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

ASI | Advanced Sensors and Instrumentation

Linear Variable Differential Transformers (LVDTs)

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar

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Idaho National Laboratory

Project Overview

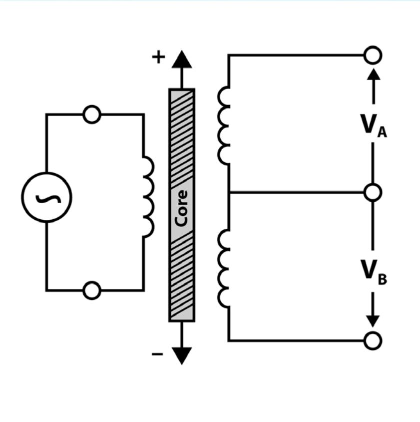
Background

- An LVDT (Linear Variable Differential Transformer) is an electromechanical transducer that converts the motion of an object into a corresponding electrical signal. Submicron motions are resolvable.

- Many phenomena produce, or can be used to produce, length changes which in turn can be measured and converted into a measurement of the phenomenon (e.g., pressure, temperature).

- The commercial LVDT device has proved to be a robust and versatile sensor, but it falls short when used at elevated temperature or when irradiated because of the materials used in construction.

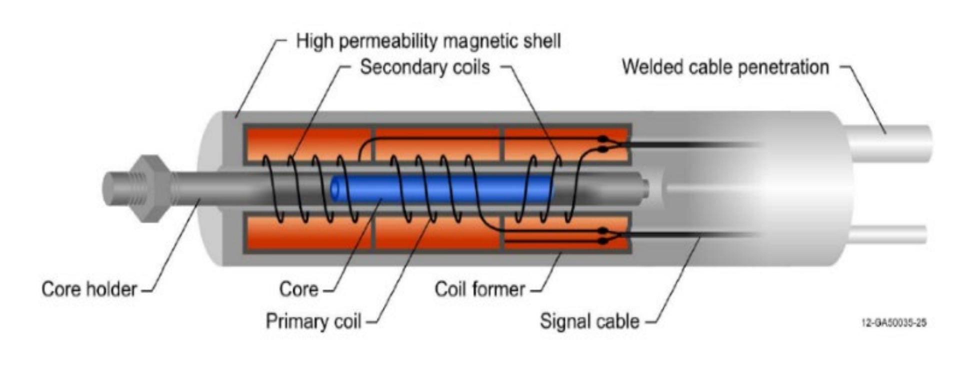
- Since 1965, IFE under the Halden Reactor Project has been developing irradiation resistant high-temperature LVDTs. They are the world leader when it comes to manufacturing LVDTs for irradiation testing.



D = (Va–Vb) / (Va+Vb)

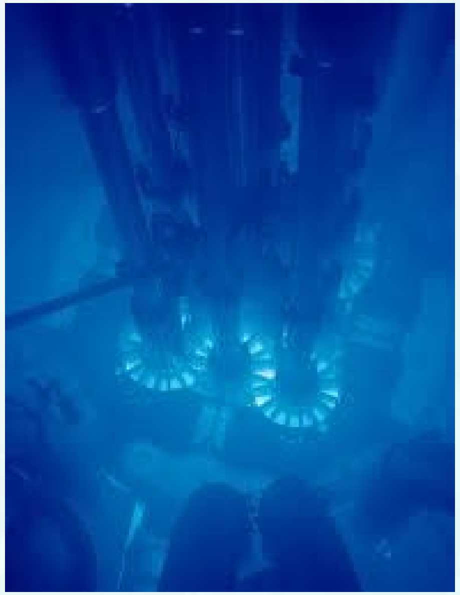
L = (Xm–Xc) / Stroke * 100%

Halden LVDT



Technology Impact 2023

Proof of Principle Test



THOR capsule fuel tests for DOE and Japan Atomic Energy Agency (JAEA)

Commercial LVDT

NEWTEK Sensor Solutions
Providing Custom Sensor Solutions

LVDT Development

Michael Marciante

MADE IN USA

INL
Idaho National Laboratory

LVDT Evaluation

Kurt Davis (PI), Austin Fleming, and Malwina Wilding

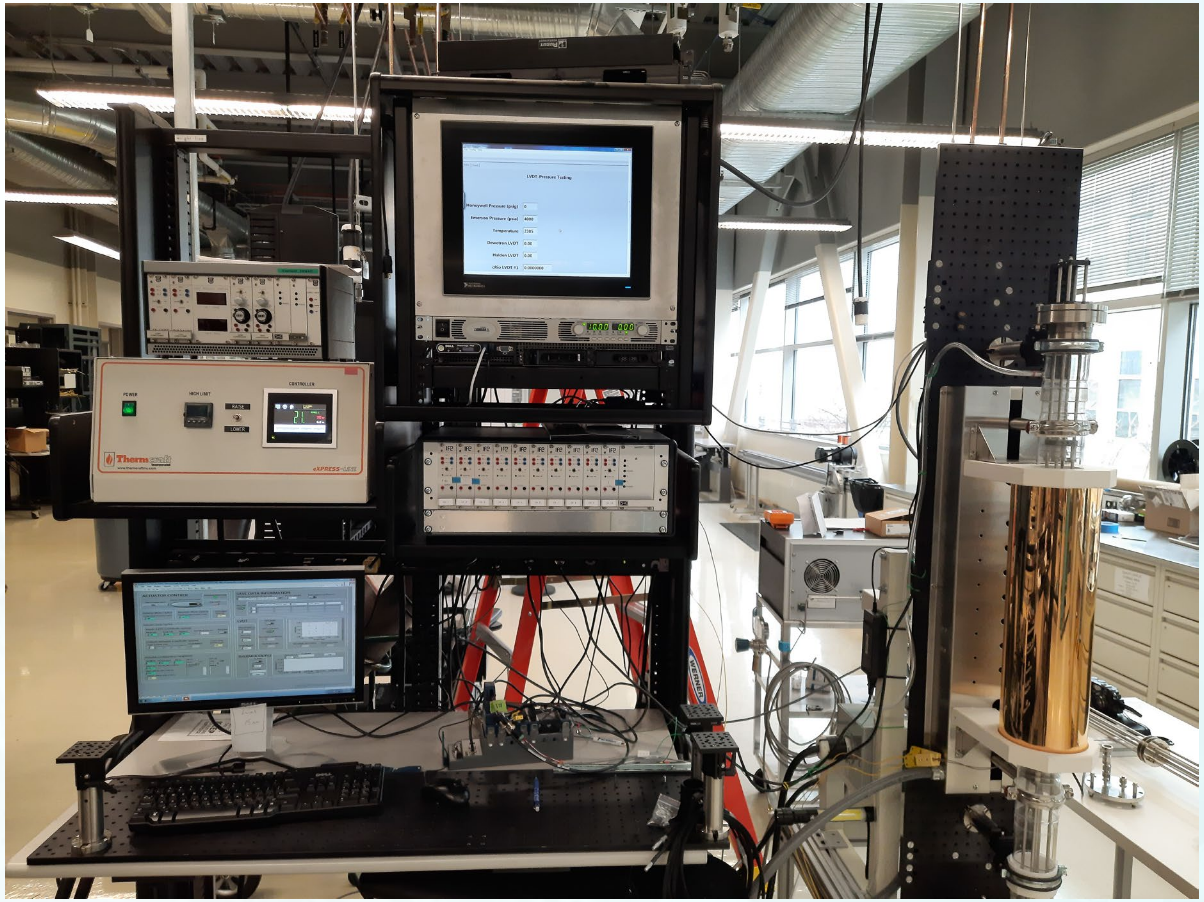
Commercial LVDT

LVDT Desired Performance

- Operate in ATR PWR loops: The peak thermal flux is 1x1015 n/cm^2-sec and fast flux is 5x1014 n/cm^2-sec. Coolant temperature, pressure and water chemistry similar to commercial PWR operating conditions.
- Stroke of +/- 2.5 mm with 0.5% linearity or better
- Driven at 5000 Hz @ 7 V
- Operate in inert atmosphere at 700 C
- Interface to current INL test hardware
- Similar to IFE's Type 5 Short LVDT in form, fit and function

LVDT Evaluation

Testing



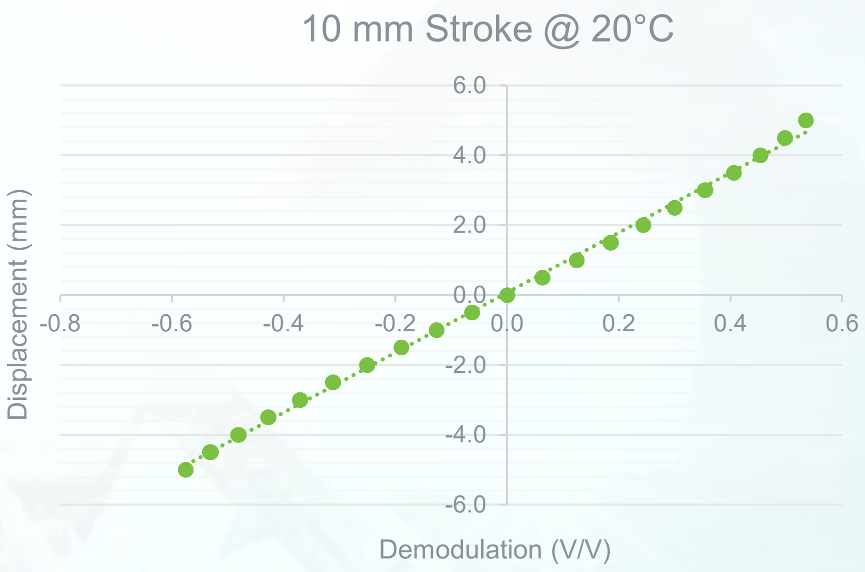
Vertical orientation

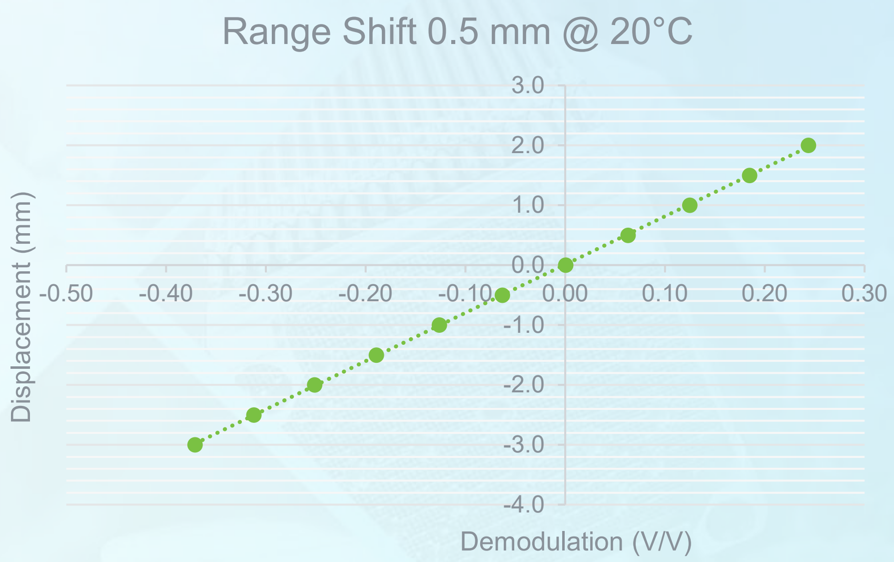
Test temperature 20, 100, 200, 300, 400, 500, 600°C

Ultra pure argon @ 2 l/m

Data collected beyond full range of motion 5 mm

LVDT Evaluation





LVDT Evaluation

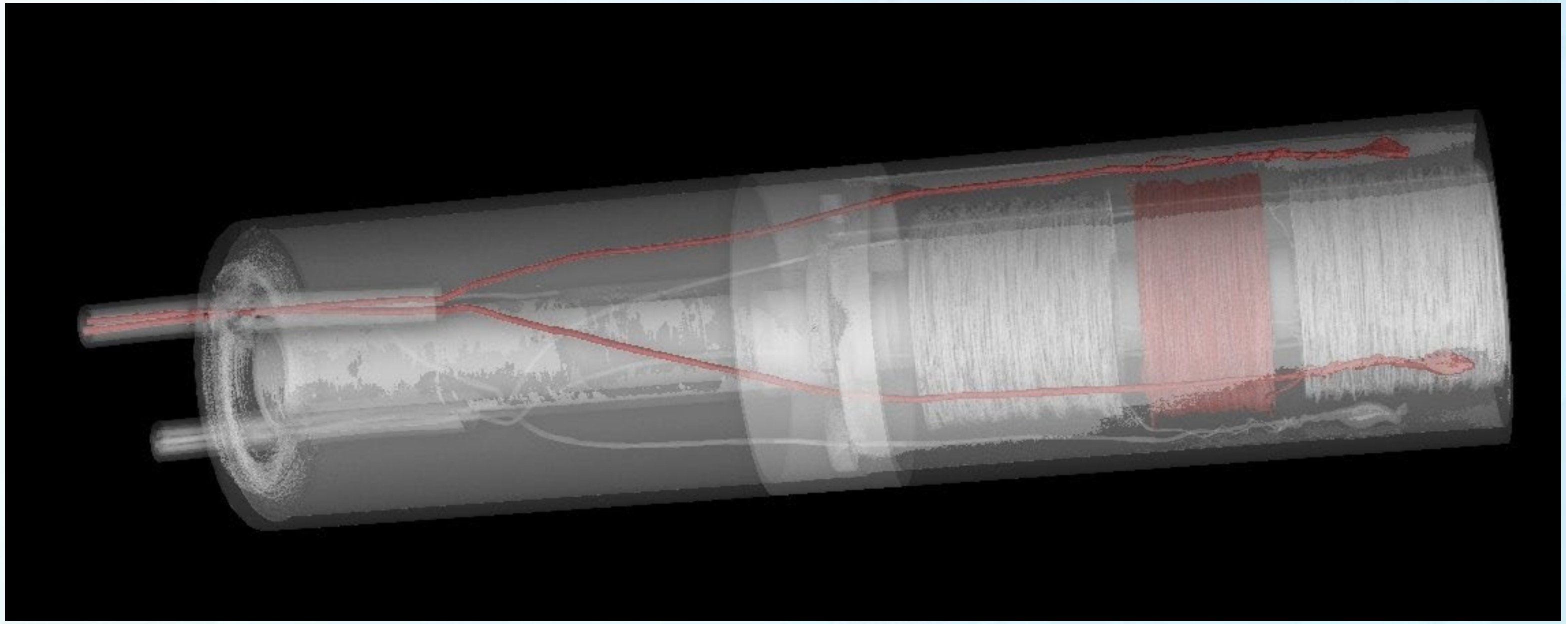
Temperature	Linearity	Sensitivity	Resolution Test (linearity)	Repeatability Test, 1σ (Top of Stroke)	Repeatability Test, 1σ (Bottom of Stroke)
20°C	0.4%	0.124 (V/V)/mm	0.7%	0.4 μm	0.5 μm
100°C	0.4%	0.126 (V/V)/mm	0.2%	0.2 μm	0.6 μm
200°C	0.4%	0.126 (V/V)/mm	0.3%	0.4 μm	0.6 μm
300°C	0.3%	0.126 (V/V)/mm	0.4%	0.6 μm	1.2 μm
400°C	0.8%	0.131 (V/V)/mm	0.8%	2.6 μm	7.3 μm

Failure Analysis

- Testing at 500° C was halted due to the prototype LVDT's cessation of operation.
- The core has a curie temperature of 450° C so a loss of operation was anticipated at 500° C.
- Returning to 20° C, the LVDT remained non-functional. This result was not anticipated.
- Resistance measurements between conductors and sheath indicated potential physical damage within the LVDT body. Ordinarily, such measurements yield values equal to or greater than 10 GΩ.
- Post-failure readings were considerably lower, with primary conductors registering 1 KΩ and secondary conductors at 0.5 KΩ.
- Future Newtek LVDT designs will have ferritic cores with curie temperatures in excess of 700° C, however this testing revealed the need for additional design changes.

NDE

- Computed Tomography (CT) scans were employed to construct intricate 3D models of the LVDT before and after testing. Primary coil and conductors are red.



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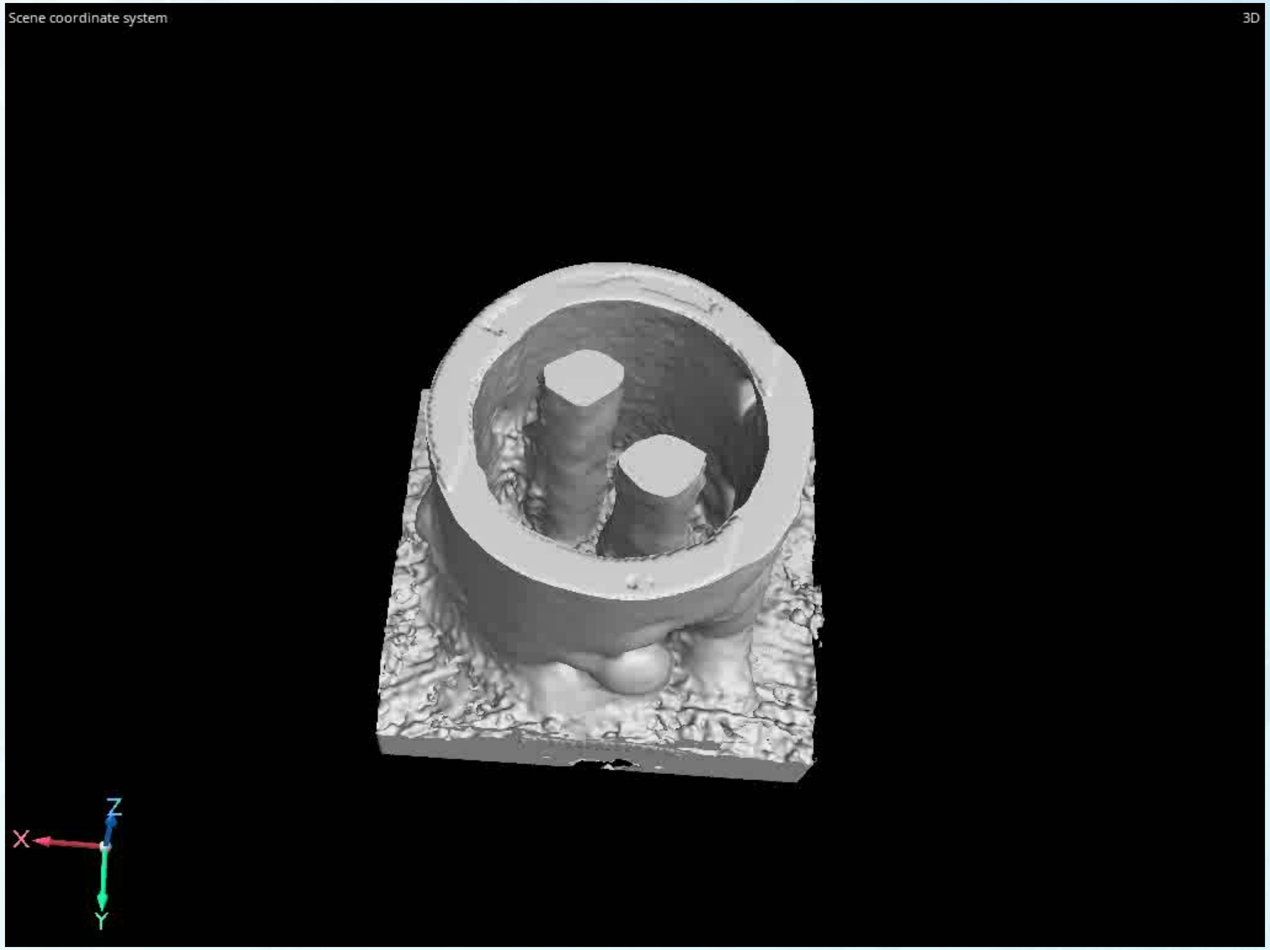
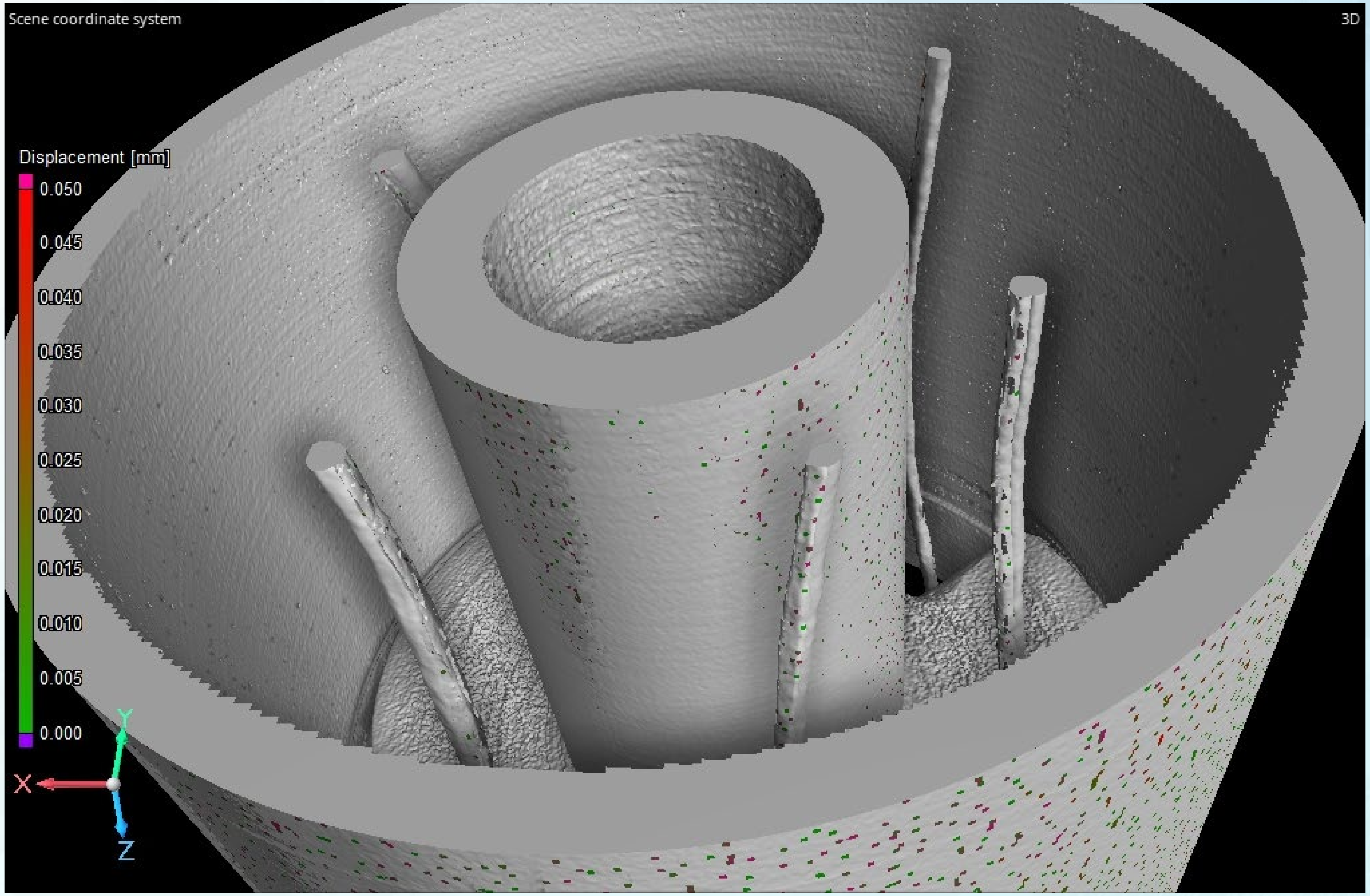
- CT interrogation of weld area, where the primary mineral insulated cable was joined to the body.
- Discernible leak path within the weld.
- Receipt inspection 0.7 GΩ
- Test initiation, 85 MΩ.
- H_2O diffusion into the primary cable.



NDE

- A displacement analysis was conducted on the 3D models generated pre- and post-test.
- The disparity between the two models was minimal.
- No movements capable of causing a short between any of the conductors and the LVDT body were identified.



Destructive Examination

- Following testing at INL, the LVDT was returned to Newtek Sensor Solutions for a comprehensive destructive examination.
- LVDT was received with the primary conductor shorting to the case, and the secondary conductors were found to be entirely open.
- Upon cutting open the body, it was discovered that the secondary conductors were severed at the point of exit from the MI cable.
- Another noteworthy observation during the destructive examination was a condition where the primary conductors intermittently shorted to the case while manipulating sleeving covering them near the exit from the MI cable.

Concluding Remarks

- The comprehensive evaluation of the Newtek Sensor Solutions prototype LVDT has provided valuable insights into its performance.
- Linearity, a critical factor in precise measurements, remained within acceptable limits for all tests conducted below 400° C, with a slight deviation of 0.8% observed at 400° C. Sensitivity demonstrated stability over the temperature range, with minor increases noted just above room temperature and at 400° C. The prototype LVDT exhibited remarkable responsiveness to minute 10 μm step motions, surpassing the targeted linearity of 0.5%. Repeatability was robust, with 1σ values consistently meeting expectations.
- Testing at 500° C led to the prototype LVDT's cessation of operation, attributed to its curie temperature limit of 450° C. Unexpectedly, the LVDT remained non-functional even after returning to 20° C, indicating physical damage within the LVDT body.
- Computed Tomography (CT) scans revealed a discernible leak path at the weld area, necessitating a reevaluation of the welding technique.

Concluding Remarks

- Newtek Sensor Solutions will provide a new prototype LVDT in early 2024 with design changes guided by the insights gained from testing.
- Testing will be repeated in 2024 with the expectation that the new commercial LVDT exceed current capabilities.

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Thank You