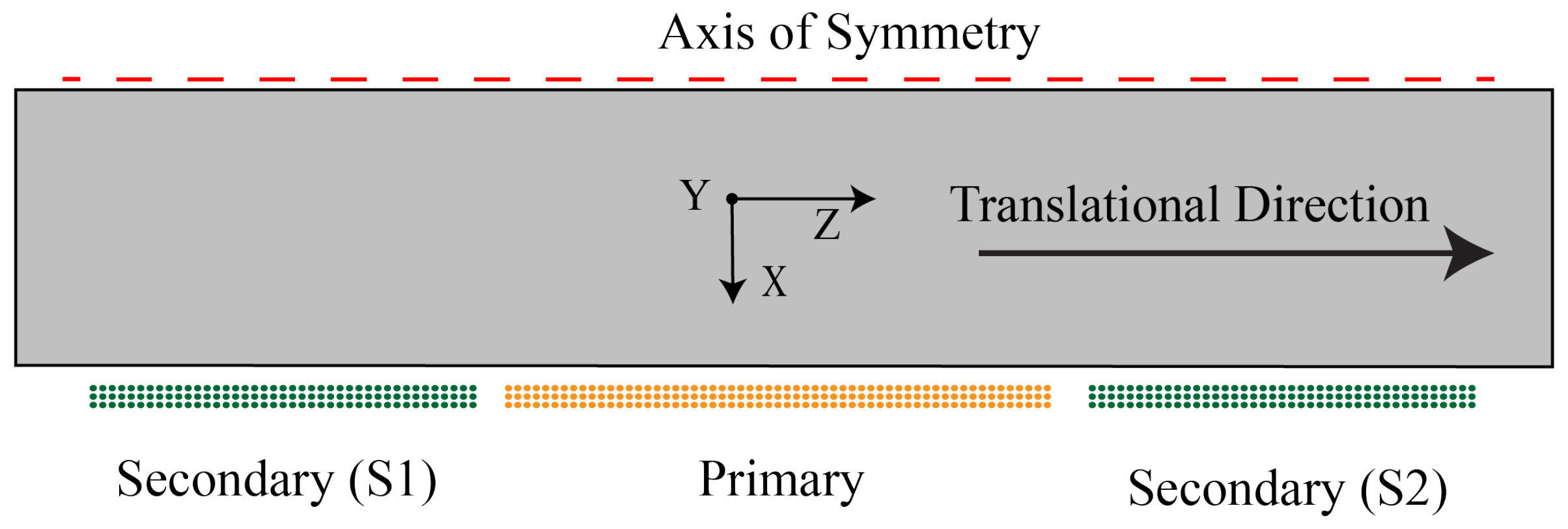

Fig. 4. Axisymmetric model used to simulate dry testing of the ECFM. Note the axis of symmetry where the model would be revolved to produce a three dimensional model

- ANSYS Maxwell solver used to simulate conditions of dry testing experiment
- 2D – axisymmetric model about z axis used to simplify computation time
- Transient analysis used to capture motion of the aluminum rod within the ECFM core
- $\Delta t = 100$ ns

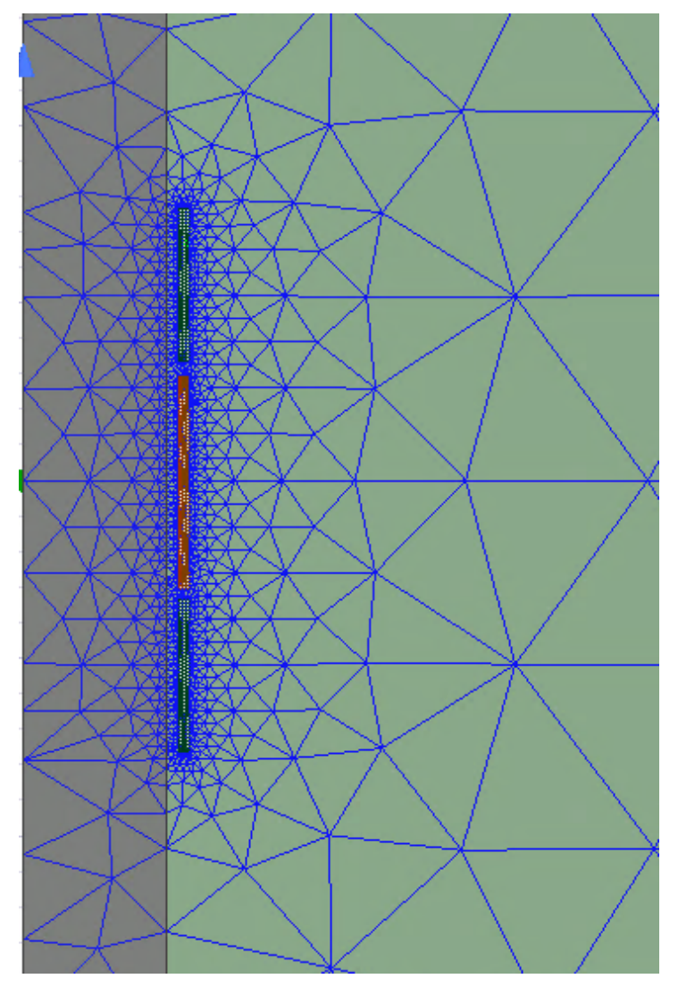

Fig. 5. Mesh of ANSYS model

RESULTS

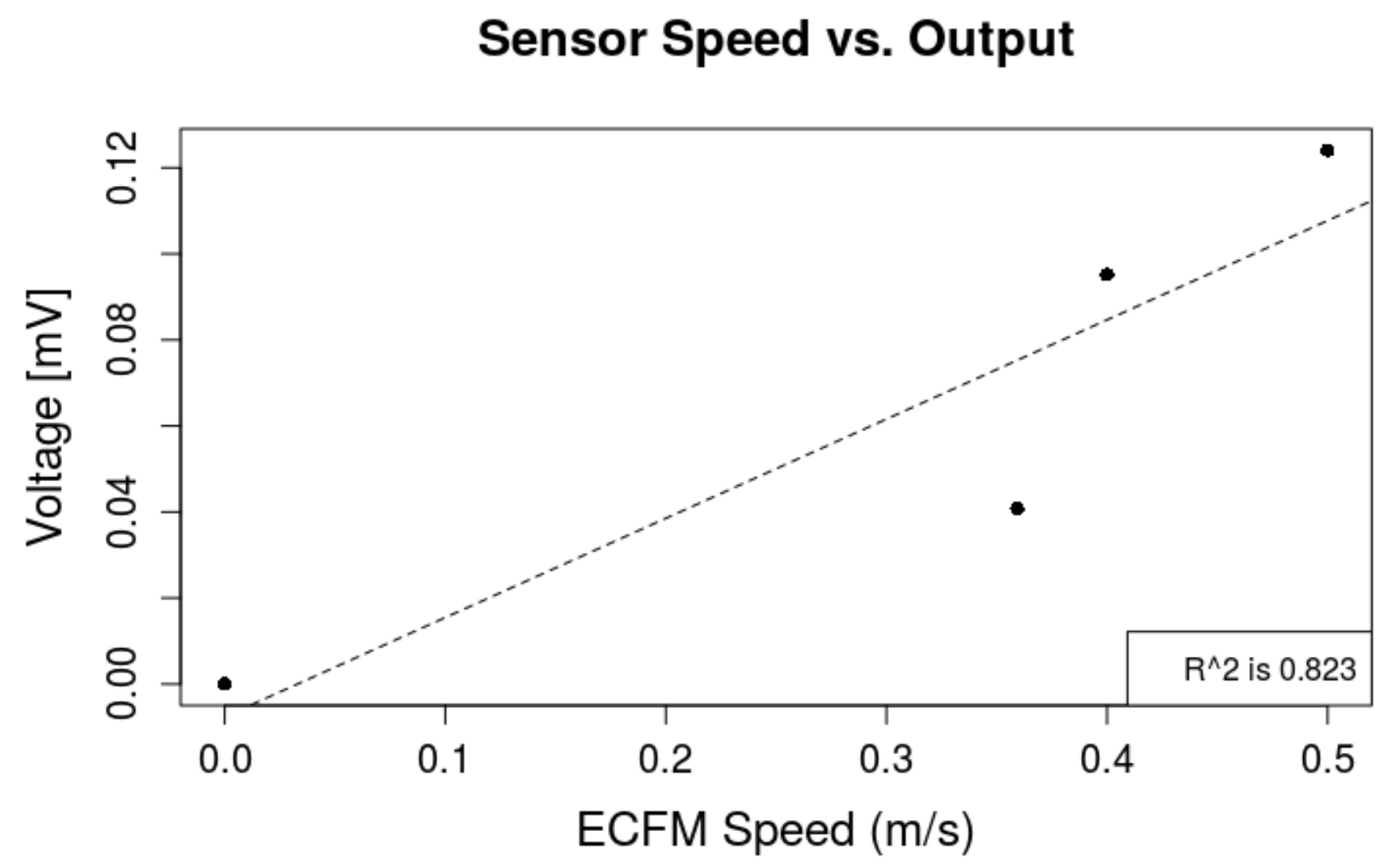

Fig. 6. Correlation between secondary coil differential RMS voltage and sensor speed during experimental dry testing.

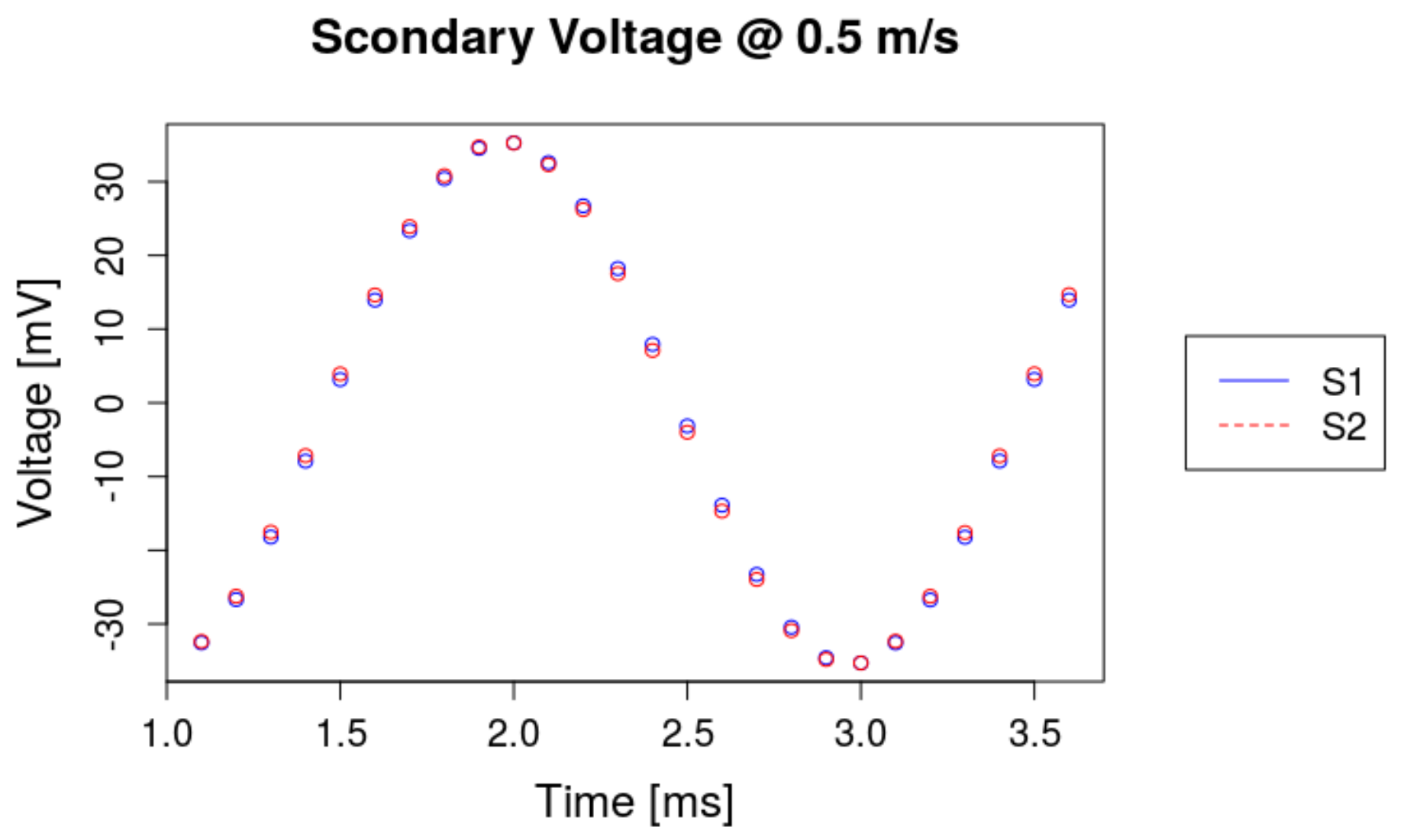

Fig. 7. Secondary coil signals for experimental dry testing of ECFM at a speed of 0.5 m/s

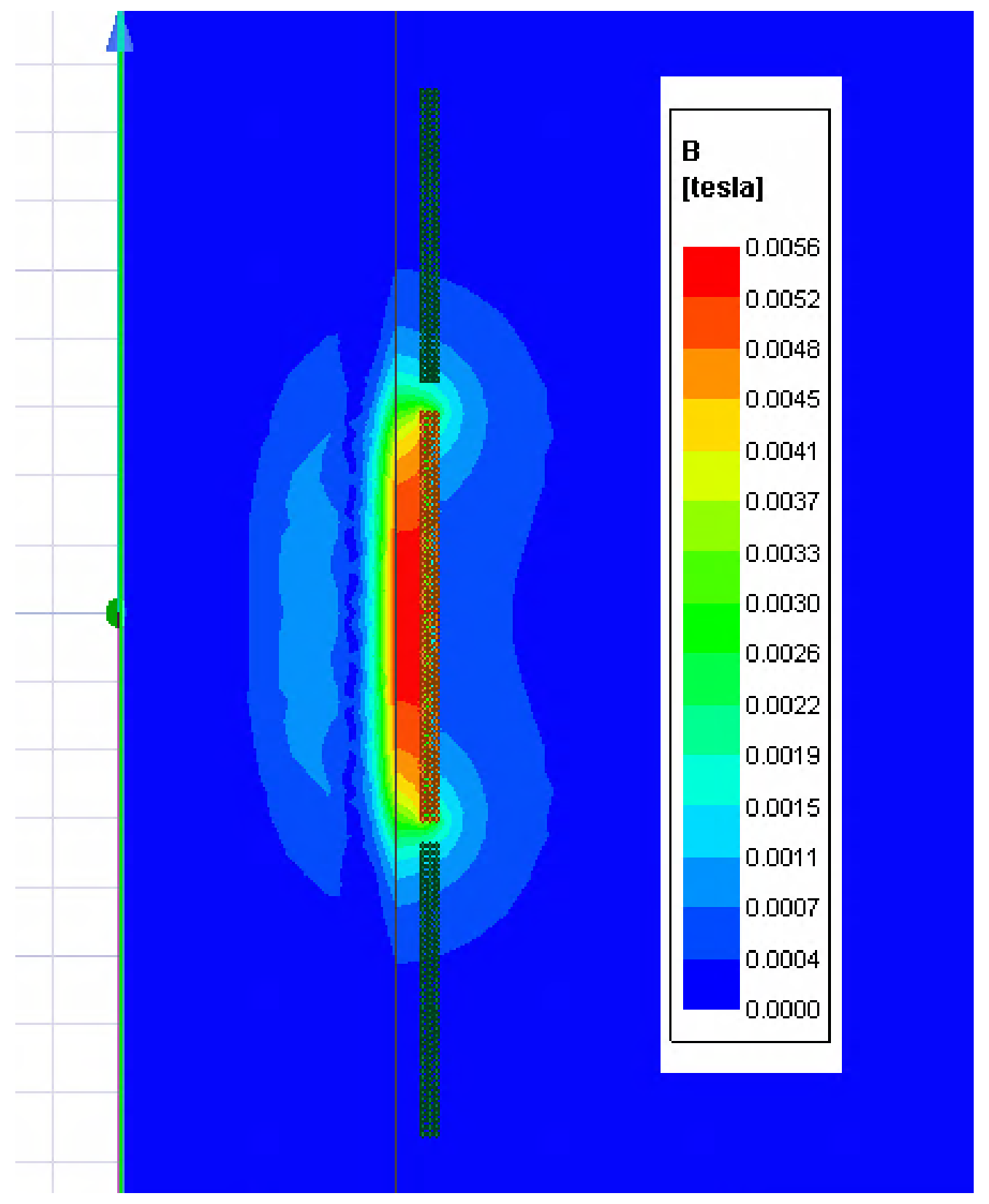

Fig. 8. Simulation magnetic B field at max secondary coil voltage during no motion.

- Linear response of the sensor with respect to sensor velocity was found
  - This response was expected and validates theoretical models, as well as previous data
- Phase shift is found to be the cause of voltage difference between the two secondary coils
  - The amplitude of the two secondary signals will not change with respect sensor speed
- Simulation shows that a majority of the magnetic fields strength is passed through the ends of the secondary coils
  - Sensor geometry can be varied to take advantage of this effect in the future
- Penetration depth of the magnetic field into the aluminum rod can be seen in the figure and follows theoretical models of skin depth.

CONCLUSION

- Theoretical and simulation models we validated to some extent with the experimental data shown thus far
- Some discrepancies were found between simulation and experimental voltage peaks
- Simulation model could not be completely validated base on these results
- Data shown gives promising correlation to expected results

NEXT STEP

- Trouble shoot discrepancy in experimental simulation amplitude
- Test various geometric configuration with the experimental dry test
- Use validated simulation to find optimal design conditions
- Begin experimental and simulation of room temperature fluid flow testing (i.e. "wet testing") of the sensor.