SELF-DIAGNOSITIC, SELF-HEALING MULTIFUNCTIONAL FIBER-OPTICS NETWORKS FOR COMPOSITE STRUCTURES

A. Schmalz (BSECE), M. Golt (BSECE), and D. Lipiecki (BSECE)

University of Delaware • Center for Composite Materials • Department of Electrical and Computer Engineering

Project Summary

- Develop a smart network that can interrogate the state of the structure while serving as a fiber-optic network for communication
- Implement the use of fiber optic Bragg gratings operating at 1550nm to sense strain and temperature, while multiplexing 1310nm for communications
- Define a process for embedding gratings into a composite representing missile casings, composite armor, etc.
- Design algorithms to continuously monitor strain calculated from Bragg wavelength shift and control the switching of the embedded fibers to diagnose and heal the network

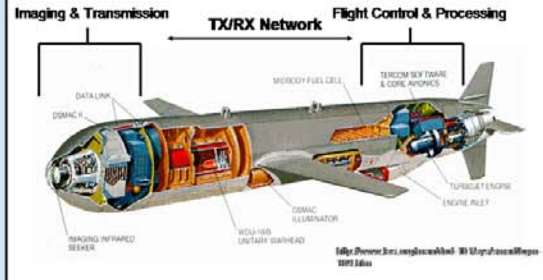
Why a Self-Diagnostic, Self-Healing Fiber-Optic Network?

Next generation autonomous air and space systems

- Increasing emphasis on reliability, prognostics, and autonomous operation
- Damage to these systems can lead to loss of control or data
- Smarter "Smart" bombs and missiles, smart armor

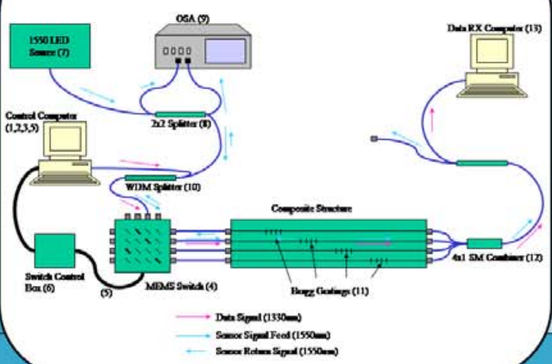
- Fiber optics are inherently lightweight, immune to electromagnetic interference, and capable of high bandwidth communication

Missile Systems Configuration



BGM-109 Tomahawk

System Set-Up



Test Panel Manufacturing Procedure

- Composite panels fabricated from E-glass fabric and SC-15 resin
- Bragg grating fibers spaced evenly across panel between bottom two layers of glass
- Thin furcation tubing used as sleeve to protect fibers against breakage at composite interface
- Ends of tubing sealed with epoxy to maintain airtight seal during VARTM infusion

Test Panel Manufacturing Procedure

- All fibers were connectorized and measured for loss to determine effect of manufacturing process on transmission loss

Composite 1 (4 FBGs)

	1310 nm	1550 nm
Fiber	Loss (dB)	
1	5.9	12.3
2	1.7	6.8
3	1.3	6.9
4	38	38.8

Note: Fiber 4 was broken during manufacturing

Composite 2 (3 FBGs, 3 SM fibers)

	1310nm	1550nm
Fiber	Loss (dB)	
FBG1	0.2	1.3
FBG2	0.4	1.2
FBG3	1.1	2.9
SM1	0.1	0.3
SM2	0.8	1
SM3	0.2	0.5

Second composite yielded better loss numbers

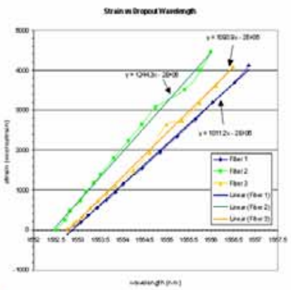
- Loss numbers higher at 1550 nm in FBGs due to back reflection of the grating

Manufacturing Design Modifications

- Fiber egress currently located at end of composite span
  - Protruding fibers clutter the setup and are susceptible to breakage
  - Limits machinability of panel edges
- Fabrication methods being investigated to implement mid-span fiber egress and/or embedded connectors
  - Will help minimize system fragility and enhance design efficiency
  - Surface connectors allow for easy access and mating durability

Procedures

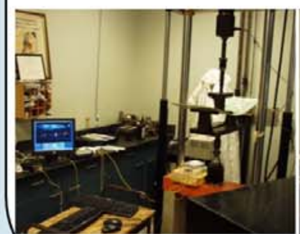
- 3-point bend test showed a linear relationship between strain and wavelength shift of the embedded Bragg gratings



3-point bend test performed using 1550nm light source fed through each fiber with an optical spectrum analyzer displaying the wavelength

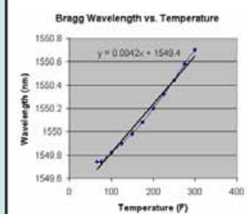
Procedures

- Performed a maximum strain test while networking a video feed to study the effects of intense strain upon the composite and to characterize signal loss at composite failure.
- Approaching failure, the video signal became choppy after 1.3% elongation. Then, as the fiber was broken completely at 1.4%, the connection along with the video stopped altogether.



Procedures

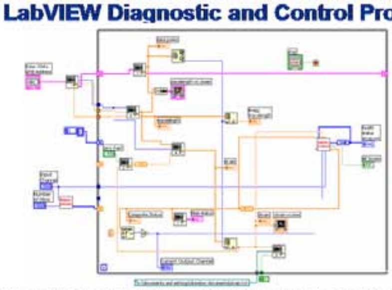
Conducted a wavelength shift vs. temperature test to define a calibration constant.



Test was performed using a 1550nm light source fed through a single Bragg grating placed inside an oven. The wavelength shift was displayed on an OSA

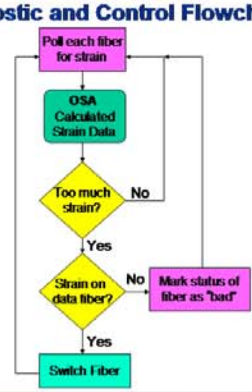
- Found a linear relationship between wavelength shift and change in temperature
- Only a small change in wavelength over a large change in temperature (230°F ΔT = .96 $\Delta\lambda$)
- Temperature Constant = 0.0042

LabVIEW Diagnostic and Control Program

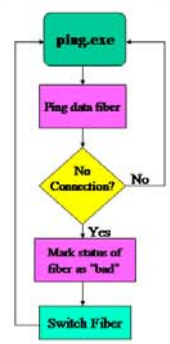


- Reads and interprets the 1550nm dropout wavelength from OSA
- Calculates the fibers' strain based on wavelength shift
- Monitors fibers for broken connection
- Maintains status of each fiber in an array
- Decides whether fiber has too much strain for data transmission and switches data to another fiber

LabVIEW STRAIN Diagnostic and Control Flowchart



LabVIEW DATA Diagnostic and Control Flowchart



Future Work

- Further integrate fiber network functionality into composite structure
- Demonstrate approaches to embedding networks into cylindrical structures
- Evaluate stability and survivability of network in severe shock environments
- Incorporate remote wireless sensing and control capability
- Investigate benefits of using multimode fibers/gratings

Acknowledgements

This work is supported by the U.S. Army Space and Missile Defense Command.