U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

ASI Advanced Sensors and Instrumentation

Linear Variable Differential Transformers

Advanced Sensors and Instrumentation (ASI)

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Boise State University

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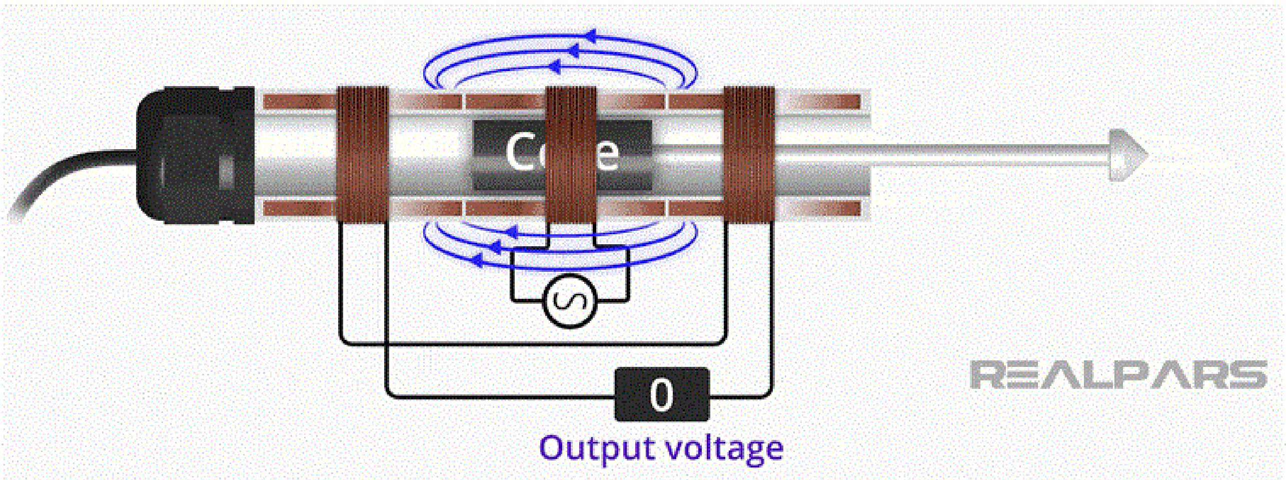
Project Overview

Motivation:

- Linear Variable Differential Transformer (LVDT) has enabled real-time pressure and dimensional measurements in fuel and fuel cladding during irradiations
- < 10% failure rate after 5 years of operation in boiling water reactor, pressurized water reactor, or Canada Deuterium Uranium reactor (>2200 different LVDTs in total)

Needs: The Institute for Energy Technology limit the availability of LVDTs

Objective: Identify potential suppliers of LVDTs that can meet the in-pile testing needs



Project Team

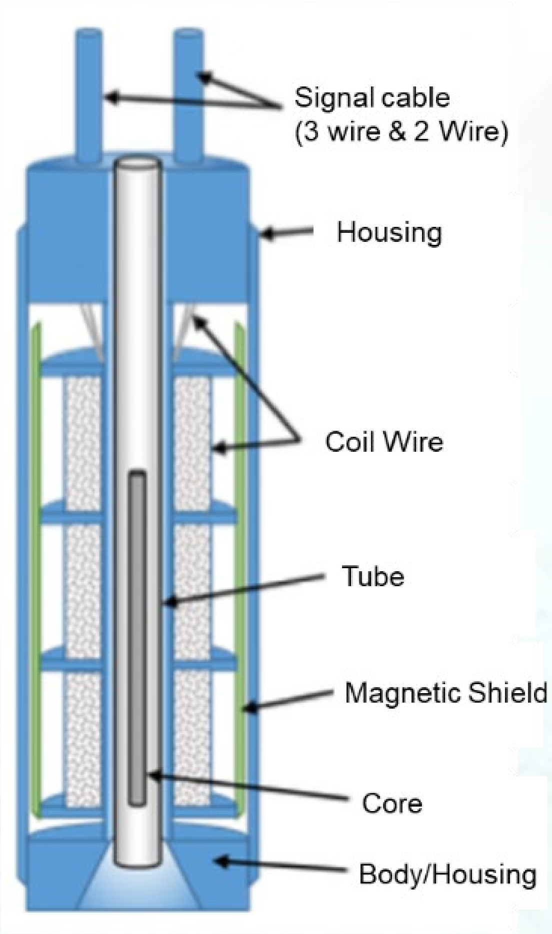
INL Lead: Kurt Davis, Malwina Wilding, Austin Fleming

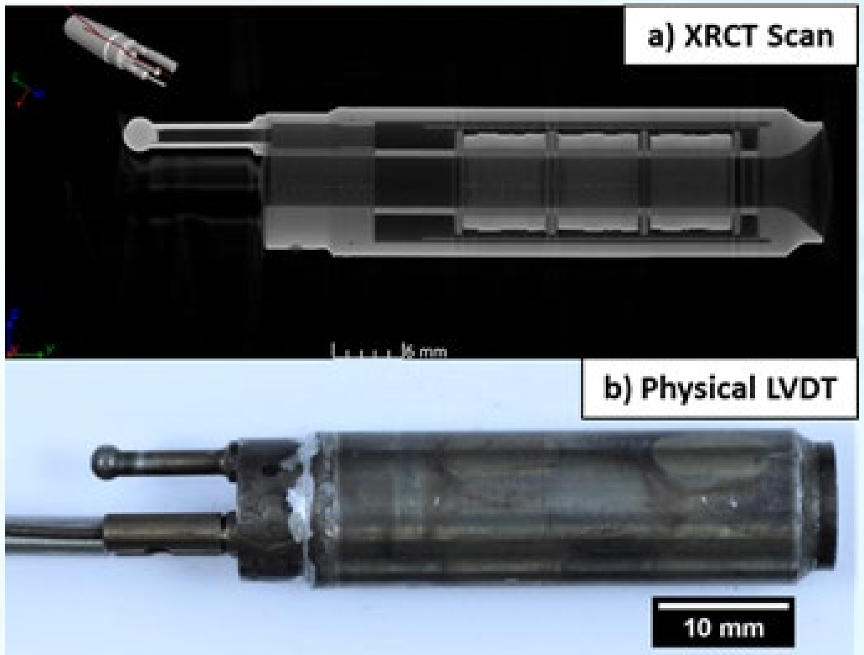
Graduate Students: N.A.

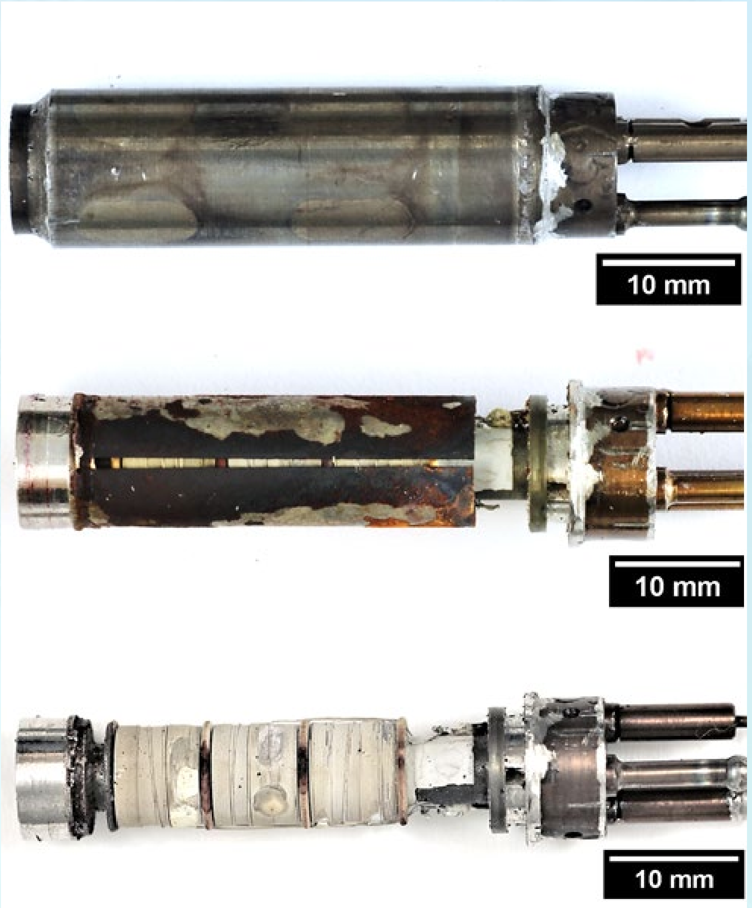
Undergraduates: Alex Draper, Joshua Poorbaugh

#1: Characterize Commercial LVDT

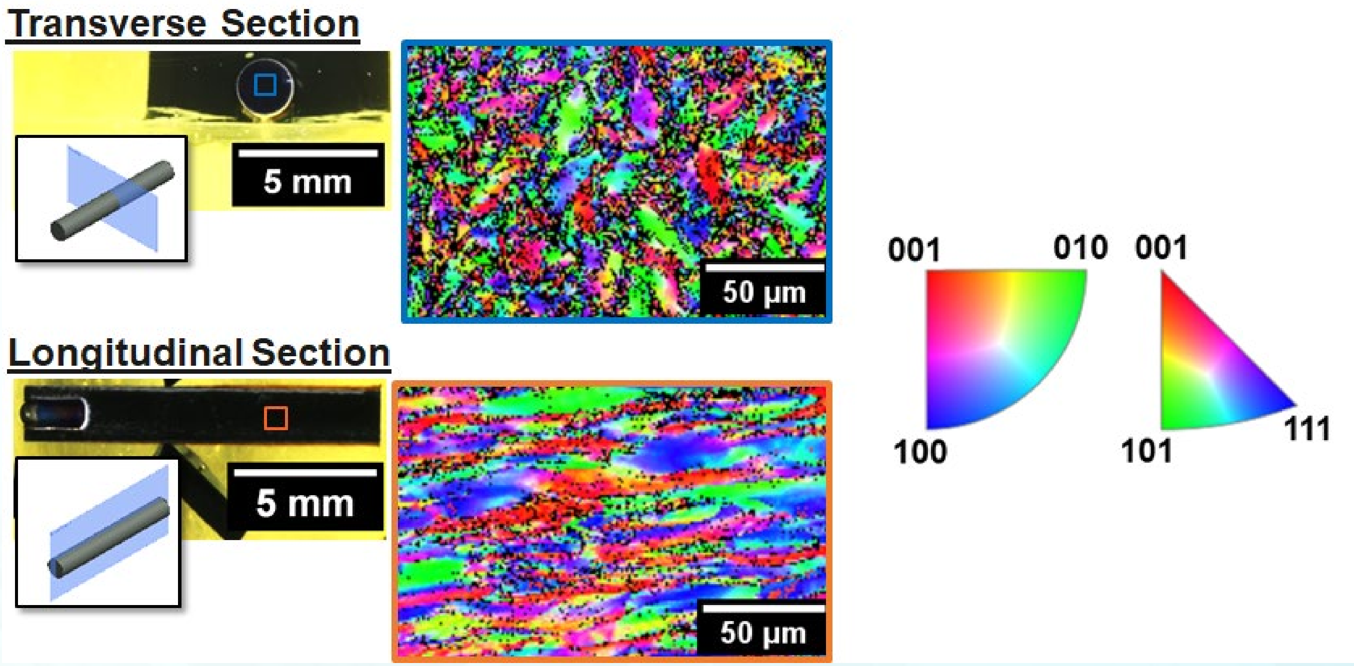
Task 1: Analyze LVDT dimensions and materials





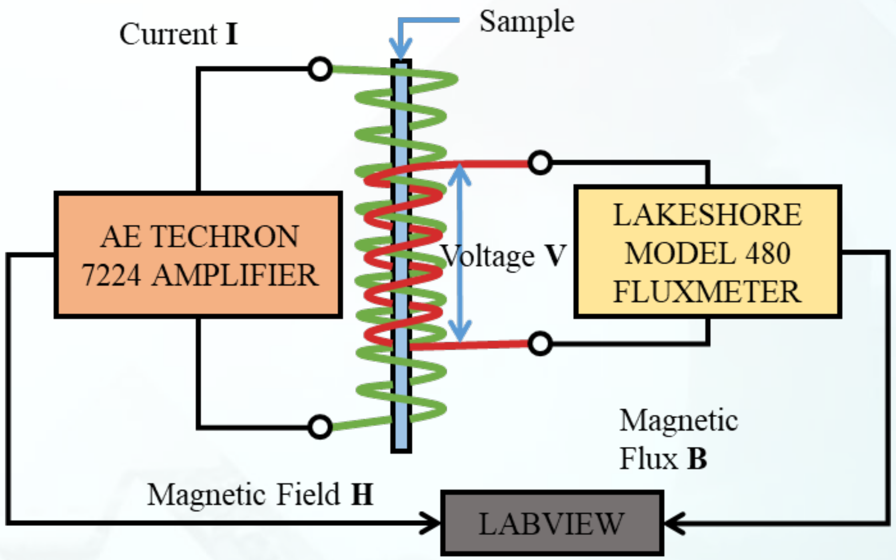


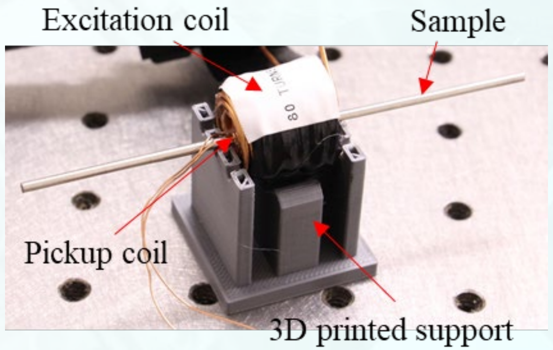
Task 2: Understand the chemical and microstructural properties of LVDT core



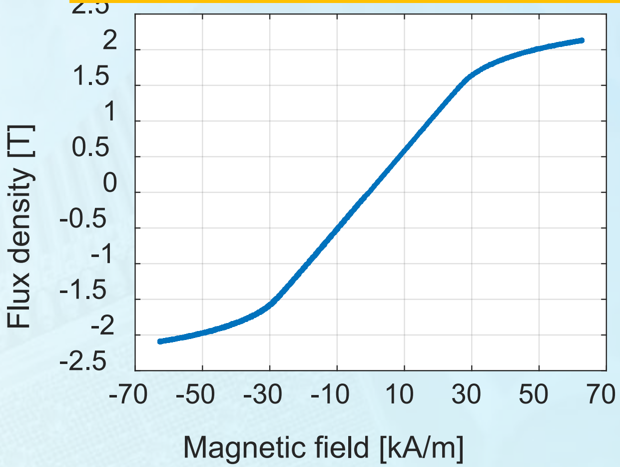
X-ray fluorescent (XRF) scan indicates 97.85 % of Fe and 0.52 % of Mn

Task 3: Understand the magnetic properties of LVDT core

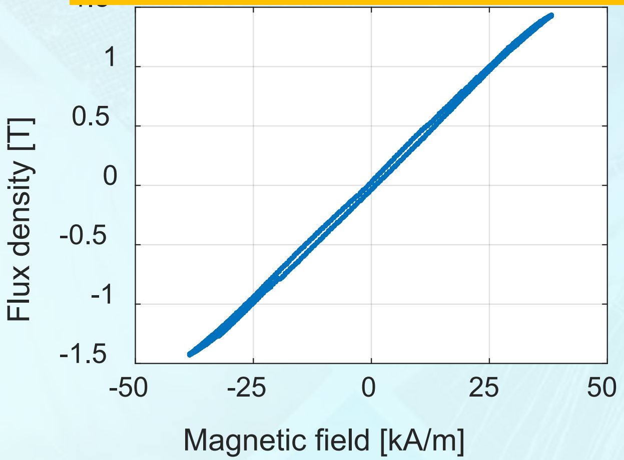




Magnetization (large field)

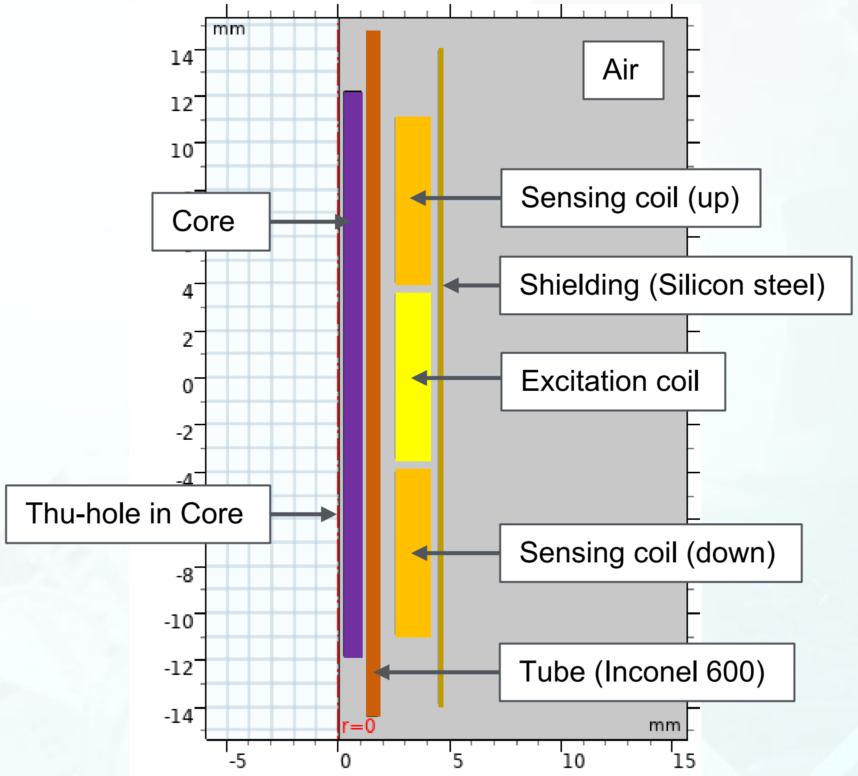


Magnetization (small field)

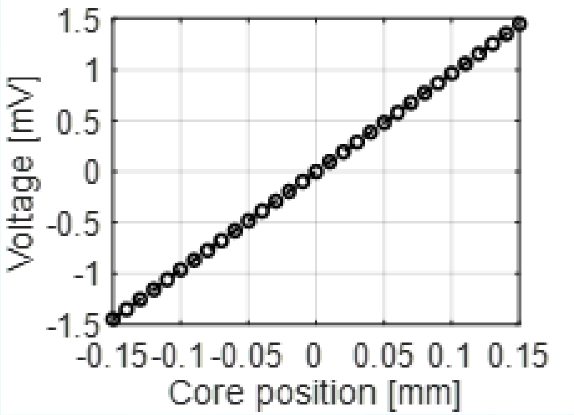


#2: Model Commercial LVDT

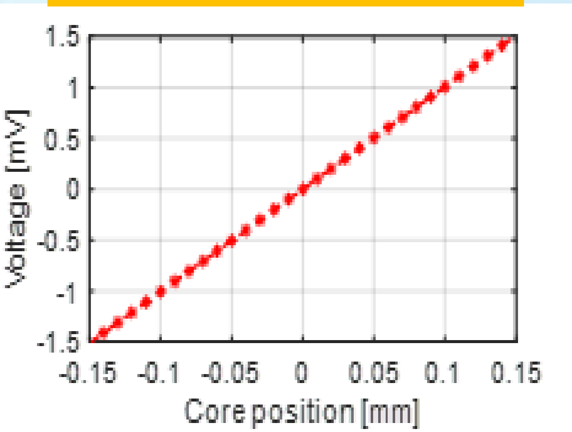
Task 1: Model the LVDT in COMSOL Multiphysics



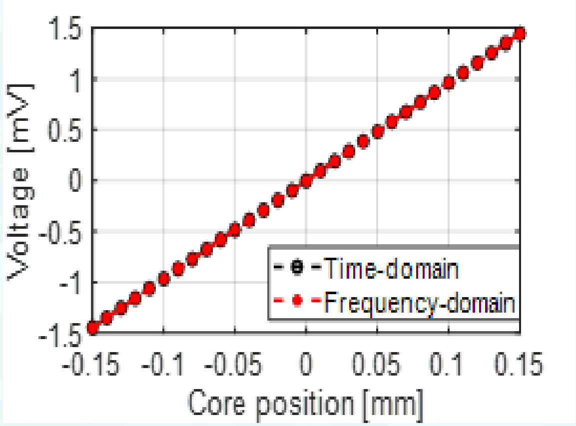
Time-domain (Nonlinear)

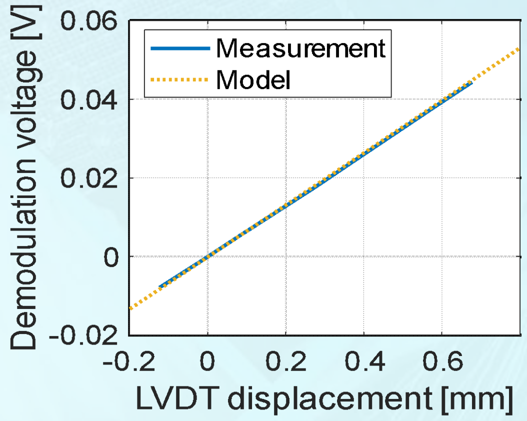


Time-domain (Linear)



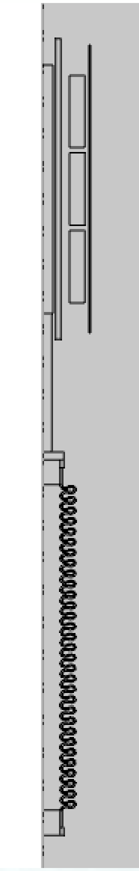
Frequency-domain (Linear)

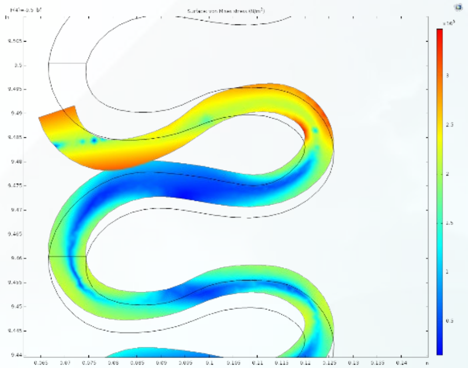


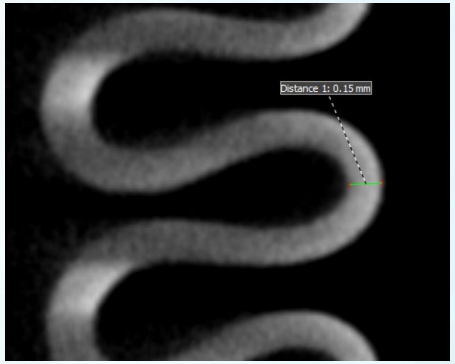


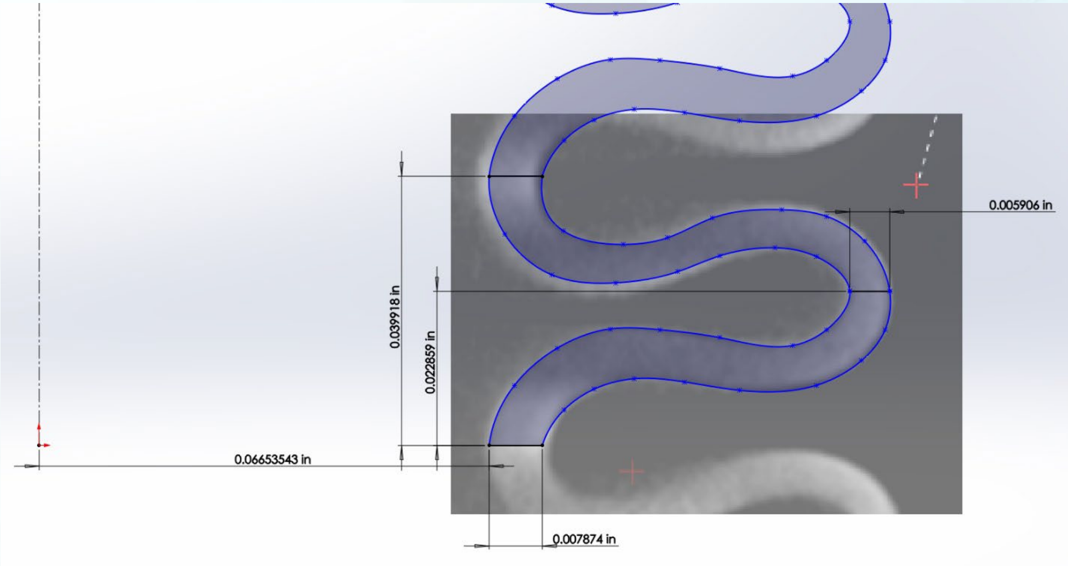
#3: Pressure Sensor Including LVDT and Bellows

Task 1: Recreate the bellow geometries in SolidWorks

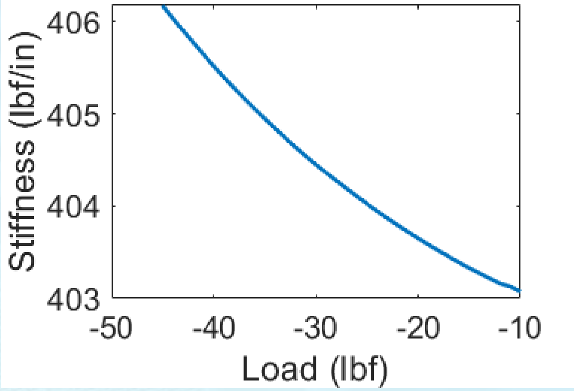




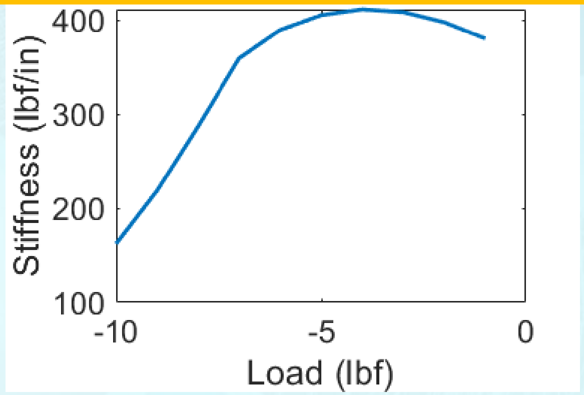




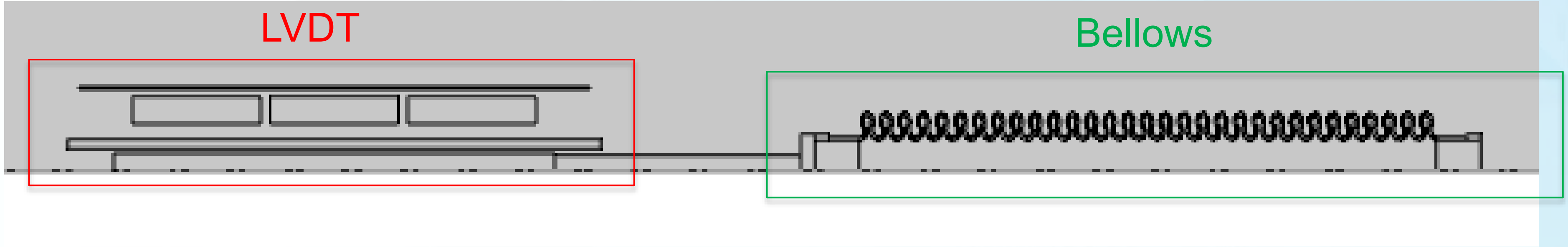
Stiffness vs. Load (Linear modulus)



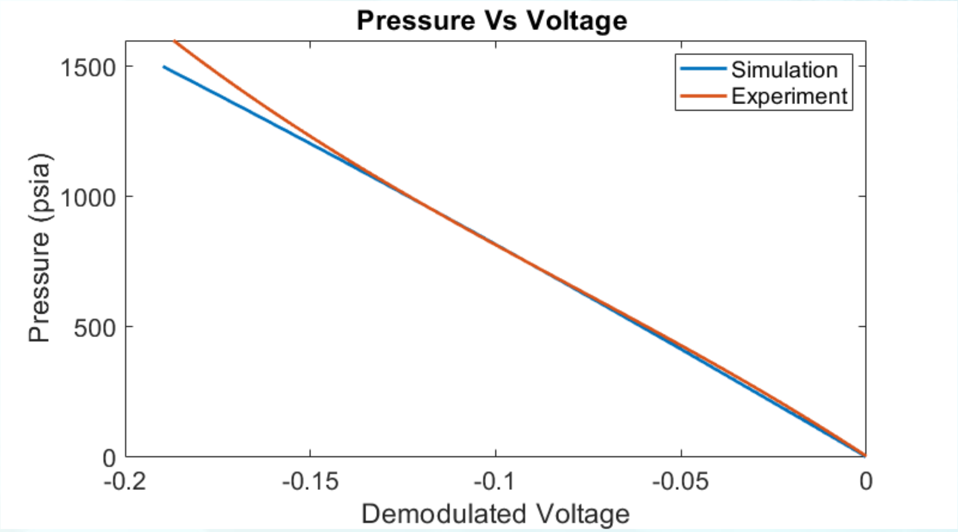
Stiffness vs. Load (Nonlinear modulus)



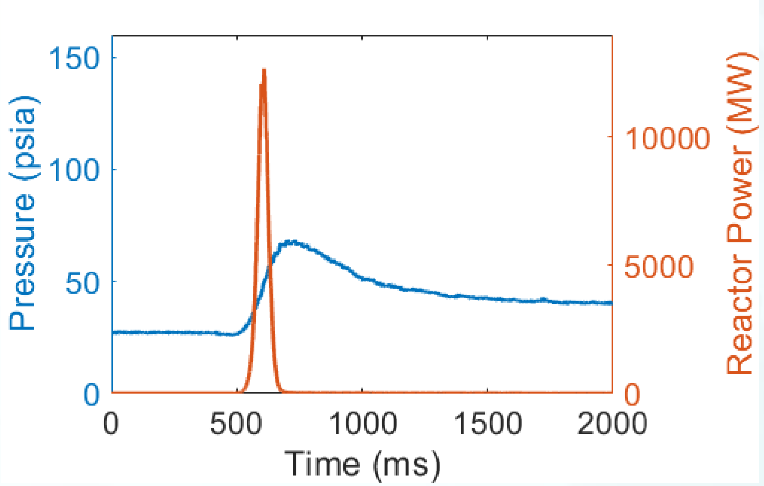
Task 2: Simulate the pressure sensor at room temperature

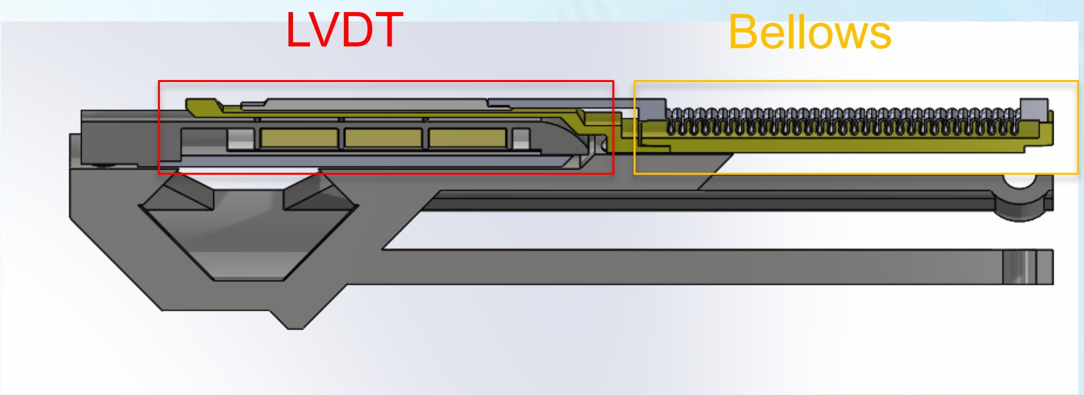


Impulse neutron radiation → Fission gas release → Pressure increment → Deformation of bellows → LVDT core displacement → Modulated voltage from LVDT



Task 3: Simulate the pressure sensor at high temperature



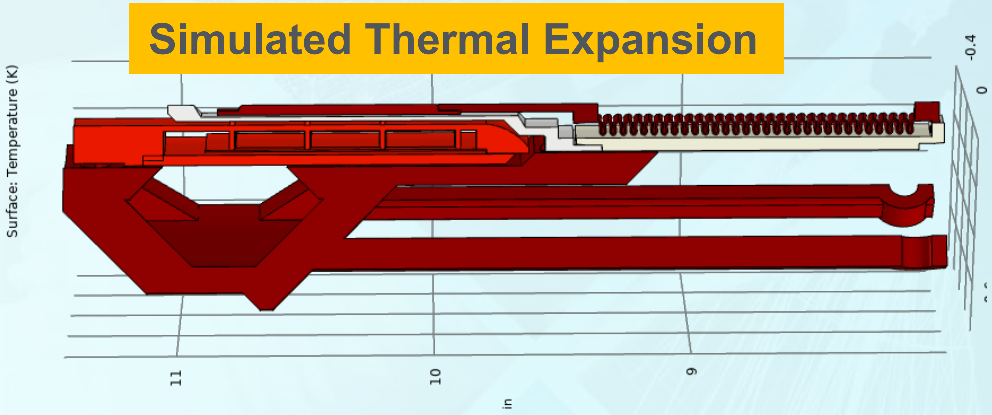


Problem

A pressure reading of 12.7 psi was observed immediately after the neutron radiation spike; fusion gas release from the fuel pellets becomes significant only after the first 2.5 seconds.

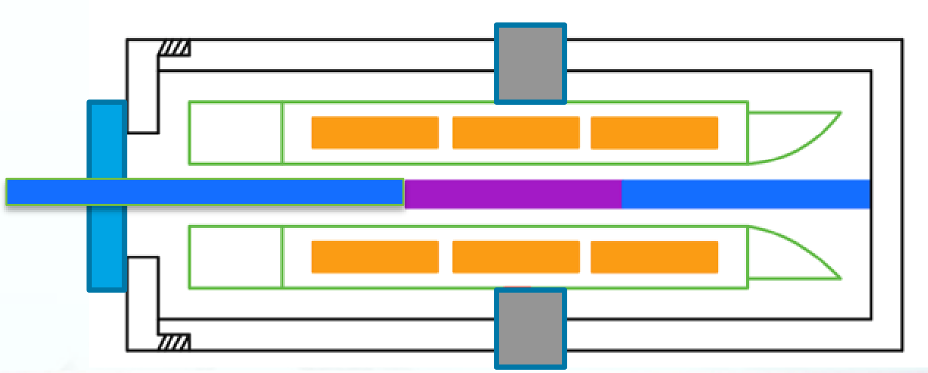
Hypothesis

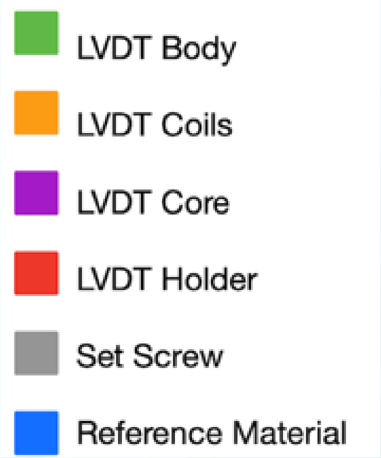
The transient response and steady-state response are due to the thermal expansion of the pressure sensor.

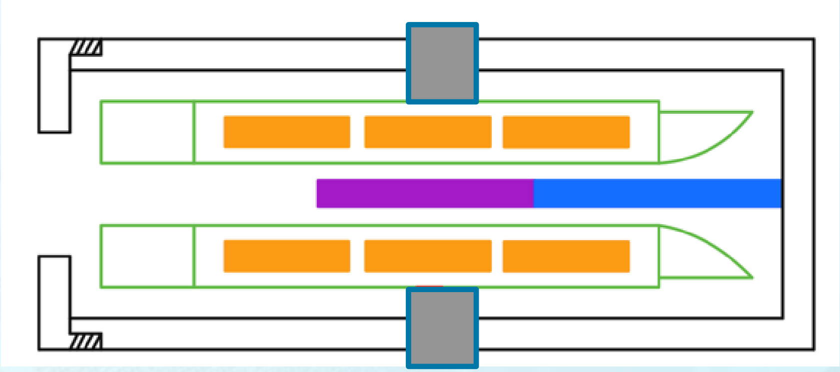


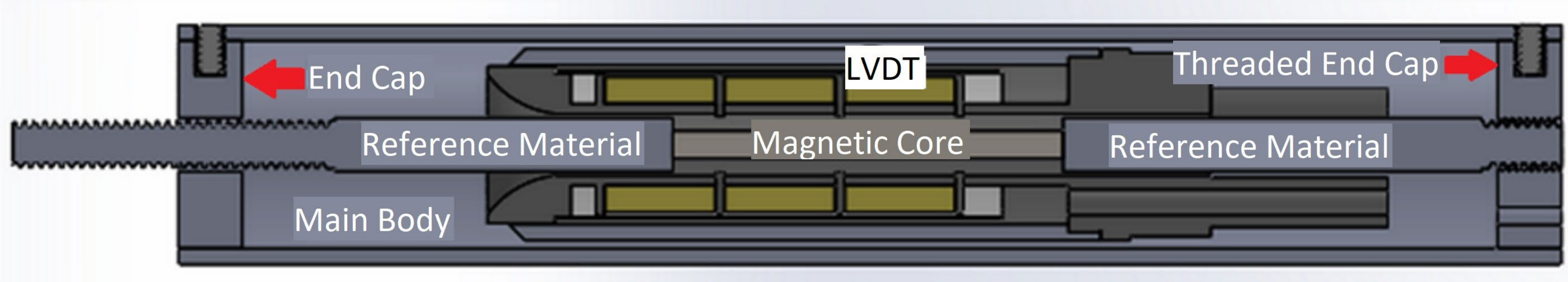
#4: Simulate Pressure Sensor at High Temperature

Task 1: Design a test rig that can generate controllable thermal expansion in LVDT, especially the relative deformation between the LVDT core and coils.



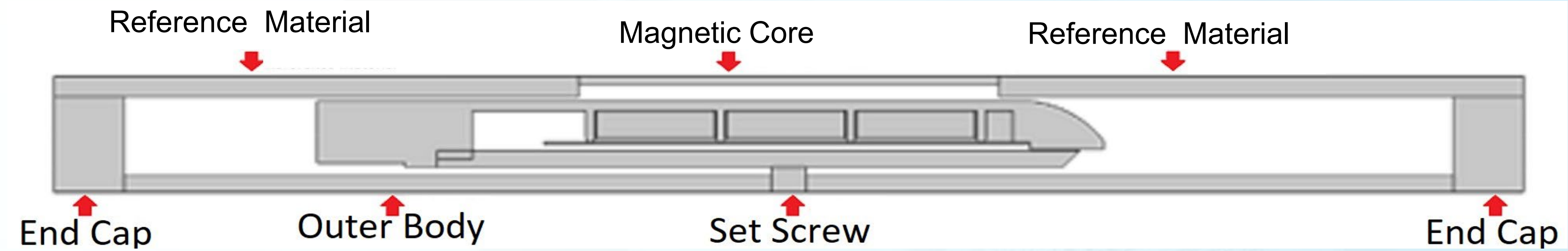




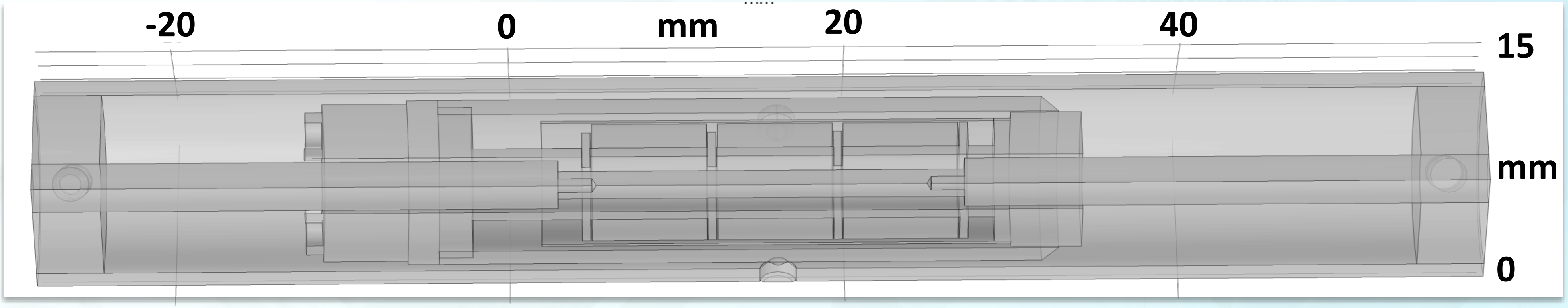


Task 2: Use finite element model to validate the design

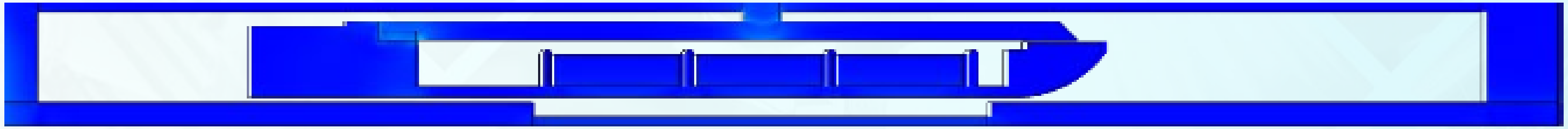
2D Model

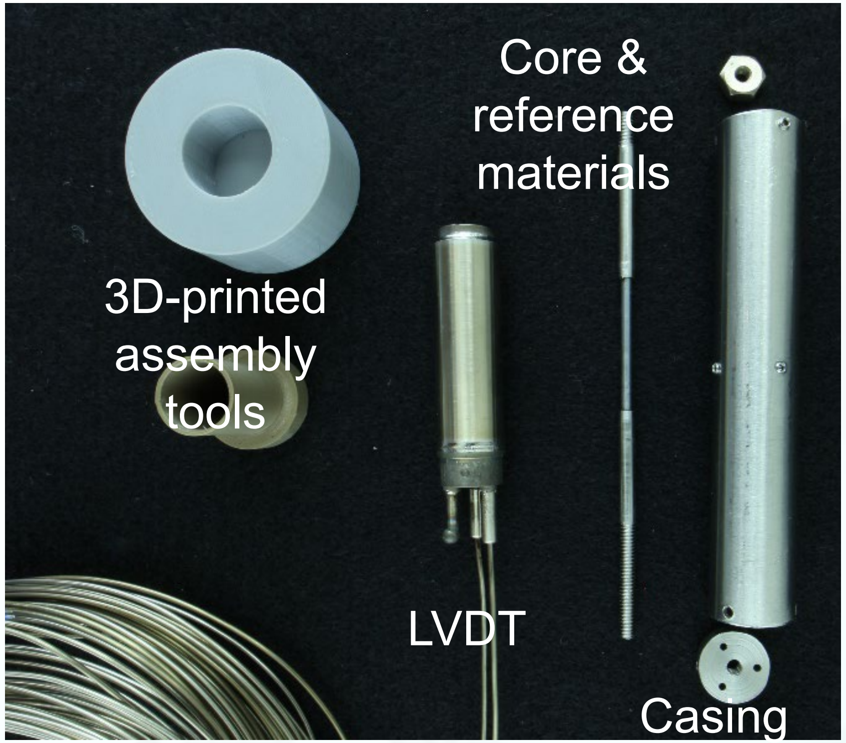


3D Model

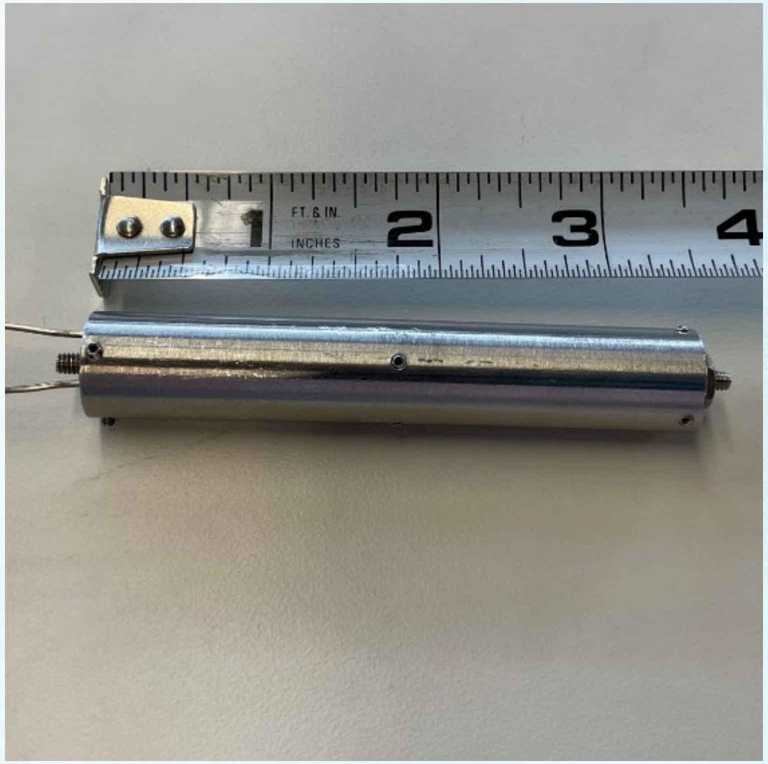


Thermal Stress

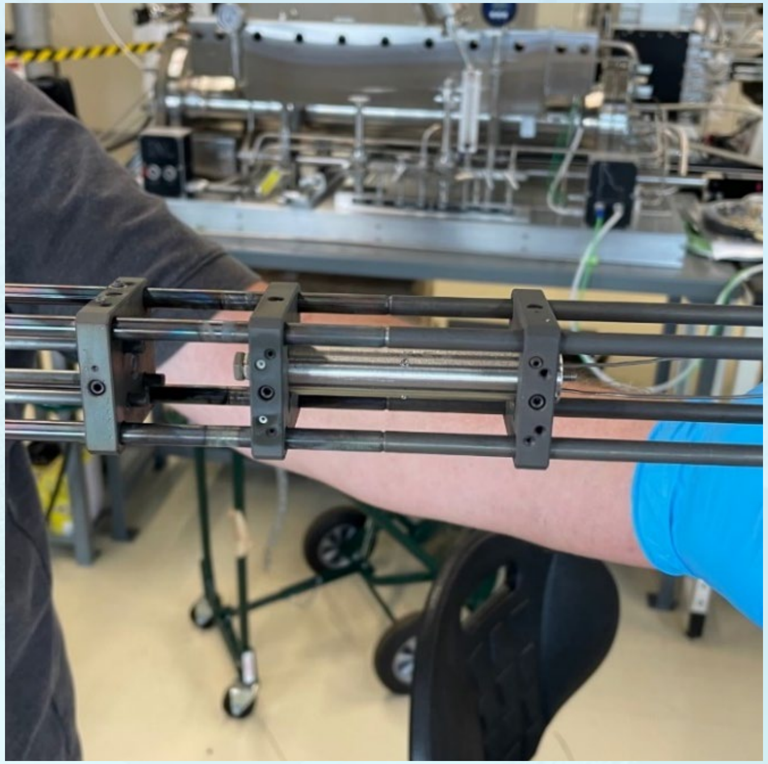




Setup #1 actual assembly



Setup for tube furnace testing



Run #1

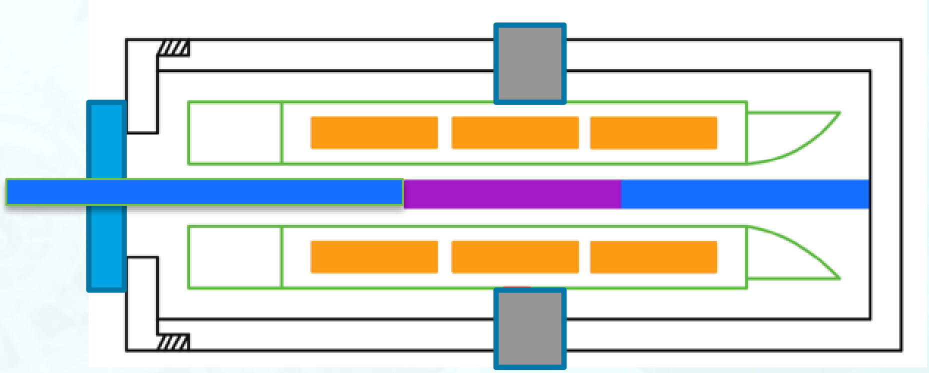
- Tested at 20, 200, 400, and 600°C
- Took 3-4 hours to reach thermal equilibrium between temperature settings
- Assembly was secured in two places in the support frame

Run #2

- Tested at 20,400, 600, and 700°C
- Took 3-4 hours to reach thermal equilibrium between temperature settings
- Assembly was secured in two places in the support frame

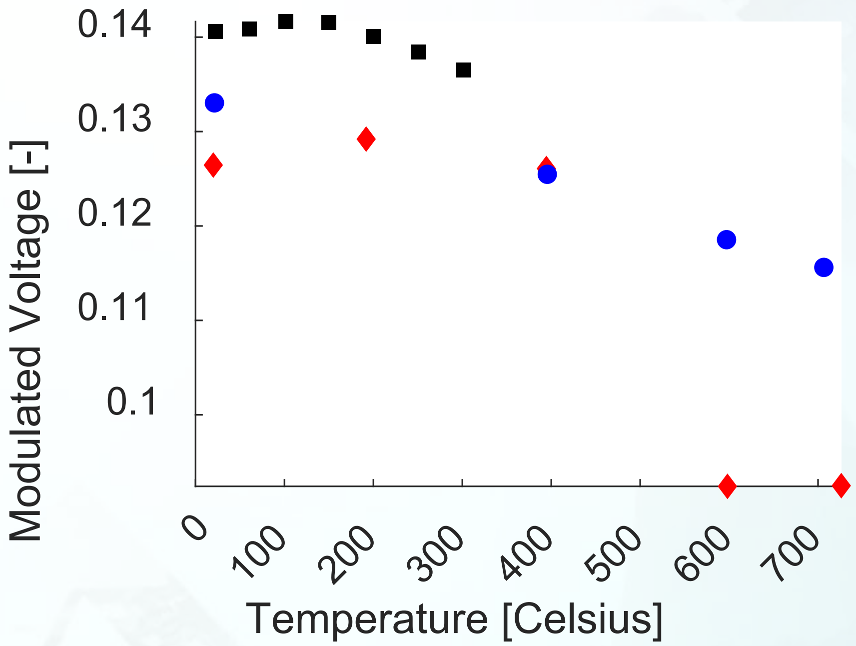
Run #3

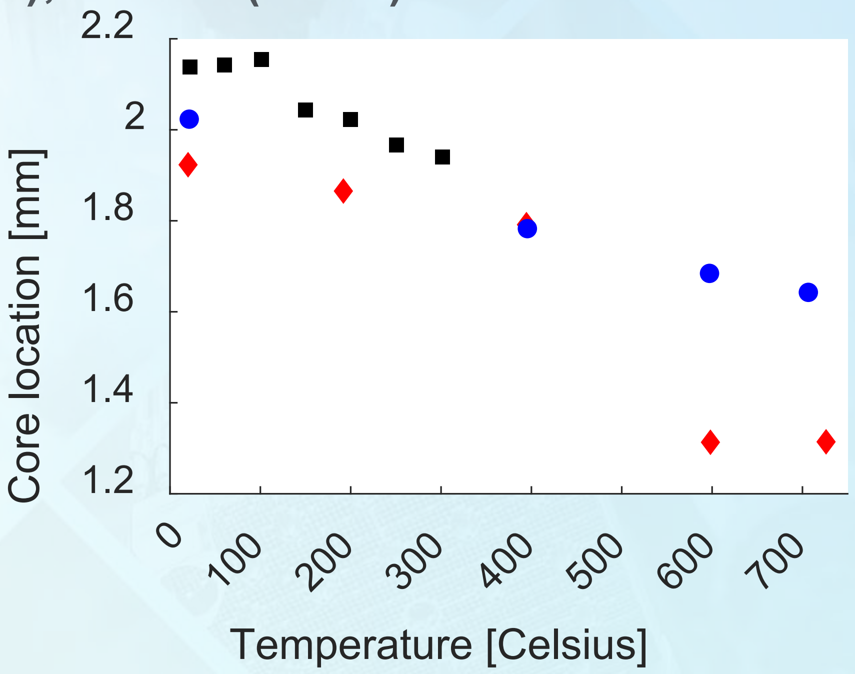
- Heated from 20 to 300°C, stopping at intervals of 50°C
- Did not wait to reach thermal equilibrium when collecting data
- Assembly was secured at one point

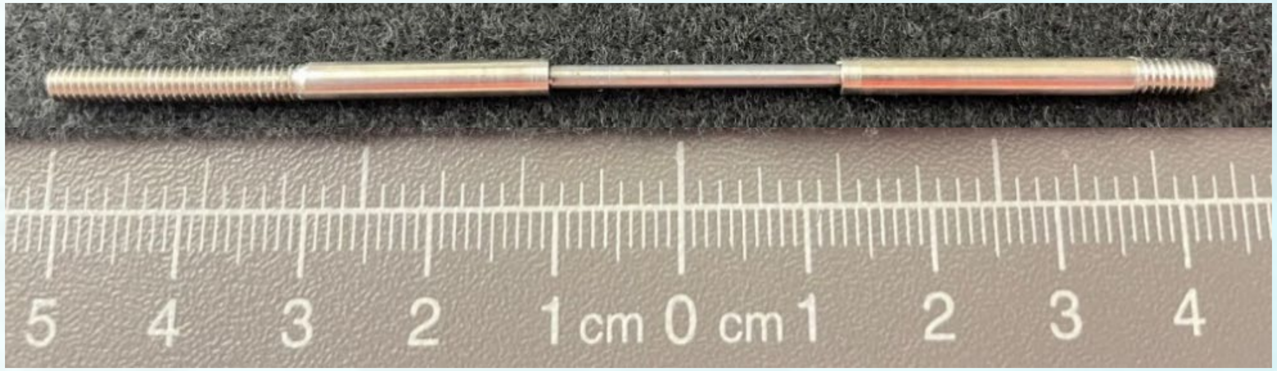


Tube Furnace Configuration

Run #1 (Blue); Run #2 (Red); Run #3 (Black)







Concluding Remarks

- An efficient and accurate model for LVDT has been developed
- The model can also accurately recreate the performance of the pressure sensor at room temperature
- Model accuracy at high temperatures still require experimental validation

Thank You