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RESEARCH SYMPOSIUM

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Flexible Pipe Wire Failure Detection Using Large Format, Linear-Drive ET-Arrays

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Notice

The initial abstract included additional authors based in Brazil that were not able to obtain approval from their customer for their part of the originally planned presentation. Accordingly, this presentation only includes the work of the US-based authors (as listed on the cover slide).

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Abstract (Updated)

Wire armor failures in flexible pipes occur due to stress corrosion cracking and fatigue. There is a need to inspect wire armor in offshore deep-water pipes having 10 to 70 mm of thermal insulation. The simplest application is for relatively thin insulation and two layers of wire armor (inner and outer). Insulation can be as thick 70 mm but the majority of flexible pipes have insulation under 50 mm thick. This presentation will introduce a large format, linear-drive eddy current array sensor ("MWM-Array") suitable for this application. A flat riser wire test bed has been created to evaluate the MWM-Array's sensitivity to wire failures. Results on the flat riser wire test bed show promising sensitivity even for thick insulation. This presentation will also provide background on the large-format MWM-Array technology, a comparison of the MWM-Arrays and instrumentation to multiplexed ET-array systems, a discussion of sensor fabrication, and a brief discussion of future work.

Overview

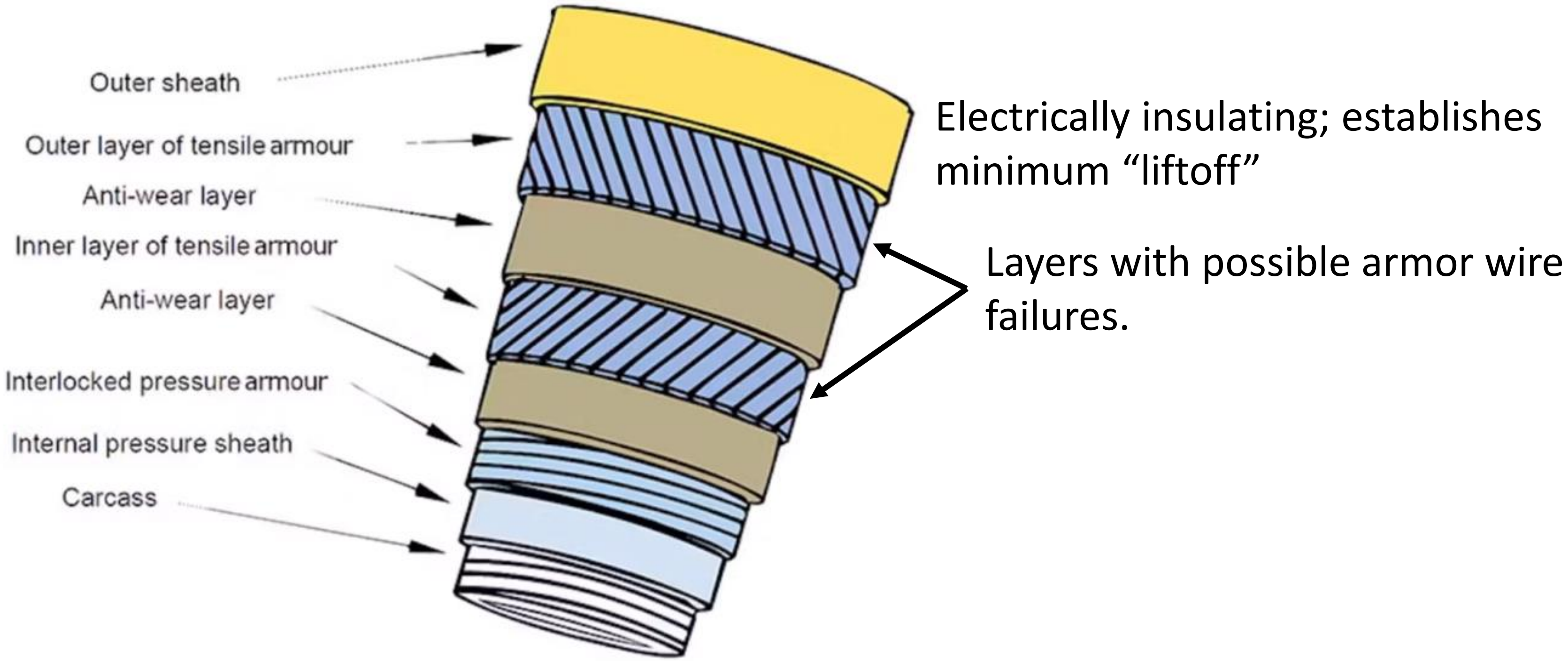
- Problem Definition
- Approach
- Linear drive eddy current arrays (“MWM®-Arrays”)
- MWM-Arrays vs. Multiplexed ET Arrays
- Fabrication of Large Inductive Arrays
- “Flat Riser” Test Bed Validation Measurements
- Future Work

Pending Patent Applications

PCT/US24/33312 “Sensor and Scanning System and Method for Risers and Other Test Objects”, JENTEK Sensors Inc., Neil Goldfine and Todd Dunford, June 10, 2024 with priority claim to 63/507,435 “Inductive Sensing Solution for Deep Water Risers and Other Applications,” June 9, 2023 and to 63/611,519 “Sensor System and Method of Manufacture and of Use,” December 18, 2023.

Problem Definition

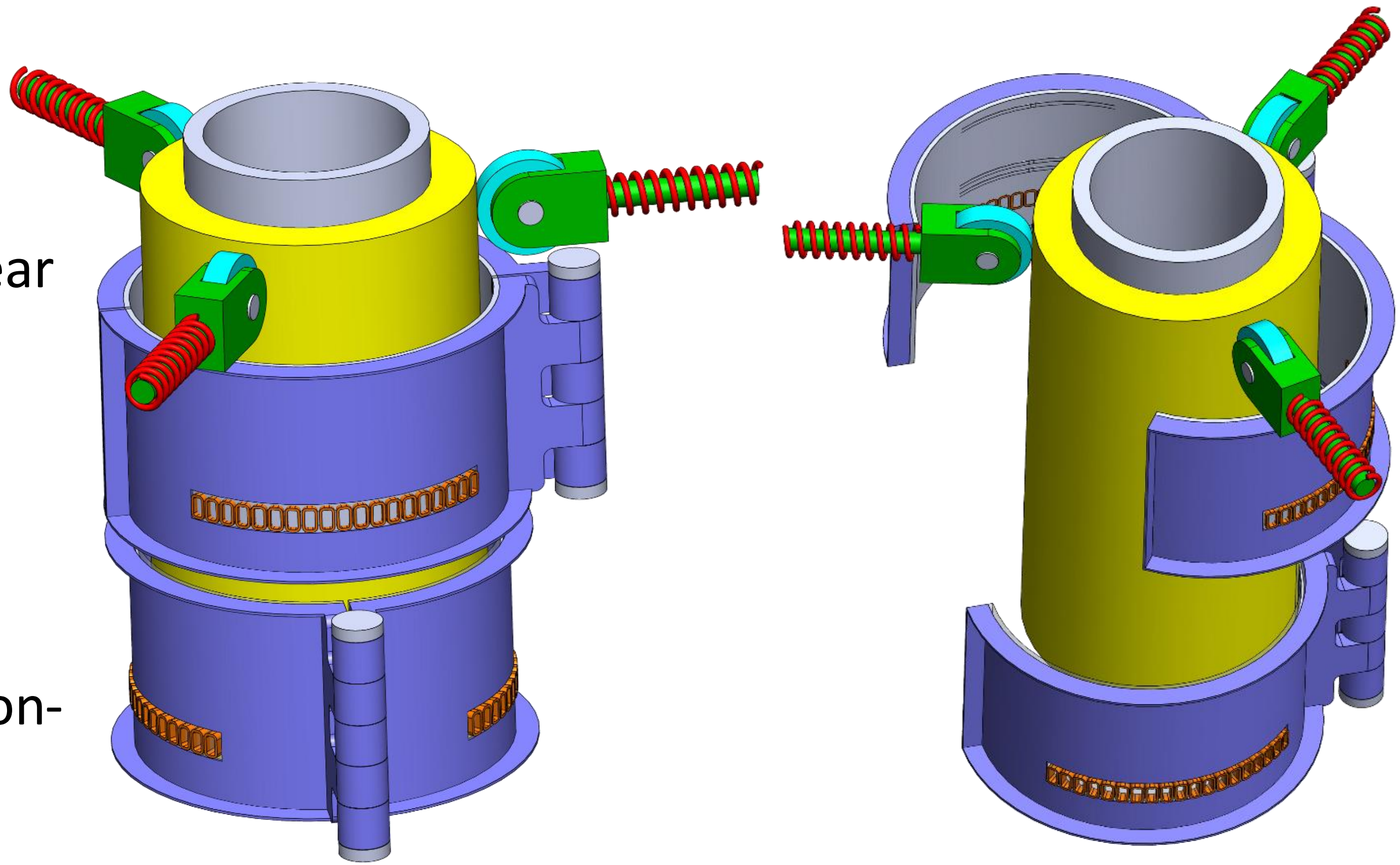
- Goal is to Inspect flexible risers for armor wire failures (cracks & wire breaks)
- Failure caused by stress corrosion cracking (SCC) and/or fatigue.



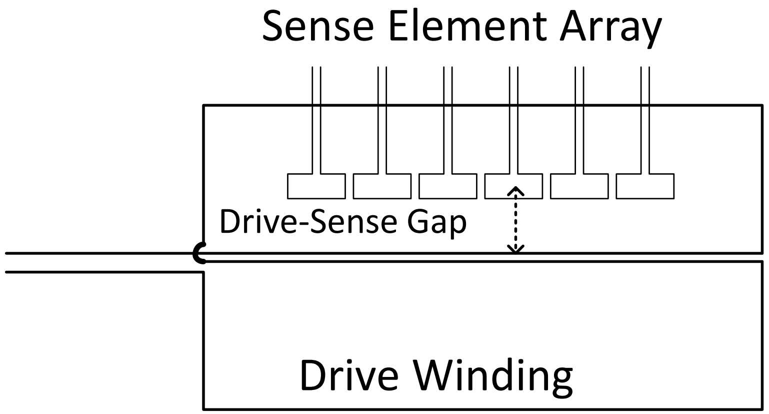
Example Riser Cross Section

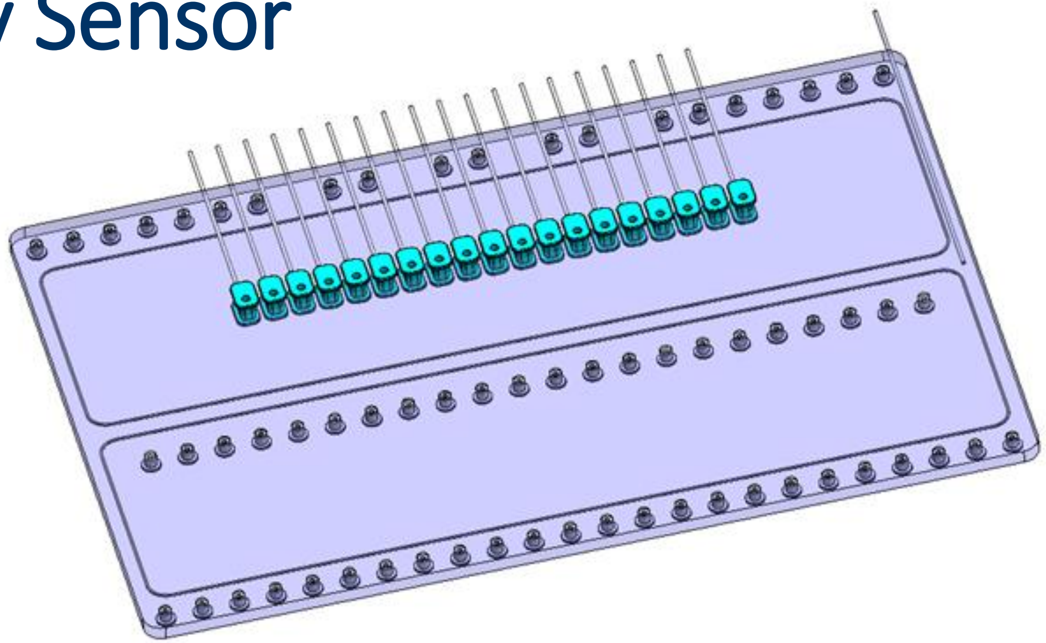
Approach – Full Coverage Axial Scanning

- **Axial scanning** with marinized Linear MWM-Array sensor system.
- 4 MWM-Arrays to provide **full circumferential coverage**.
- Rigid scanner maintains sensor geometry; suspension wheels to maintain concentric position for non-contact scanning.



19-Channel MWM-Array Sensor





MWM-Arrays vs. Multiplexed ET Arrays

When comparing scan speed, scan width, and detection capability of MWM-Arrays to more common multiplexed ET-Arrays, it is important to define:

- Digital resolution – measurement per second per channel in scan direction; channel pitch in the transverse direction
- Total scan width (single row arrays) equals number of sensing elements times sensing element pitch (more rows, divide by number of rows)
- Drive conductor geometry (e.g., linear)
- Sensing element footprint
- Number of physical channels in the instrument

MWM-Arrays vs. Multiplexed ET Arrays

MWM-Arrays

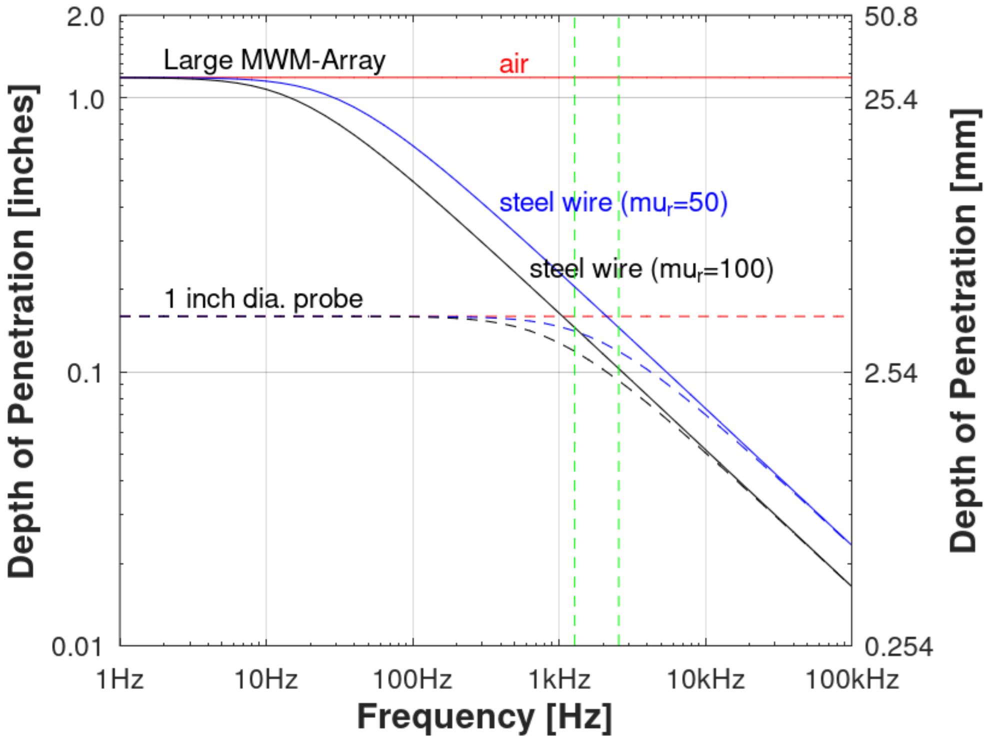
High Resolution Deep Penetration Imaging

Large single rectangle or dual rectangle drive with linear array of small sensing elements at a fixed drive-sense gap. Large drive-sense gap enables deep presentation while retaining high resolution.

Multiplexed ET Arrays

High Resolution Imaging without Deep Penetration

Multiplexed arrays generally do not provide both deep penetration and high resolution at the same time. Large ET coils can provide deep penetration at low frequencies but without higher resolution.



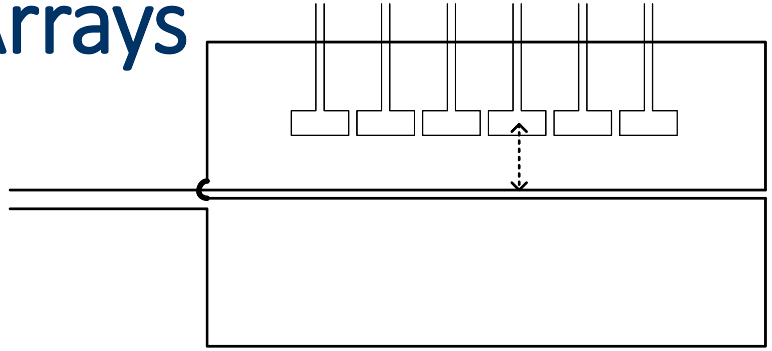
Depth of Penetration = 1/Re(Γ_n)

$$\Gamma_n = \sqrt{(2\pi n/\lambda)^2 + j2/\delta^2}$$

Low Frequency Limit = $\dfrac{\lambda}{2\pi}$

Skin depth: $\delta = \sqrt{\dfrac{1}{\pi f \mu \sigma}}$

MWM-Arrays vs. Multiplexed ET Arrays



MWM-Arrays

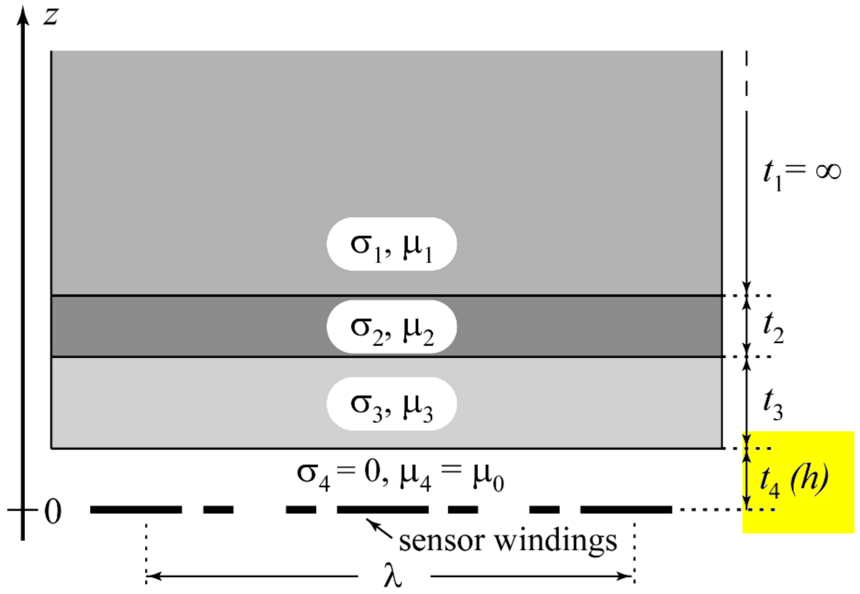
Physics Model Based Data Analytics and no Crosstalk

Drive and sense construct is designed to eliminate difficult to model behavior. Sense elements provide independent responses without crosstalk.

Multiplexed ET Arrays

Challenging Physics Based Modeling and Crosstalk

Winding constructs provide varied magnetic field across the footprint and neighboring sensing and drive elements produce substantial crosstalk.



t_4 (*h*) is the sensor "liftoff" – the distance from the sensor to the first electrically conducting or magnetically permeable layer.

MWM-Arrays vs. Multiplexed ET Arrays

MWM-Arrays

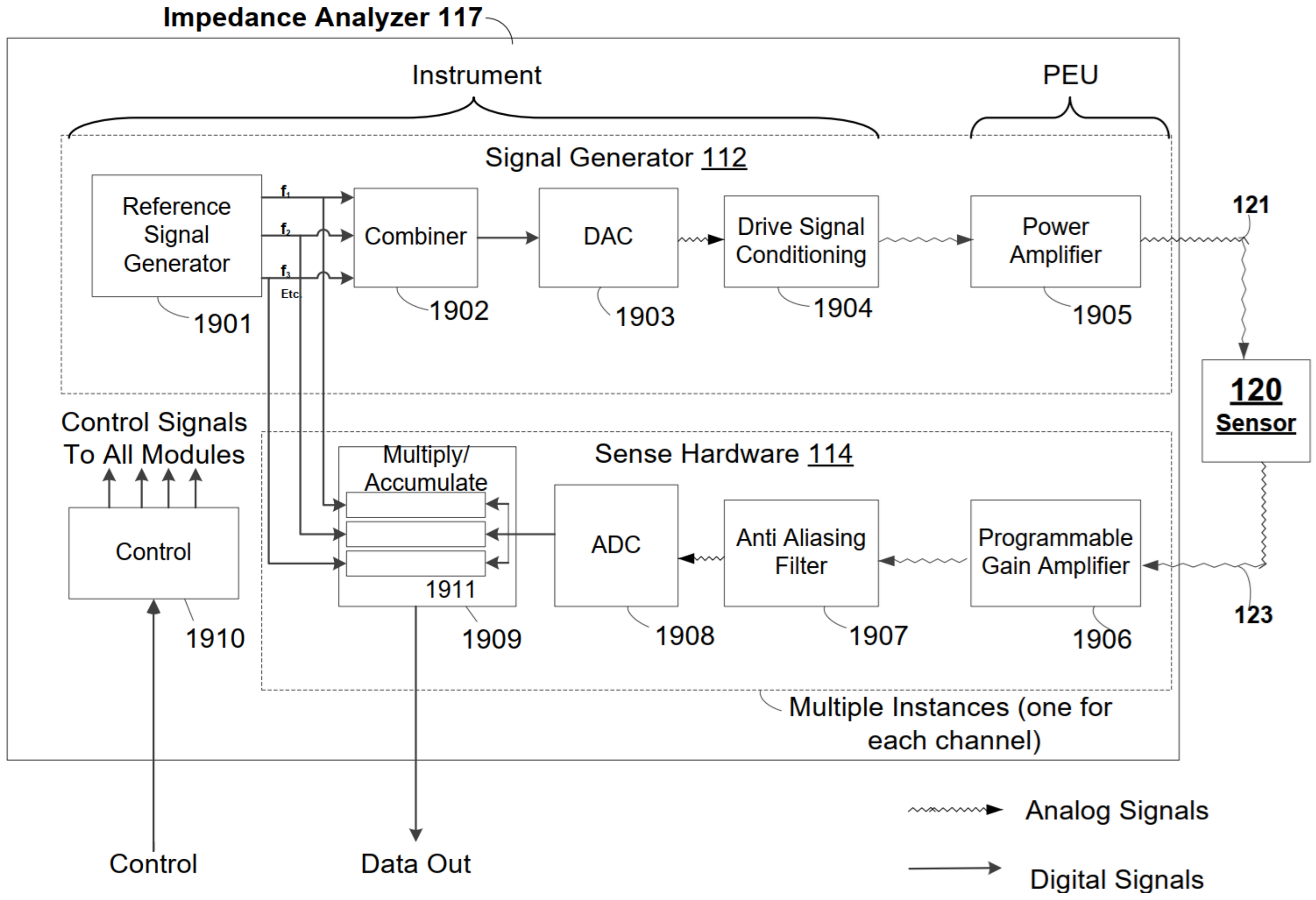
Fully Parallel Data Acquisition

Linear central conductor and linear array of sensing elements with uniform magnetic field across the array enable simultaneous measurement at each sensing element in the array.

Multiplexed ET Arrays

Multiplexed Data Acquisition

Multiplexing (switching) is required since neighboring sensing elements cannot be measured simultaneously due to crosstalk (interference between neighboring drive and sense channels).



From USPN 10,324,062 "Method and Apparatus for Measurement of Material Condition", S.A. Denenberg et al. June 18, 2019.

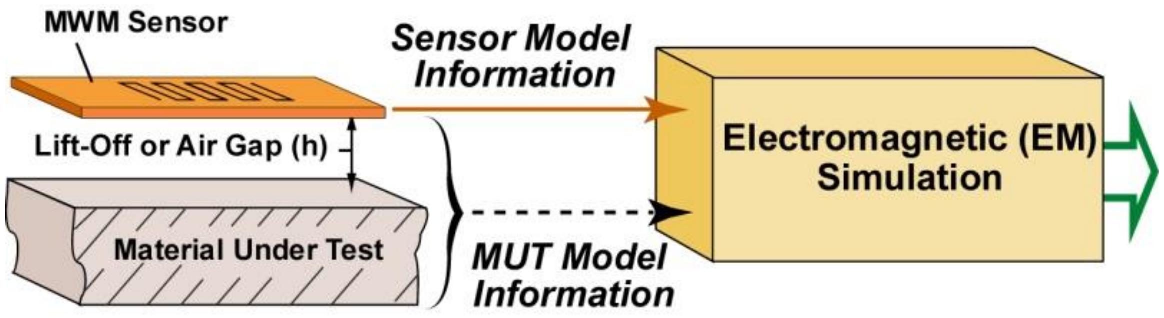
MWM-Arrays vs. Multiplexed ET Arrays

MWM-Arrays	Multiplexed ET Arrays
Rapid Scanning at Low Frequencies By acquiring data from all sense elements simultaneously, more rapid scanning is possible at low frequencies. Improved image resolution is also provided.	**Slow Scanning at Low Frequencies** At low frequencies (e.g., 10 Hz) scanning must be slow enough to allow switching between channels to maintain necessary image resolution.

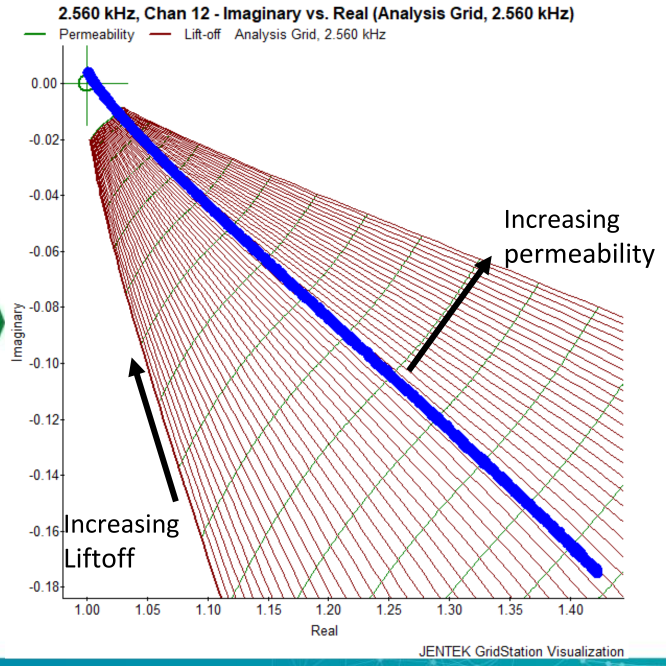
MWM-Arrays vs. Multiplexed ET Arrays

MWM-Arrays	Multiplexed ET Arrays
Large Liftoff Compensation – Large liftoffs is enabled by the large drive-sense gap and model based inverse methods.	**Limited Liftoff and Liftoff Compensation** – Modelling limitations and sensor constructs limit allowable liftoff and degrade ability to correct for variable liftoff. This is particularly limiting for inspection through riser insulation to detect wire failures.

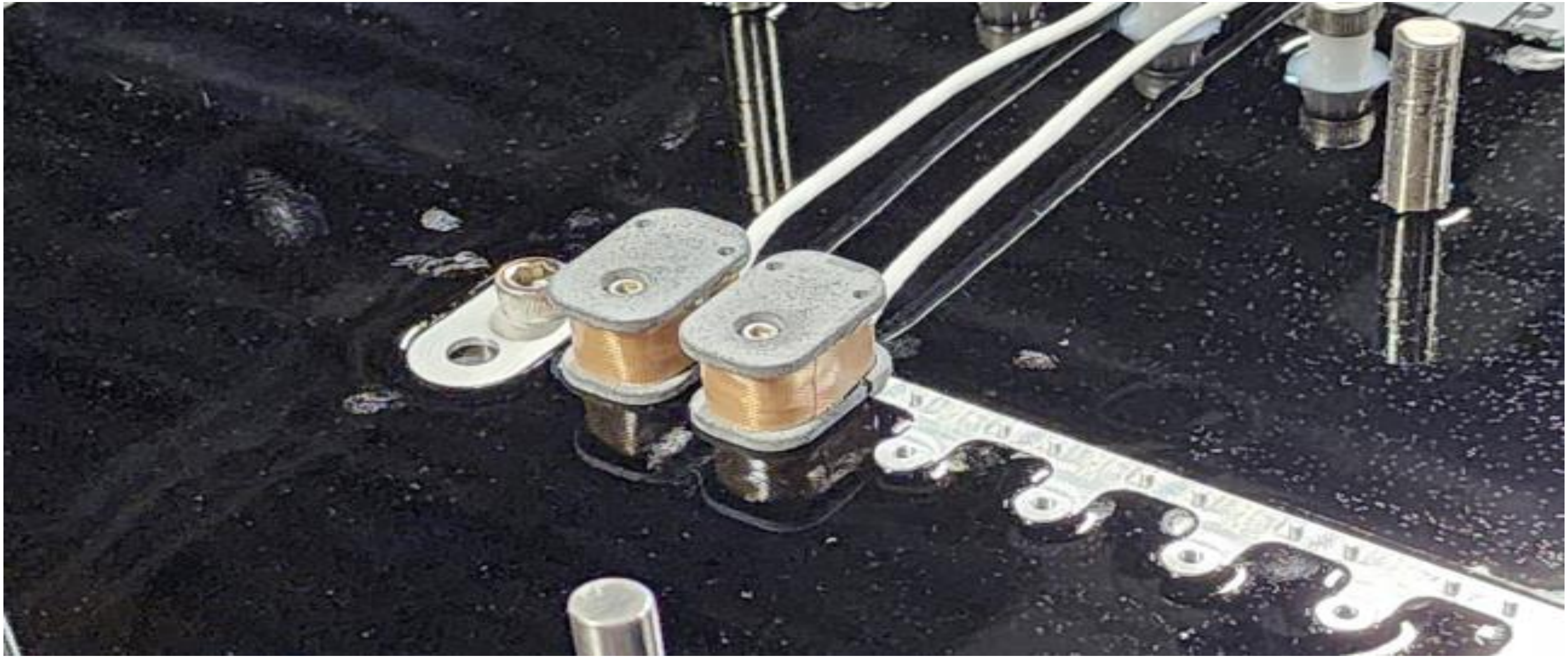
MWM and MUT Model



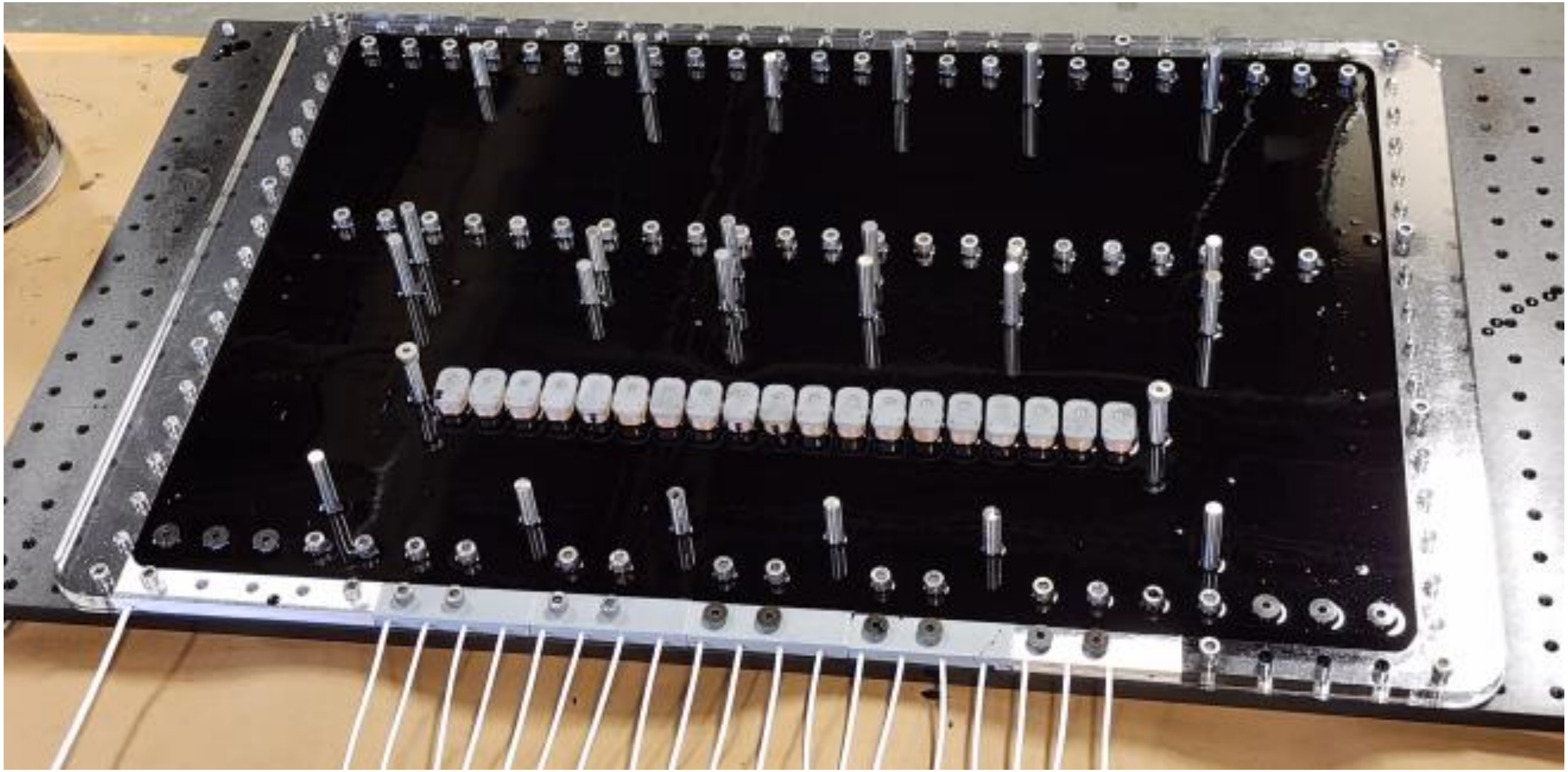
Measurement Grid



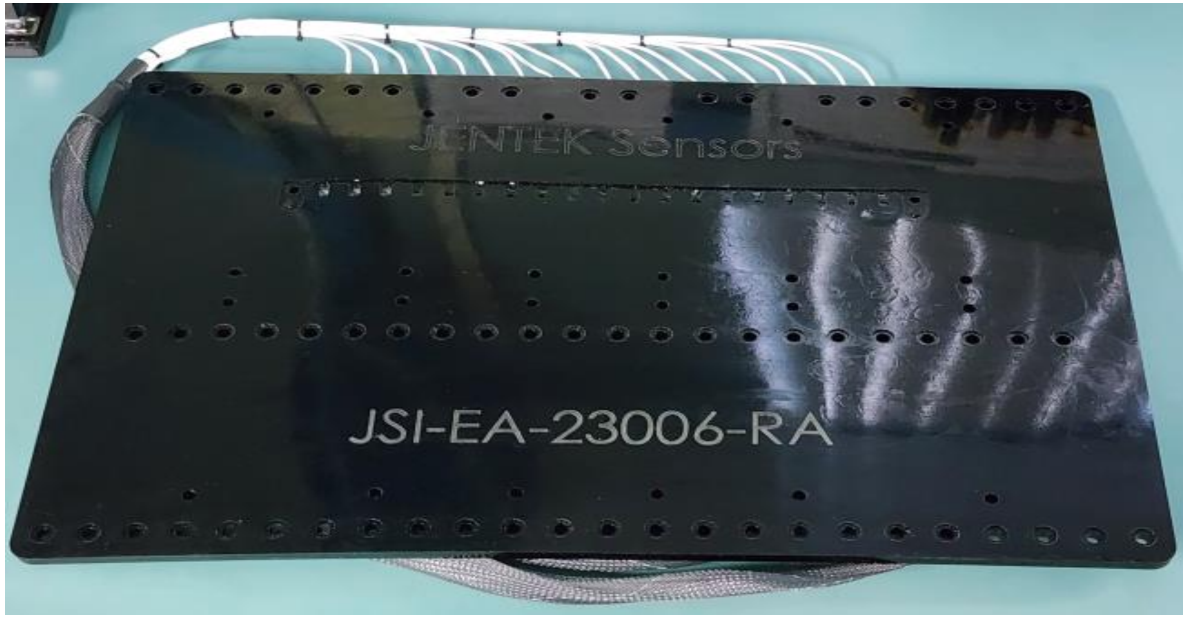
MWM-Array Sensor Fabrication



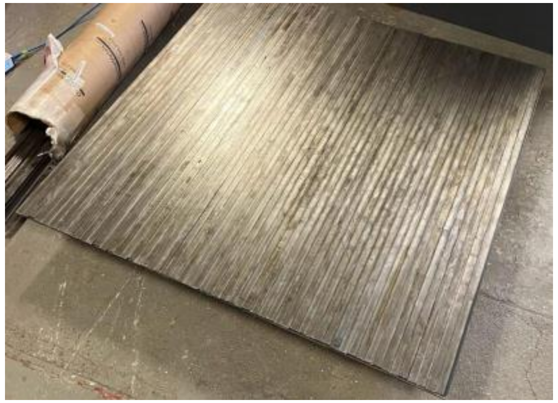
MWM-Array Sensor Fabrication

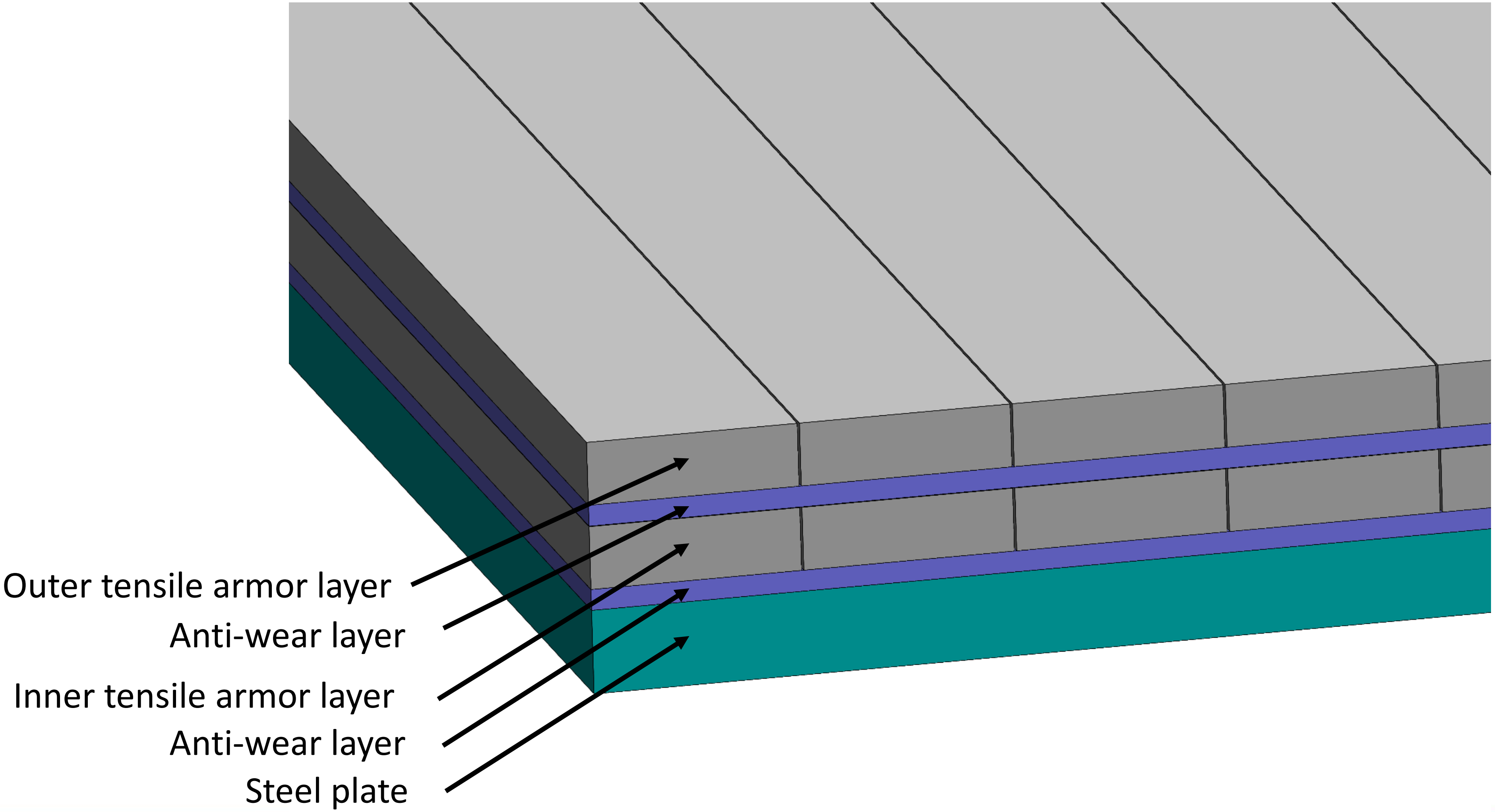


Completed MWM-Array Sensor



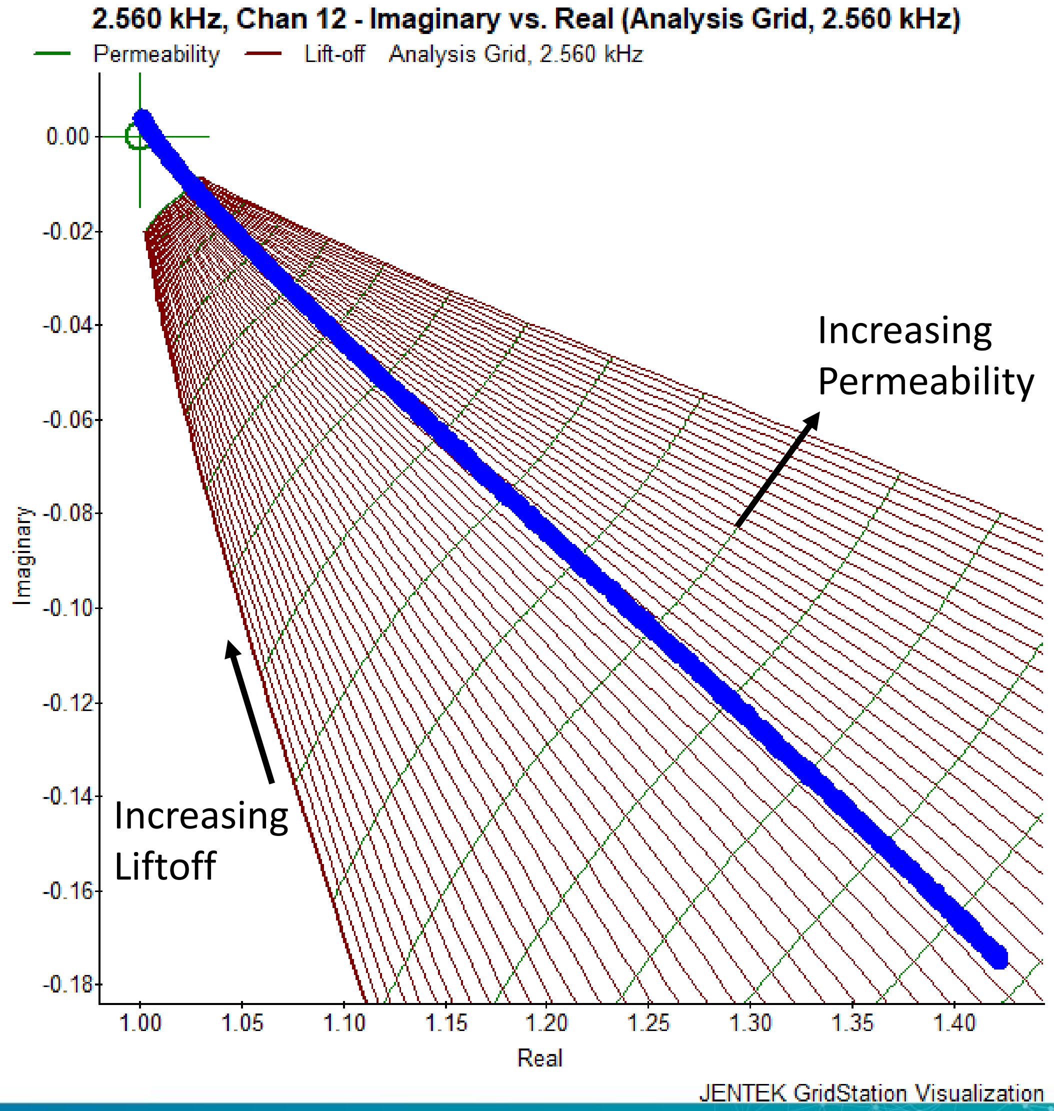
“Flat Riser” Test Bed





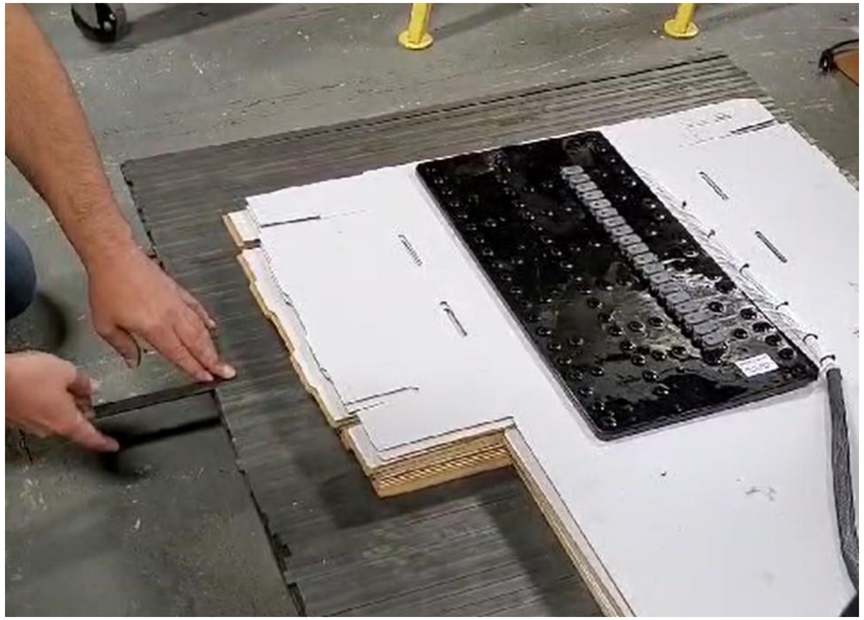
Liftoff Test to Estimate Electrical Conductivity

- To use permeability-liftoff database (grid), electrical conductivity must be fixed.
- Conductivity selected via a “liftoff test.”
- “Correct” conductivity results in liftoff-independent permeability.

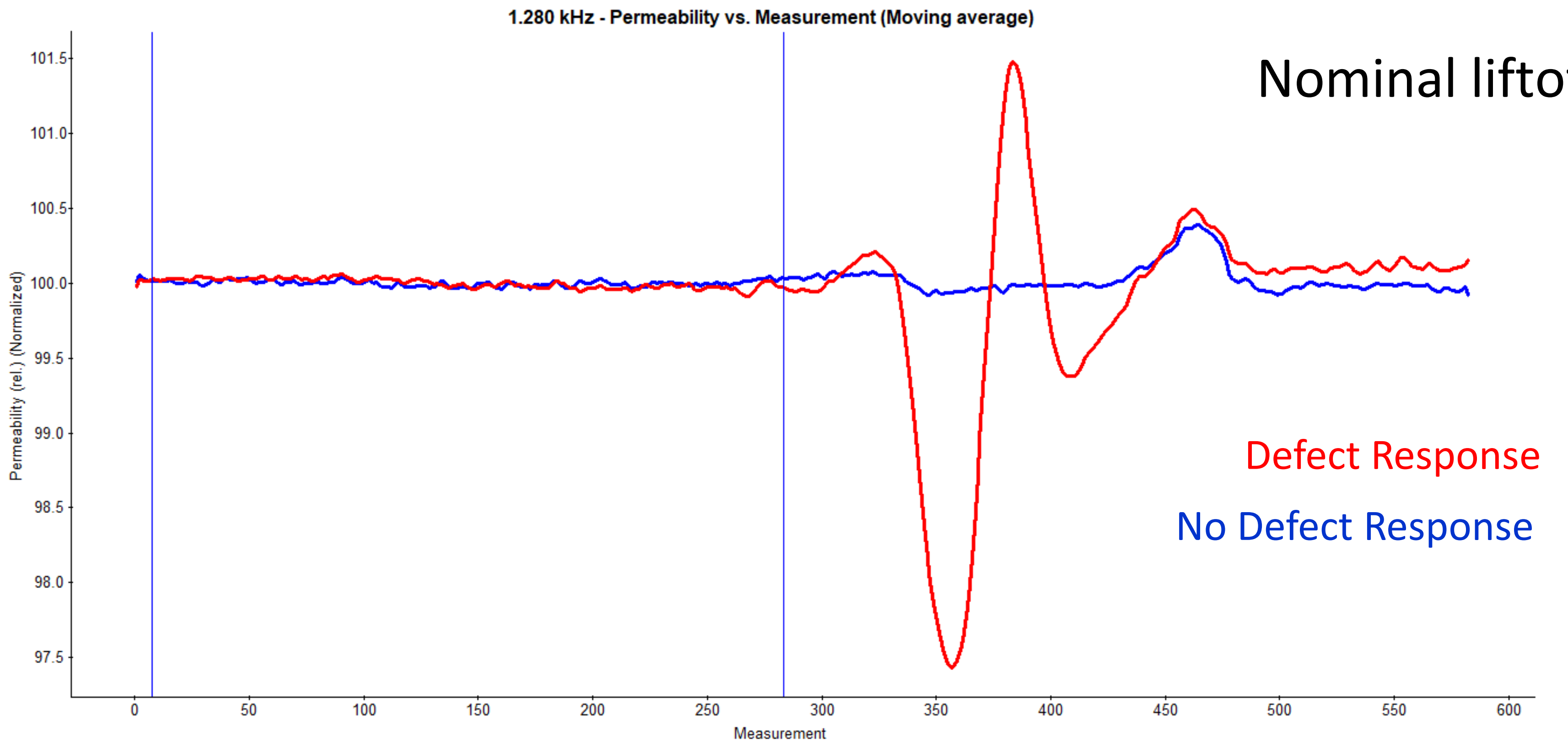


Moving Defect Test

- Simulated zero-gap wire break defect
- 1.28 kHz Excitation freq.
- Nominal liftoff 60mm
- Data processed with permeability-liftoff grid



Moving Defect Test - Outer Tensile Armor Layer Defect



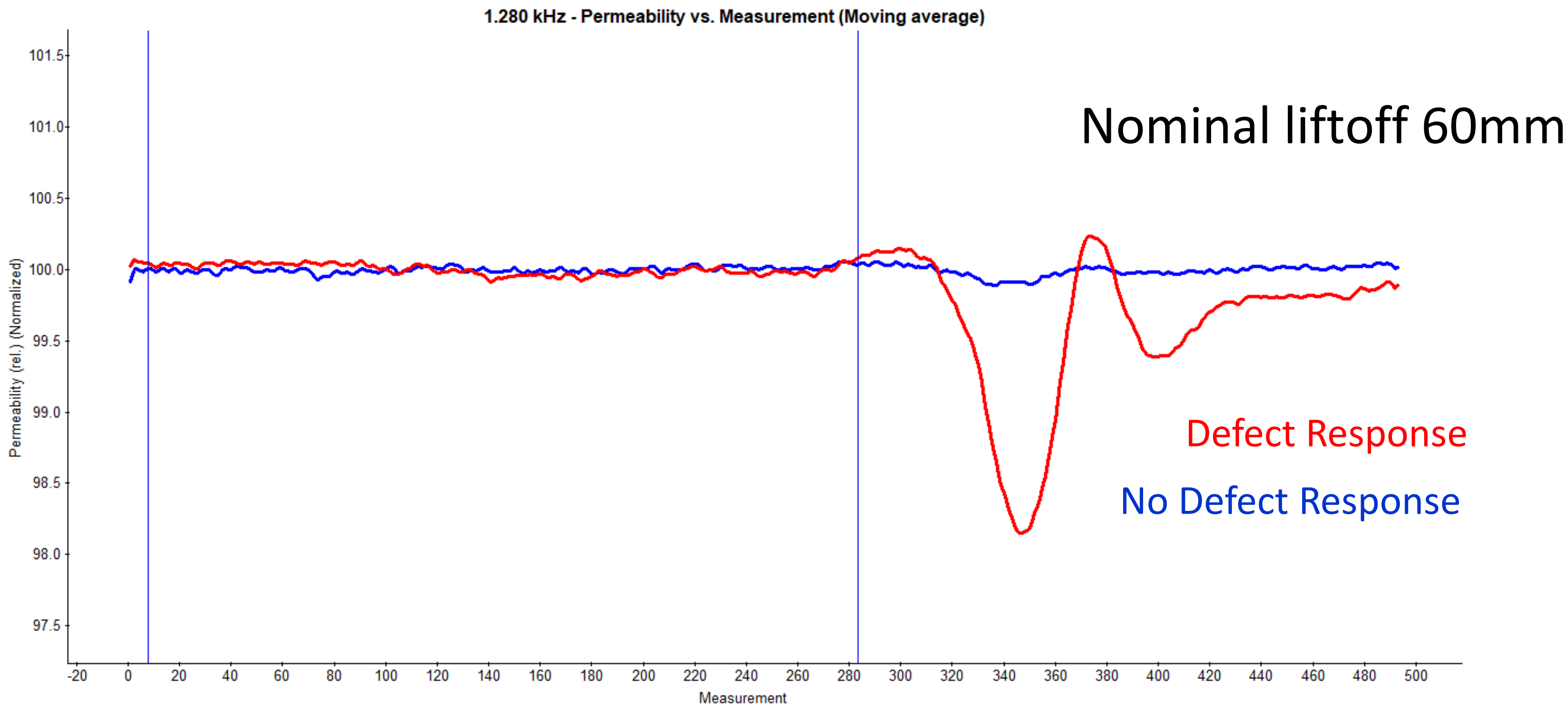
Nominal liftoff 60mm

Defect Response

No Defect Response

“Normalization” establishes the same average value for each measurement channel

Moving Defect Test - Inner Tensile Armor Layer Defect

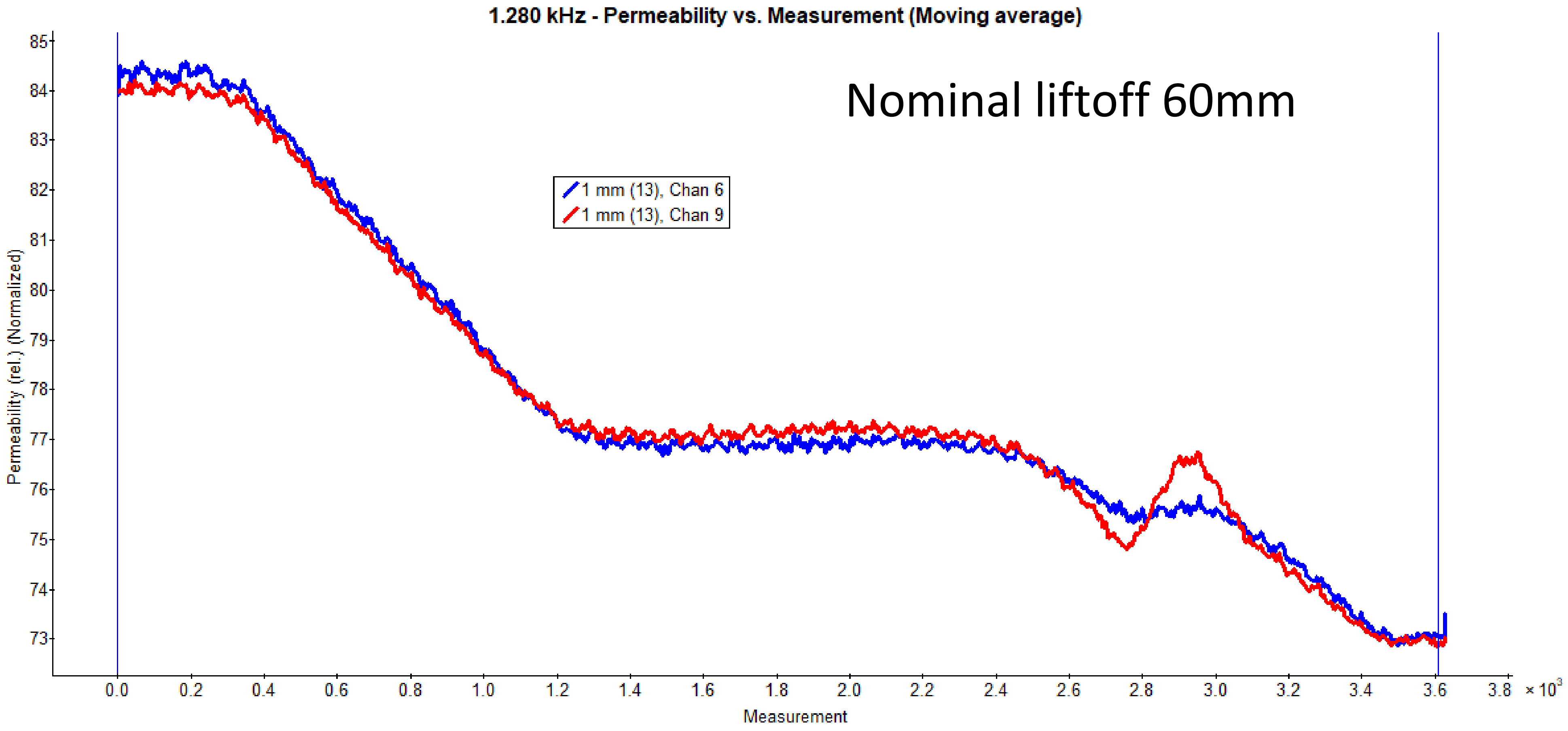


“Normalization” establishes the same average value for each measurement channel

Moving Sensor Test

- Same defect (placed in middle of test bed)
- Sensor manually scanned across test bed
- Same data processing

Moving Sensor Test - Outer Tensile Armor Layer Defect



The limited physical extent of the test bed is unmodelled and is the primary source of "common mode" permeability variation.

Future Work

- Continue development of large MWM-Arrays
- Continue work on riser wire failure detection
- Develop dedicated instrumentation and scanners for deep water off-shore applications