Application of Terahertz Imaging and Backscatter Radiography to Space Shuttle Foam Inspection

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Background

• **External Fuel Tank Background**
  – ET holds cryogenic liquid hydrogen and oxygen fuel for shuttle main engines
  – Polyurethane foam insulation prevents cryogenic fuel from boiling as well as ice formation
  – Aero loads during launch can produce foam debris potentially damaging the shuttle orbiter
  – After the Columbia accident, ET foam debris was identified as a likely cause of the orbiter wing damage
  – NDE is performed on ET foam as one method of preventing critical foam debris during launch
External Fuel Tank Foam

**NDE Difficulties in Polyurethane Foam Inspection**
- Does not lend itself to conventional NDE methods
- Very low density (~2.5 lbs/cu ft) so air voids do not exhibit significant density change
- Non homogeneous material with density variations
- Inspection must be single sided due to access restrictions
- No history of industrial inspection of foam

**Conventional NDE Method Assessment**
- UT: Foam attenuates UT
- X-ray: Requires two sided access
- Thermography: Foam is an insulator
- Air-Coupled, Low Freq. UT: Non-homogeneous foam structure impairs technique

![Typical Slice of ET Foam (Backlit to Emphasize Density Variations and Voids)](image-url)
Backscatter Radiography

- Collimated beam of x-rays (55-70 kV) interact with sample molecules
- Backscatter x-rays are emitted (Compton Scattering), possibly after multiple subsequent scattering events, and detected by NaI or YSO detectors
- Collimation provides some preferential sensitivity to selected depth
- The x-ray beam and detectors are scanned across the part to generate a 2-D presentation of the internal make-up of the foam
Examples of BSX Defect Indications

IFR test panel
Terahertz Imaging

- Terahertz inspection uses high frequency RF energy in the band between microwave and infrared
- Terahertz beam is transmitted through object and reflects off the aluminum substrate
- Due to foam attenuation, received pulse is approx. 0.1 to 0.3 THz (100 GHz to 300 GHz)
- Presence of defects produces changes in amplitude, phase and frequency of received beam
- Less attenuation can indicate less material such as the presence of a void but in reality there are complex refracting effects occurring in the foam, making interpretation challenging
- The terahertz beam is scanned across the part to generate a 2-D presentation of the internal make-up of the foam

Each pixel in the Terahertz image corresponds to an individual waveform
Examples of THZ Defect Indications

IFR test panel
Combined BSX/THZ Methods

- **Example 1**
  - THZ image has distinct response from void
  - BSX image has marginal response from void
• **Example 2**
  - BSX image has distinct response from void
  - THZ image has marginal response from void
Combined BSX/THZ Methods

- THZ scans are limited by substrate geometry
  - THZ is ‘blinded’ by irregular part geometry so no THZ data can be obtained in those regions
  - THZ is most effective in the first 3” to 4” of foam adjacent to the substrate, less effective at higher elevations above the substrate

- BSX provides
  - high spatial resolution
  - most effective near the part surface

Combined BSX and THZ method provides maximum surface and substrate sensitivity and is the baseline TPS NDE inspection for volumetric defects
**Detection Capability**
- Probability of Detection Study
- Based on combined result from both BSX and THZ inspections
- Multivariate regression analysis
- Samples consisted of 100 natural defects and 300 blanks
- 90/95 detection capability established
- Zero false calls

**Probability of Detection Results**

- 0.41” dia. X 0.20” thick (under 2” of foam)
- 0.63” dia. X 0.31” thick (under 8” of foam)

90/95 POD Results
EXTERNAL TANK FOAM INSPECTION SYSTEM

NDE Activity in Building 420 at the Michoud Assembly Facility

Overhead Crane

Ice Frost Ramps

ET

Scanner
Conclusion

- Two state of the art technologies have been developed for External Fuel Tank foam inspections
- Results of POD tests have shown Backscatter Radiography and Terahertz imaging detect critical defects with no false positive issue
- These techniques are currently in use on the External Tank program as one component in the foam quality assurance program

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