STRUCTURAL HEALTH MONITORING FOR LONG DURATION SPACE HABITATS

NASA 2017 In-Space Inspection Workshop
2/1/2017

Dan Xiang, Ph.D.
X-wave Innovations, Inc.
555 Quince Orchard Road, Suite 510
Gaithersburg, MD 20878
dxiang@x-waveinnovations.com
(301)200-8128

X-WAVE INNOVATIONS, INC.
X-Wave Innovations, Inc. (XII)

Company Overview
- Woman-owned small business
- Founded in 2009
- R&D oriented firm
- Located in Gaithersburg, Maryland

Core Technologies
- Sensor Technology
  - New sensing technologies & systems, Sensor network & fusion
- NDT and SHM
  - Acoustics /Ultrasonics, Vibration, Electromagnetic, Guided/Defused waves, Structural health monitoring
- Signal/Image Processing
  - Pattern recognition, fault detection, identification, and classification, digital image correlation
- Advanced Materials and Processing
  - Surface material treatment, nanomaterials process and test
HURFS™ - hybrid ultrasonic-RF sensor system for composite material inspection and characterization
URBMCS™ - Universal Reconfigurable Battery Management and Control System

![Battery Management System Diagram]

- Real degradation curve of Capacity
- Failure threshold
- Prediction with ND-AR (T1)
- Starting Point T1=30
- Prediction with ND-AR (T2)
- Starting Point T2=55
- Prediction with ND-AR (T3)
- Starting Point T3=80

Failure threshold U=0.88

End of Life

Battery Capacity/Ah

Charge and discharge cycles /cycle

Failure threshold U=1.38

End of Life

Battery Capacity/Ah

Charge and discharge cycles /cycle
SoniX-IR™ – portable Sonic-IR inspection system for rapid, full-field NDT&E
SurfSCAN™ – rapid and accurate 3D surface scanner for dimensional measurements
Wireless Acoustic Emission Technology for Detecting Early Stages of Cracks in Rotating Gearbox Components

AE sensors installed on the test gearbox and a recorded waveform with strong background noise

Extracted AE features and accumulated AE results from processed data
CaseHitter™ – conclusive ballistic identification software
High-Precision Random Profile Roughness Specimen - ISO 5436 and ASME B46 Standards
Acknowledgement

The following work was funded by NASA SBIR Phase I program under contract NNX16CL97P. We are very grateful for the technical support of Mr. Thomas C. Jones, and his colleagues at NASA Langley Research Center, Hampton, VA.
PROBLEM

- NASA seeks innovative, multifunctional and lightweight approach to integrate long-duration structural health monitoring (SHM) capabilities for space habitat long-duration mission concepts.
- The enabling sensing technology and integration approach should not compromise the load-carrying capability or other structural design requirement.
- Sensing capabilities by fusing multiple sensors to predict and locate critical damage areas and probable failure zones are highly demanded.
OUR SOLUTION

- Multi-functional sensor network system (MFSNS) consisting of AE, UT and SS under one sensor platform with piezoelectric sensors embedded in structures allows accurate precursor/damage diagnostics and RUL prognostics for critical space habitat structures.

- AE technology has proven to be effective to detect precursors and material microstructure changes as well as damage initiation and growth under load.

- UGW technology has been widely used in SHM for detect and characterize defects in large structures.

- SS has long been adopted for assessment of damage precursors or material state under loading.
PHASE I ACHIEVEMENTS

- Conducted numerical simulations of guided waves in softgoods structures
- Designed and constructed a loading fixture to simulate in-service conditions for softgoods specimen testing
- Developed a LabVIEW program with graphic user interface for data acquisition and processing
- Assembled a MFSNS prototype using flexible macrofiber composite (MFC) sensors and data acquisition circuitry
- Conduct systematic experiments with MFSNS prototype and a fabric specimen for based on AE, UT, and SS measurements
- Demonstrated the feasibility of MFSNS for integrity or condition monitoring of softgoods structures
FEM of GUW Propagation

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density (lb/in³)</th>
<th>Young’s Modulus (psi)</th>
<th>Poisson’s Ratio</th>
<th>Thickness (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vectran Plain Weave</td>
<td>0.01672</td>
<td>9400000</td>
<td>0.36</td>
<td>0.0075</td>
</tr>
</tbody>
</table>

Signal arrived at Sensor 1 & 3
Sensor 1
Sensor 3
Signal arrived at Sensor 2
Zoom
**Sensor Selection**

- The Macro Fiber Composite (MFC) is a flexible and durable low-profile actuator and sensor.
- These sensors are available as elongators ($d_{33}$ mode) and contractors ($d_{31}$ mode); i.e., in-plane and out-of-plane wave displacement when used as ultrasonic sensors.
LOADING SETUP DESIGN AND ASSEMBLY

Additional grip support will be attached in case of additional gripping requirement.

Perforated 1.5"x1.5" steel angles
7/16"-14 threaded rod with nut
Assuming 12"x12"

DAQ and Signal Processing
Arduino
MFC Sensors
PicoScope 3000a
Auxiliary Resistor
Turnbuckle
STRAIN MEASUREMENTS - IMPEDANCE

Increasing Load

Gain [dB]

Phase [deg.]

Frequency [kHz]

Increasing Load

Gain [dB]

Phase [deg.]

Frequency [kHz]
STRAIN MEASUREMENTS - REPRODUCIBILITY

![Graphs showing strain measurements and reproducibility](image-url)
ACOUSTIC EMISSION DETECTION AND SOURCE LOCATION
AE FOR CREEP MEASUREMENT
GUIDED WAVE INSPECTION
**TAKE AWAY SUMMARY**

- XII is developing a MFSNS system that can
  - Monitor creep or material state;
  - Detect and characterize damage;
  - Assess sensor health or condition;
  - Estimate the remaining useful life (RUL) of softgoods structures in space habitats.

- Promising initial results
  - Built a MFSNS prototype and test setup;
  - Conducted AE, UT, SS measurements with prototype;
  - Successfully proved the concept of MFSNS for sensing and determining damage precursor, defect size and location in space habitat structures.
Future work

- Customize and improve transducer design and placement
- Complete multi-channel/multi-mode data acquisition system development
- Implement damage detection algorithms
- Develop diagnostics/prognostics algorithm for SHM and RUL prediction
- Test and improve MFSNS prototype performance
Question?