Phased Array Ultrasonics and Eddy Current Examination for Graphite Components

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Overview of Activities

• Identify nondestructive evaluation (NDE) techniques for graphite
  – Expect material variations within billets, billet to billet and lot to lot
  – Material condition will change with service
  – Need inspection techniques suitable for large billets, fabricated components and in-service inspection
  – Presently evaluating accepted technologies
    • X-ray radiography/tomography (volumetric inspections)
    • Eddy current inspection (surface/near surface inspection)
    • Ultrasonic inspection (volumetric, surface/near surface inspections)

Need to implement complementary techniques to provide a more complete understanding of material condition
Experiment with Graphite Cylinders

- Cylinders machined from a block of graphite NGB 18
- Cylinders were compressed with various pressures
- 8 samples from 0 to 70 MPa increments of 10MPa
- Expecting to see indications of micro-cracking or mechanical changes.
- NDE Techniques that can observe differences could be used for in service inspection of graphite components
NDE Techniques

• Surface scan with Eddy Current has not shown measurable differences.

• Sound speed variations are observable.

• Work in progress on application of acousto-ultrasonic techniques with conventional transducers.

• Flexibility of phased array ultrasonic are also a work in progress
  – Variations in steering, focus, and choice of aperture can be exploited
  – Developing analysis techniques to find the appropriate statistics to show relative variations.
  – Phased array allow multiple techniques to be applied concurrently.
Acoustic Velocity
Acousto-Ultrasonics

- Ultrasonic energy randomly scatters in sample
- Scatters off grains, pores, cracks, inclusions, etc
- Character of detected ultrasonic energy determined by scatter and energy dissipation mechanisms
- Potentially used to detect changes in batch to batch microstructure or microstructural damage

2.25 MHz transducers 15 mm separation
Acousto-Ultrasonics

(7 Graphite Test Samples)

Acousto-Ultrasonic Measurements

Time (microseconds)
Acousto-Ultrasonics
Acousto-Ultrasonics Analysis Sliding Window FFT
Acusto-Ultrasonics
Acousto-Ultrasonics

10 MPa Stress

70 MPa Stress
Acousto-Ultrasonic and Backscatter Techniques With Phased Array

- Goal: Explore benefits of flexibility of phased array ultrasonics on traditional acousto-ultrasonic and back scatter techniques concurrently with standard UT
- With separate apertures, steer transmit and receive beams towards each other with different depth crossings to depth profile
- Use alternating element aperture and variable depth focus for back scatter sensitive at various depths
Phased Array Setup

64 Element Linear Array 2.25Mhz
0.7 mm pitch

Olympus NDT Focus-LT

Tomoview Software

INL Custom Focal Laws
Phased Array

Managing Many Inspection Methods Concurrently

Depth
Steering
Acousto-Ultrasonics

64 Element phased array

Standard Sector Scan
Details of AU with Steering
Phased Array Back Scatter

Transmit and Receive on Alternate Elements Avoid Bang Interference
Blue Elements Transmit and Green Receive Focus at incremental Depths.
Achieves Backscatter returns with Sensitivity at Various Depth in Material.
Details of Backscatter

Varying Depth Of Focus

Alternate elements Transmit/Receive
AU samples at various compression

No Compression

Highest Compression

Greater returns from back angle focal laws
**Back Scatter**

Elimination of indication allows for statistical variations between compression levels.

But so far only small variability with current samples.
Eddy Current Inspection

Inspections based on electromagnetic properties of test material

Surface/near surface inspection due to skin effect and limited projection of magnetic field
Eddy Current Inspection

Pulse Eddy Current Image

X-Ray Image
Challenges and Barriers

- Sample sets with controlled microstructural features and known defects
  - Porosity
  - Cracking
  - Microcracking
  - Oxidation

- Ultrasonic coupling
- Test surface condition
- Statistics from new methods to compile cross-section or volumes of data.
Summary

- At current compression levels very subtle variations are found in the AU and back scatter using the traditional and new techniques.
- “Flexibility” of phased array can be further exploited to better determine signatures of materials.
- Working to arrive at a better set of samples to test the examination techniques.
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**X-Ray Radiography/Tomography**

Inspections based on attenuation of x-rays propagating through a test sample

2D projection radiograph

159 x 165 mm graphite blocks
X-Ray Radiography/Tomography

152 mm dia. graphite cylinder
1, 2, 4, 6, and 8 mm dia. drill holes
Eddy Current Inspection

Pulse Eddy Current Images
**Ultrasonic Inspection**

Inspections based on elastic properties of test material and scattering of propagating acoustic wave

- Graphite attenuates high test frequencies
  - Test frequencies ≤1 Mhz have wavelengths >2 mm
  - Limited capability for detection of small isolated defects
- Velocity and scattering measurements
Ultrasonic Inspection (Acoustic Velocity)

- **Signal Amplitude**
  - 2.25 MHz
  - 0.5 MHz

- **Signal Time of Flight**
  - 2.25 MHz
  - 0.5 MHz