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NASA

Health Monitoring of Composite Overwrapped Pressure Vessels (COPVs) using Meandering Winding Magnetometer (MWM®) Eddy Current Sensors

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Agenda

- Define COPV
- Background
- Proof of concept test plan
- MWM technology
- Coupon Testing/Results
- Full COPV Testing/Results
- Conclusions

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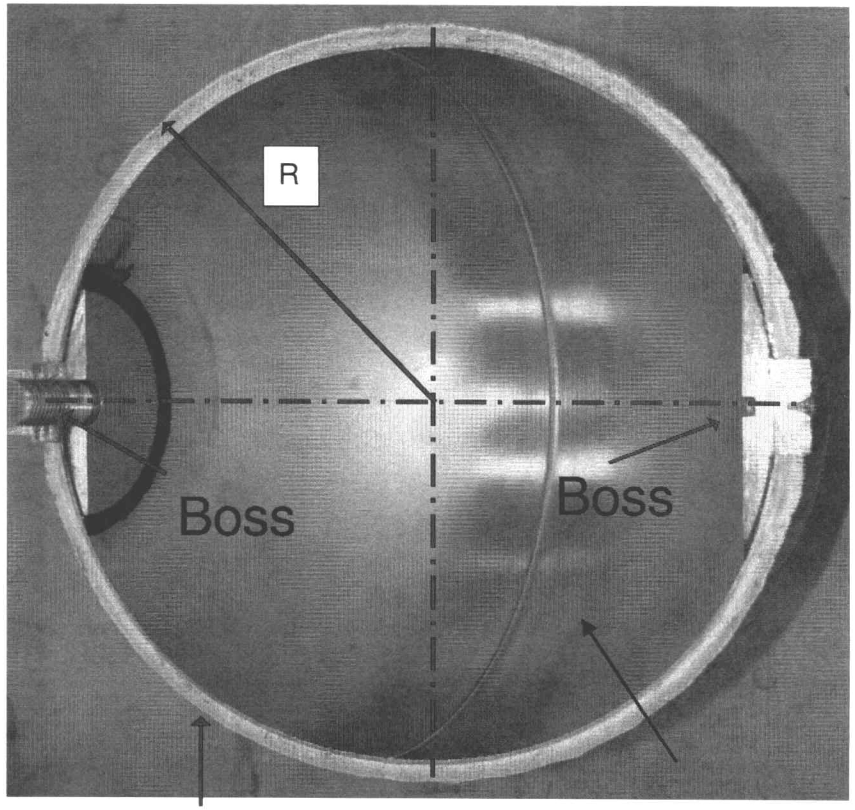
What is a COPV?

- NASA Orbiter Pressure Vessel
- Need was a light weight high strength pressure vessel
- NASA COPV was designed in 1970's
- Basic Composition:
  - Boss
  - Composite Overwrap
  - Metallic Liner
- Safety is key factor



Composite Overwrap

Metallic Liner

Background

- There are 3 mechanisms that affect the life of a COPV
  - The age life of the overwrap
  - Cyclic fatigue of the metallic liner
  - Stress Rupture life

The first two mechanisms are understood through test and analysis

- A COPV Stress Rupture is a sudden and catastrophic failure of the overwrap while holding at a stress level below the ultimate strength for an extended time.

- Currently there is no simple, deterministic method of determining the stress rupture life of a COPV, nor a screening technique to determine if a particular COPV is close to the time of a stress rupture failure.

Stress Ratio

- A key factor in the stress reliability model is the Stress Ratio

$$\textbf{STRESS RATIO} = \frac{\text{Stress in Overwrap @ MEOP}}{\text{Stress in Overwrap @ Burst}}$$

  - The stress at burst varies from vessel to vessel, therefore the discrete stress ratio varies from vessel to vessel
  - Recent Orbiter COPV testing has proven that analytic prediction of the stress ratio and subsequent reliability modeling to be highly inaccurate
    - ~20% off

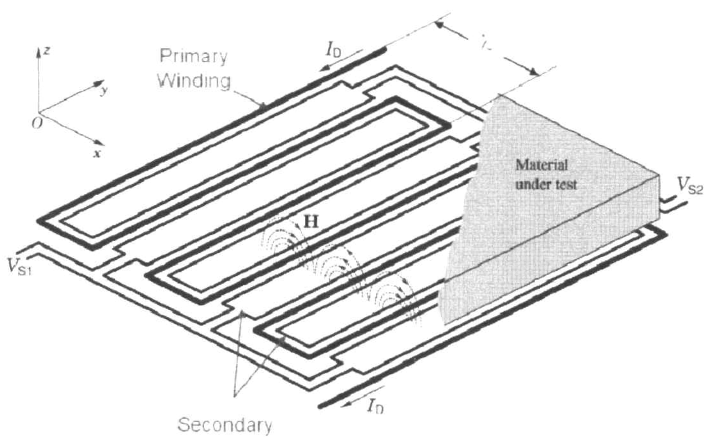
- Proposed technology would provide the ability to directly measure the stresses at various depths in the overwrap and potential directly calculate the Stress Ratio

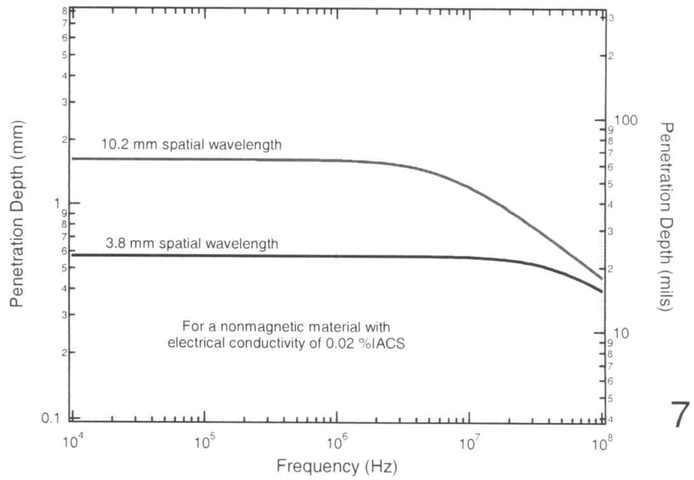
Proof of Concept Study

- KSC funded a proof-of-concept study to study the ability eddy current sensors to measure stresses in a carbon wrapped COPV
- Why MWM Eddy current?
    - MWM and MWM-Arrays measure bulk conductivity within the depth of penetration with a selectivity biased towards those fibers aligned with the sensors drive windings
    - Conductivity and density of carbon fibers varies with stress

MWM® Technology

- Magnetic Stress Gages (MSGs) will be produced utilizing Meandering Winding Magnetometer (MWM) and/or MWM-Array eddy current sensor technology
  - What is MWM? (see slide 10 for an example of an MWM-Array)
    - Primary winding is a linear construct that can be aligned with fibers
    - Secondary windings for sensing the response
    - Fabricated on thin flexible substrate creating a conformable sensor
    - Can be manufactured in various array configurations
    - Depth of penetration varies with sensor wavelength (spacing) and frequency
    - Vendor has capability to perform computer simulations





Proof-of-Concept Test Plan

- Select an MWM eddy current sensor for COPV application
- Design and test coupons for initial configuration testing
- Adapt sensors and procedures
- Hydrostatic test with sensors on full COPV
- Final report

Test Article

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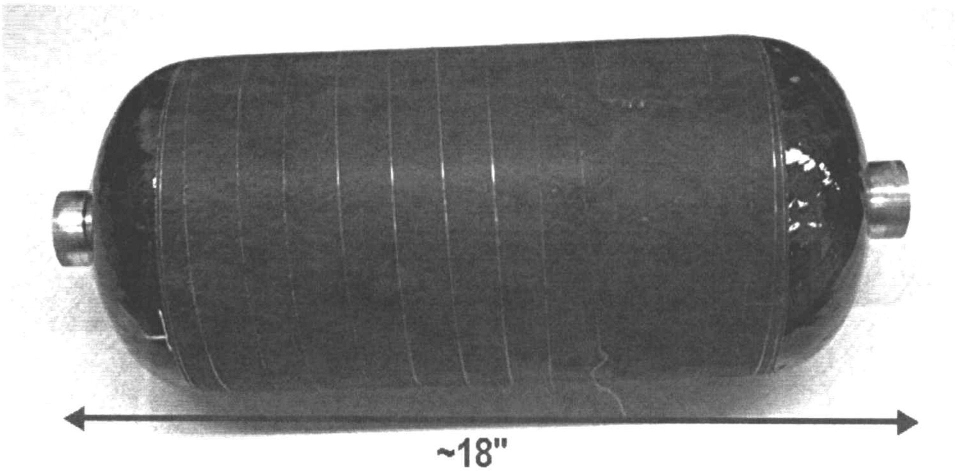
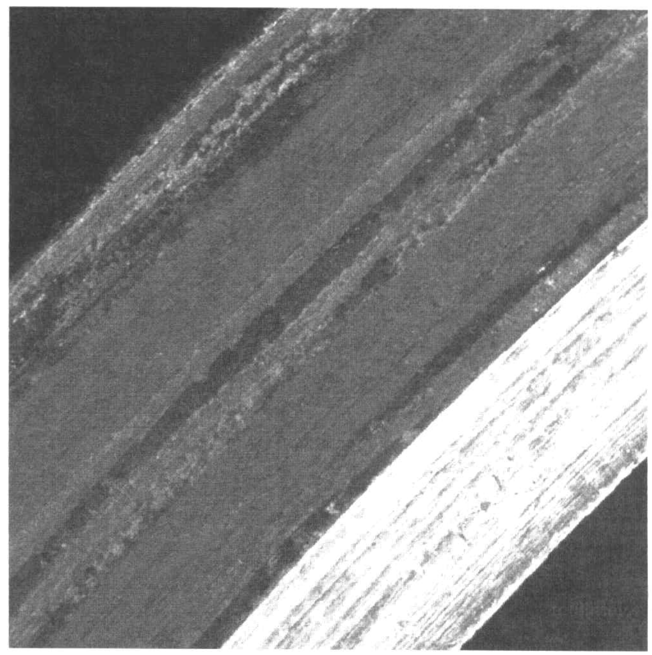


•Fibers: Toray T-800 24k
•Resin: 826/Huntsman T403

1 helical 17 degrees
5 hoops
2 helicals 18 degrees
5 hoops
1 high angle helical (60 degrees)
1 helical 17 degrees
Aluminum



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Fiber Orientation Effects

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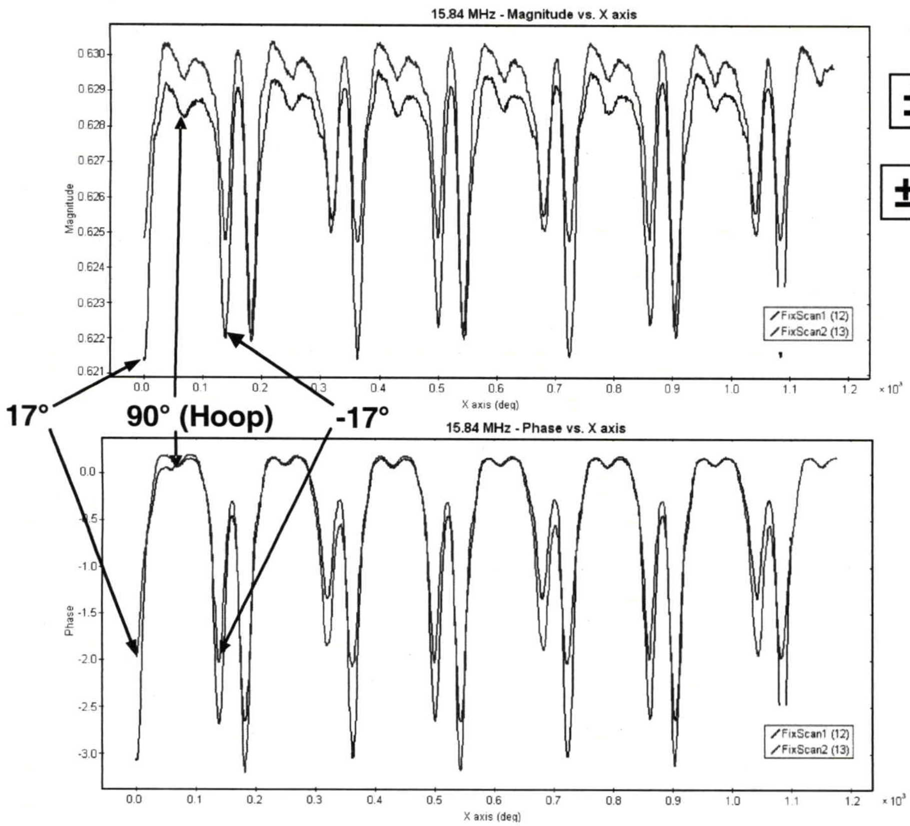
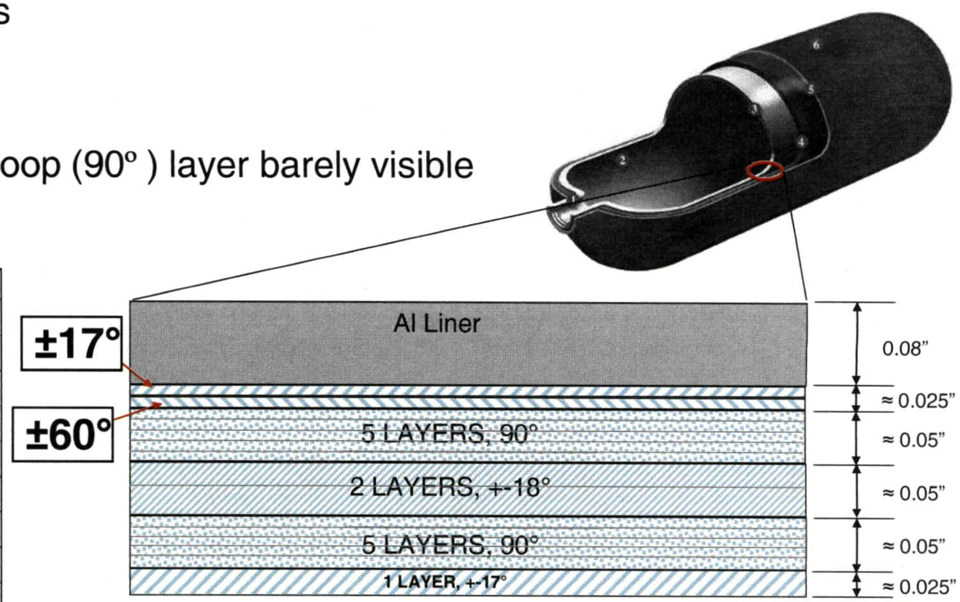
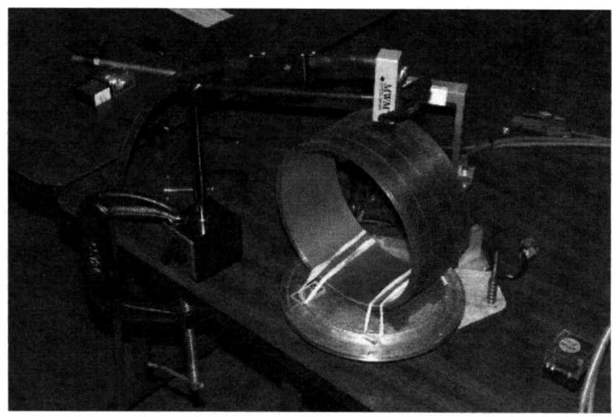
- Multiple fiber orientations in several different layers
- Orientation measurements with FS33
  - 15.8 MHz data indicated
- Limited penetration depth of MWM so outermost hoop (90°) layer barely visible

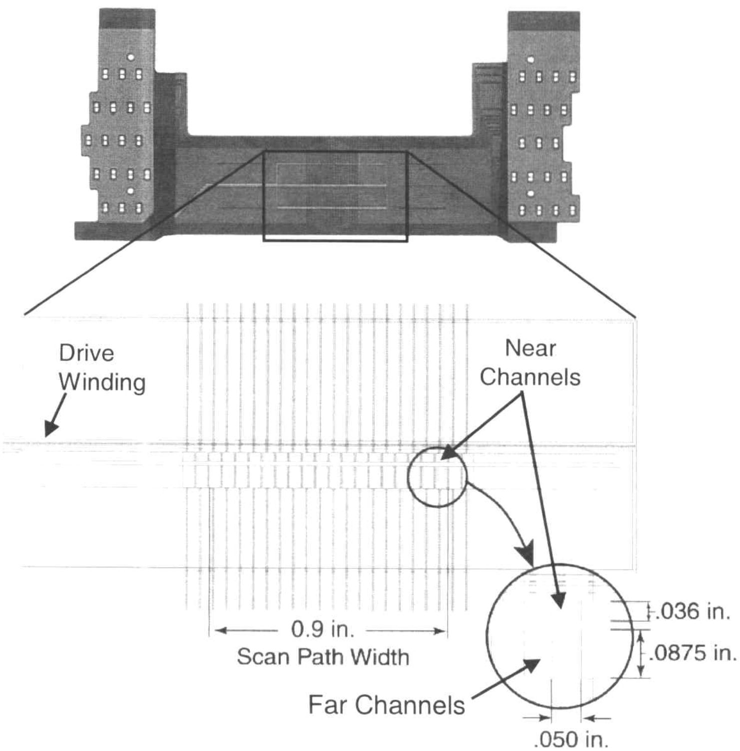






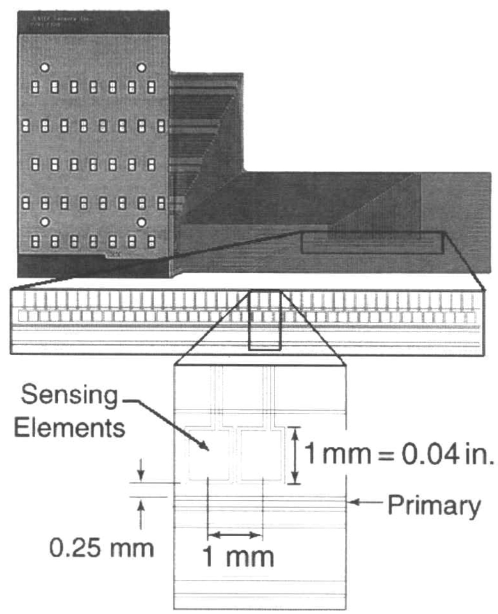
Sensors Used

MWM-Array FA41



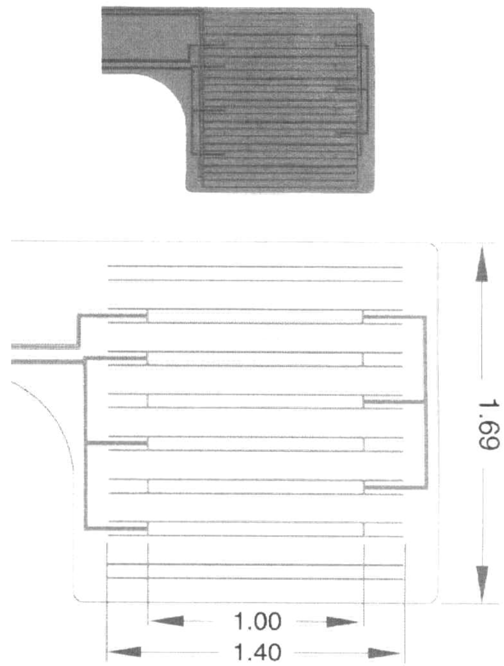
FA41 λ ≈ 480/190 mils

MWM-Array FA28



FA28 λ ≈ 150 mils

MWM FS36



FS36 λ ≈ 400.0 mils

Coupon Testing

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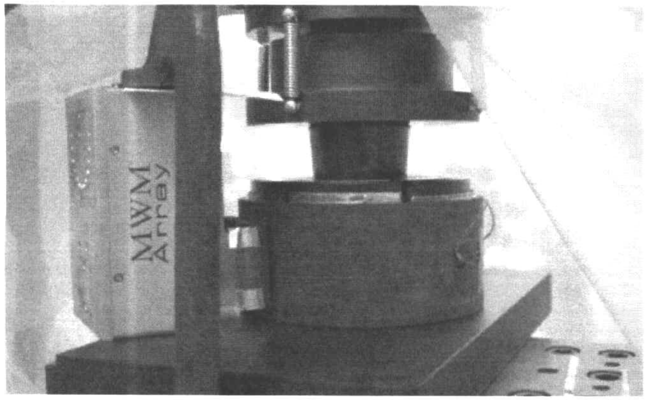
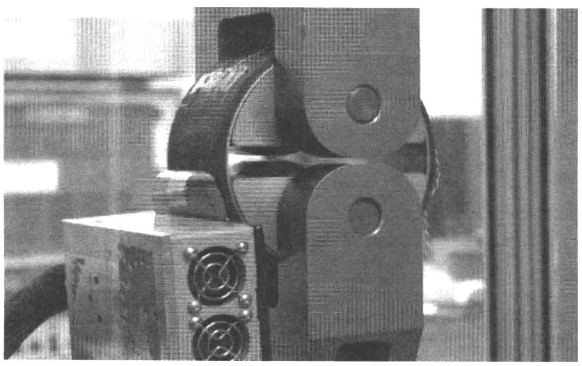
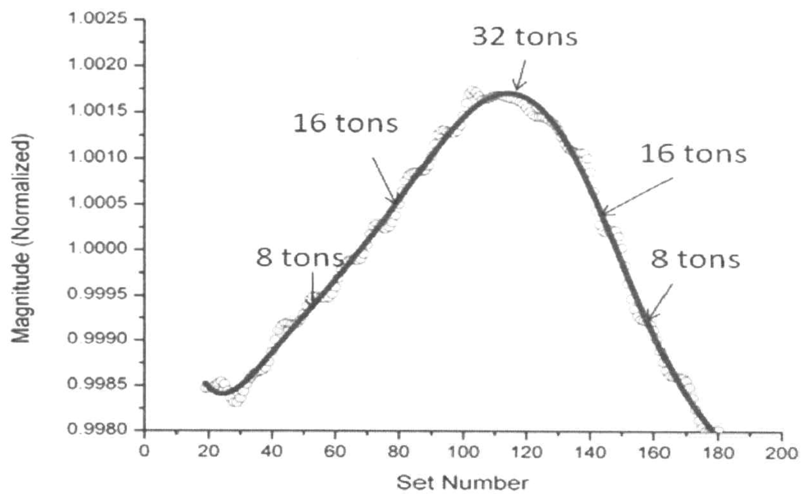


Stresses produced by compressive loading of tapered wedges

- Coupon cut from center section of COPV (~4" wide)
- Two test fixtures designed
- Due to cutting only hoop direction could be measured
- Several different sensor designs and orientations were tested



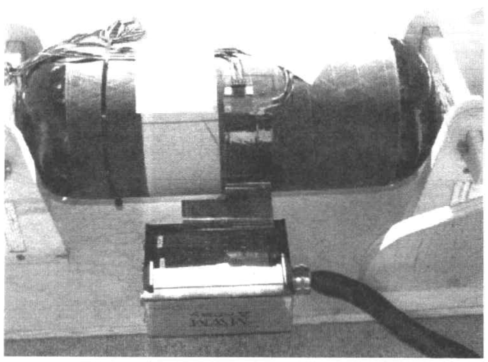
Stresses produced by tensile loading of specially design test fixture

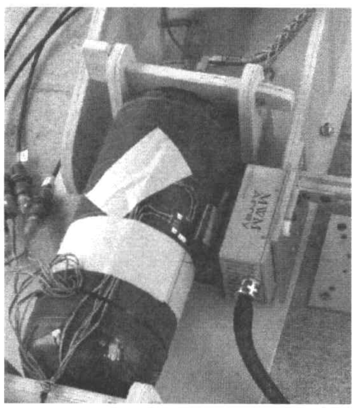


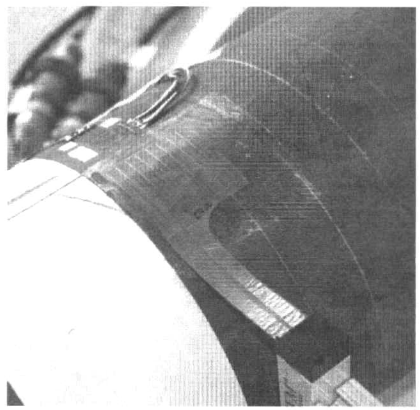
Example of results from compressive loading of tapered wedges test

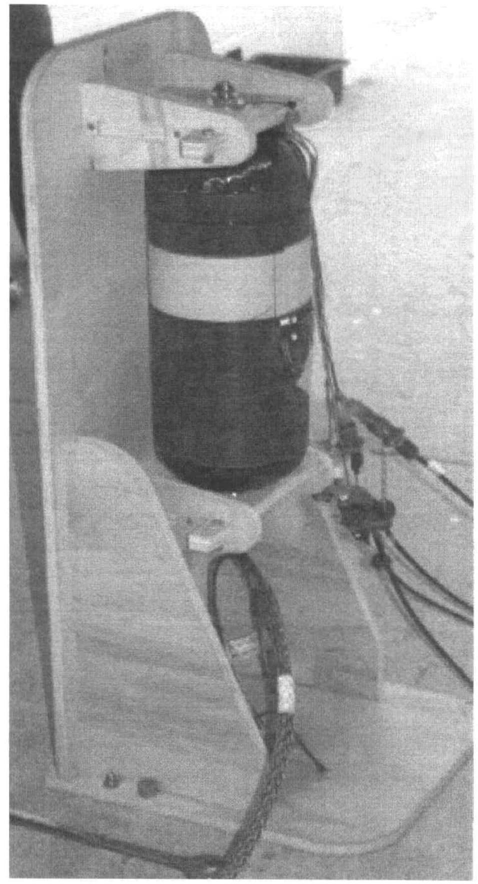
Hydrostat Test

- Full COPV tested hydrostatically at KSC on February 5, 2011
- Vessel cycled to 8,000 psi and back to zero stopping at 2,000 psi increments
  - Pressure chosen to mimic MEOP
  - Estimated design burst pressure of COPV is 16,000 psi
- Based on coupon tests 3 sensor configurations were chosen
  - Different wavelength to obtain various depth of penetration
- Tests were performed with 3 sensor orientations
  - 90º, 60º and 17º to align sensor drive with fiber orientations









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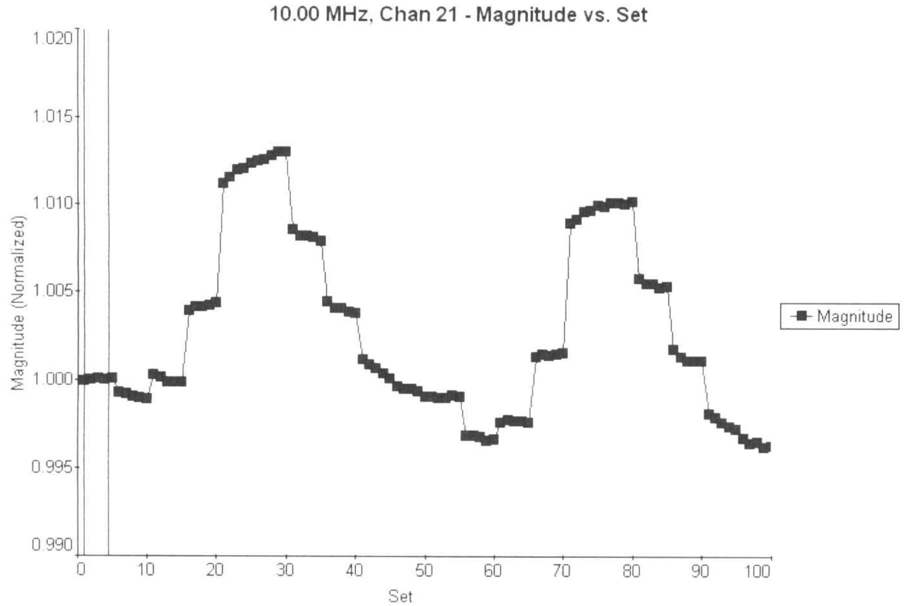
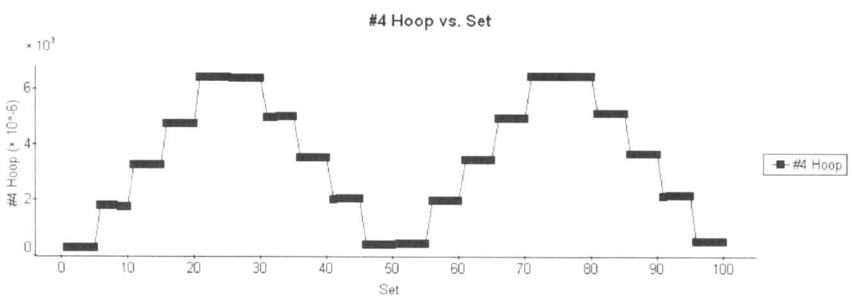
GridStation Results

FA41 (far channel) magnitude at 17° sensor orientation

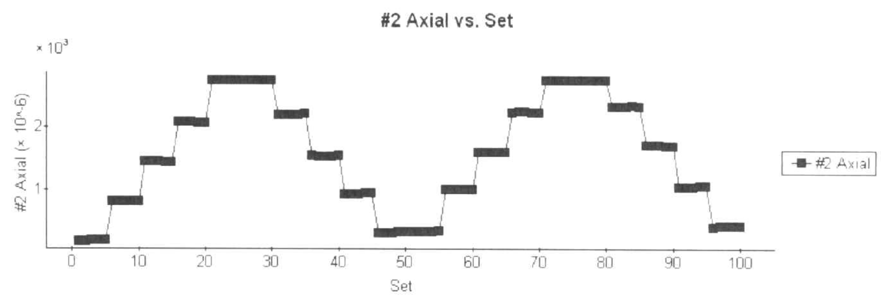


- Channel to channel variability still being studied
- Layer orientation variability will contribute to channel variability
- Sensor magnitude correlates with pressure and strain

Hoop strain from strain gage



Axial strain from stain gage



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FA41(far channel) Results: 17°, 60° and 90° Orientations

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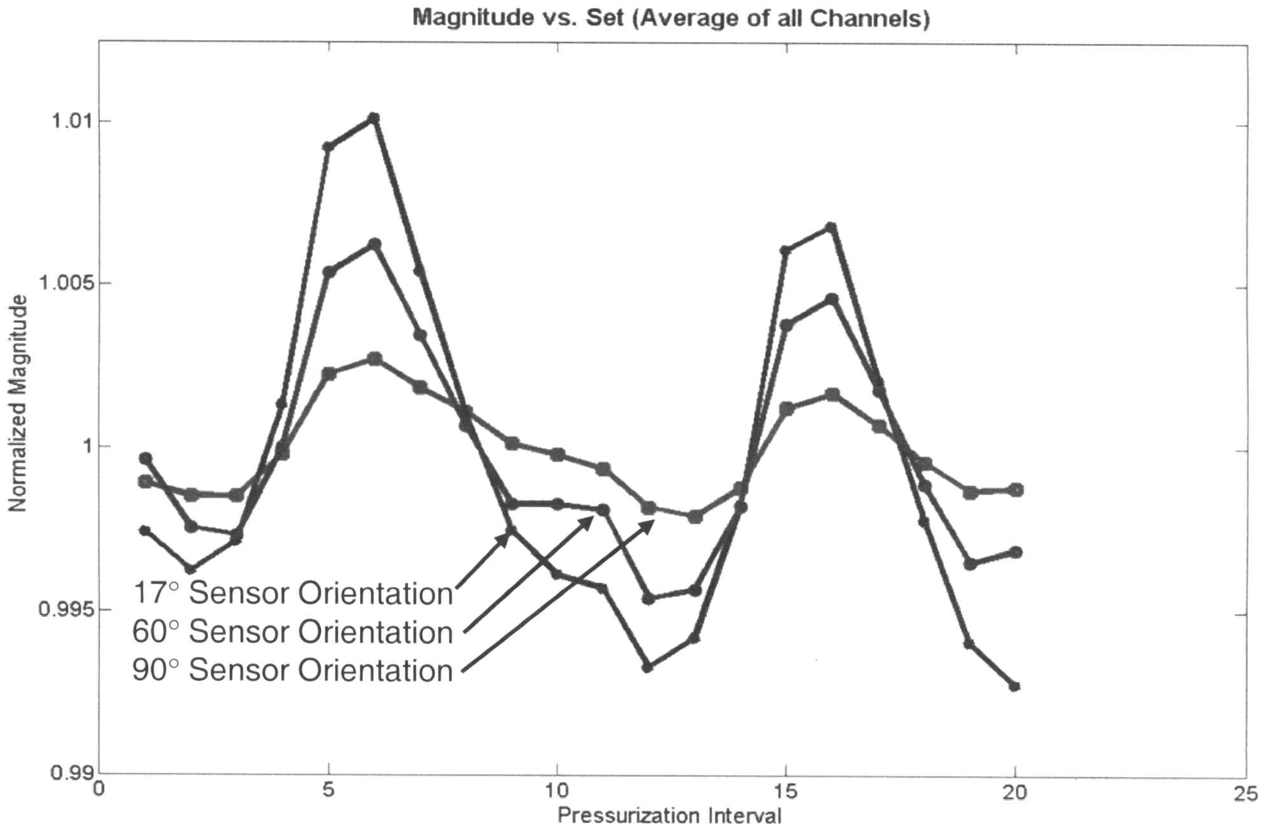
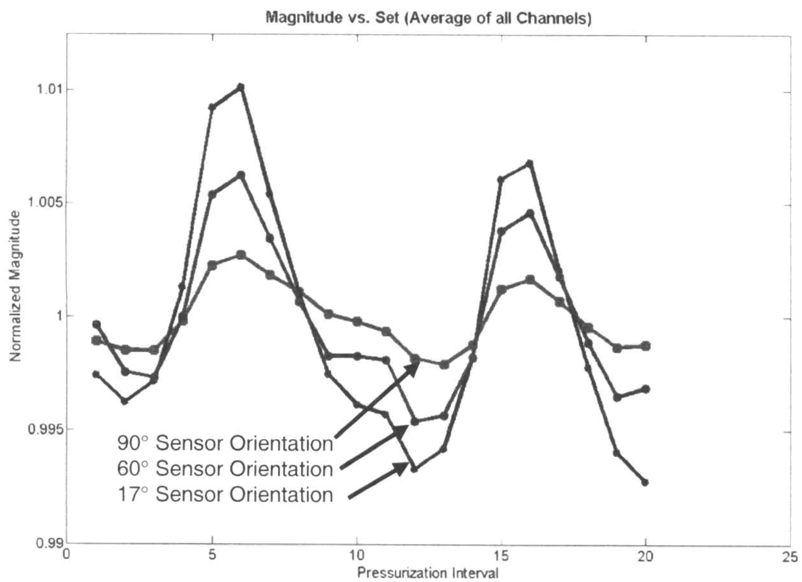


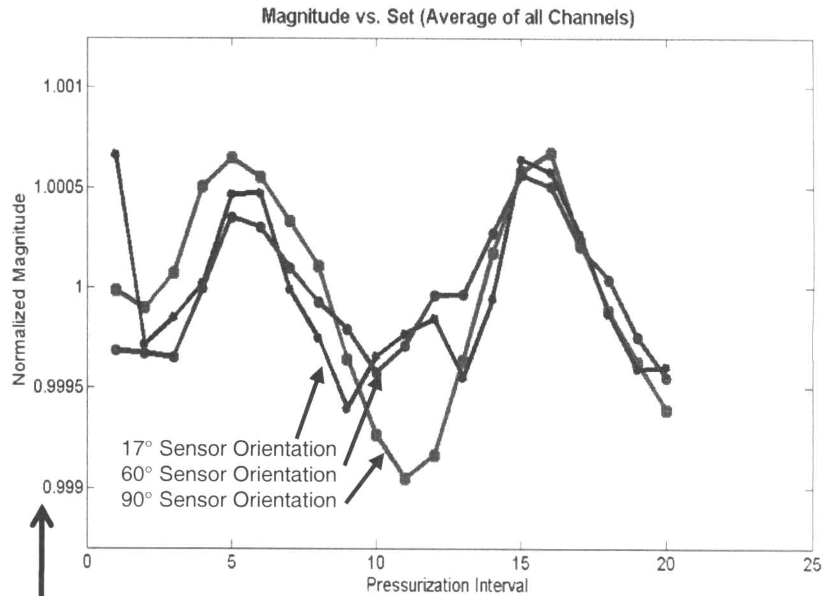
- Average of 18 far channels of the FA41
- Two repeat pressure cycles: 0 psi to 8,000 psi and back to 0 psi shown

FA41 and FA28 Comparison

FA41 Far Channels



FA28



Note Scale Change (~10x)

- Both sensors show a response and correlation with pressure
- FA41 response is much larger than FA28

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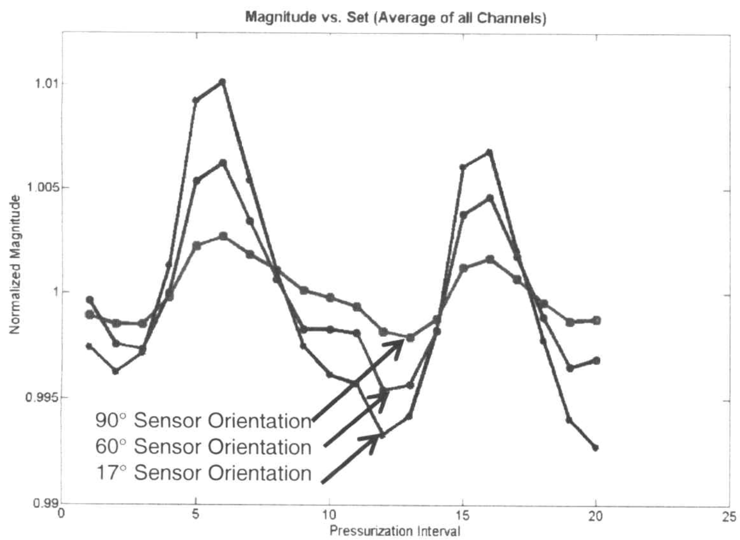
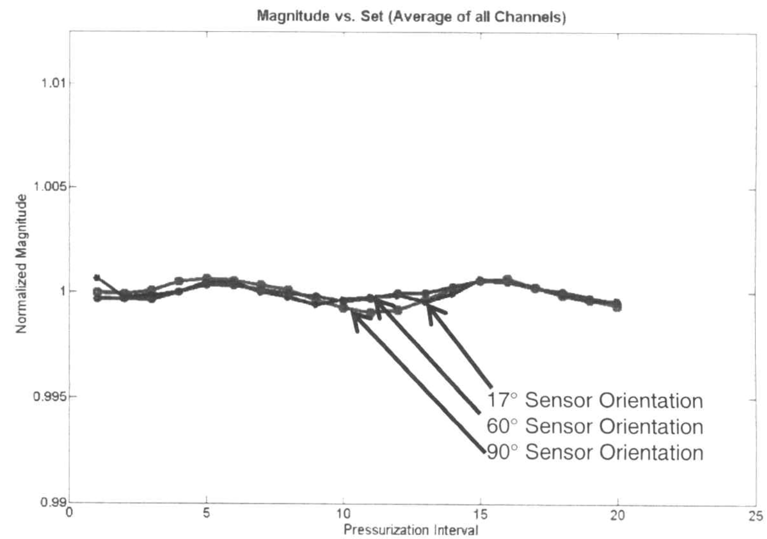
FA41 and FA28 Comparison
Results on Same Vertical Scale

FA41 Far Channels



FA28



- FA41 shows a much larger response to pressure than the FA28

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Conclusions

- Demonstrated a correlation between MWM response and pressure or strain.
- Demonstrated the ability to monitor stress in COPV at different orientations and depths.
- FA41 provides best correlation with bottle pressure or stress.