Active Monitoring of Composite Structures through Embedded Synthetic Fiber Sensor

Relevance
Current and future automobiles will increasingly use composite materials in their structures to reduce weight and increase fuel/energy efficiency. These structures, especially the critical parts such as battery housing, must be monitored for safety. The vehicle’s outer body structure, often exposed to extreme conditions and mechanical impacts, should also be closely monitored for its safety and repair failures. Innovative methods to monitor thermo-mechanical changes to these composite parts will help provide early warning of any imminent failures and enable precautionary measures to be taken to ensure safety.

Overview

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<tr>
<th>Timeline</th>
<th>Program duration: 2020/06 - 2021/03</th>
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<tbody>
<tr>
<td>Tasks</td>
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<td>- Perform initial tests to determine the need for fiber twisting, connector type, and optimal fiber length.</td>
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<td>- Designed the AMCOS Phase I system, taking into account the desired specifications.</td>
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<td>- Lack of understanding of properties with respect to fracture and energy absorption</td>
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<td>- Lack of predictive engineering and modeling tools</td>
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<td>- Lack of high-volume manufacturing capability</td>
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<td>Barriers for widespread implementation of composite materials:</td>
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AMCOS System Architecture
- Analyzed DOE requirements for AMCOS and defined target applications and system properties, focusing on automotive components from composite materials.
- Designed the AMCOS Phase I system, taking into account the desired specifications.
- Performed initial tests to determine the need for fiber twisting, connector type, and optimal fiber length.
- Built a heat-transfer model in COMSOL to evaluate heat transfer capabilities of fibers embedded in composite materials.

Electronic Reader and Software
The data-acquisition speed of the electronic reader was increased from 1 kHz to 4 kHz to better capture impact events, which happen on the ~ms timescale. This is sufficient to capture impact events in detail during operation in an automotive environment and generate structural failure warnings in real-time.

Fiber Response and Placement
A comparison of fiber sensor formulations for their electrical and mechanical properties was performed and a fiber type selected based on the findings that provide batch measurements of 241 kΩ for 10 bundles of 144 filaments at 1 ft length.

Collaboration
Test coupon fabrication and mechanical testing was performed in collaboration with:
- AMCOS System Architecture
- AMCOS Prototype and Preliminary Tests
- AMCOS Feasibility of the AMCOS System
- AMCOS Summary and Conclusion

Future Work Plan
The technology will be matured further by optimizing the sensor spacing, testing smart fiber formulations to improve sensitivity, implementing mitigation strategies for charge buildup, and performing tests to mimic conditions during transport. A facsimile automotive part with embedded sensor fibers will be manufactured as the Phase II prototype. The Phase I algorithm will be improved by developing a machine learning-based approach to reliably distinguish between different defect signatures and time-to-failure estimations. Phase II improvement will lead to a timely technology transition and commercialization.

Specific tasks to be completed:
- Improve System Architecture and Design Phase II Prototype
- Formulate and Improve Sensing Fibers
- Design and Build Electronic Reader and Multi-Channel Connector
- Perform Mechanical and Environmental Tests in Laboratory Setting
- Assemble Facsimile Automotive Part with Embedded Sensing Fibers
- Perform Vibration and Use Case Testing
- Develop and Test Machine Learning-Based Failure-Detection Algorithm
- Test the Phase II Prototype

Summary and Conclusion
In Phase I, synthetic polymer (nylon) smart fiber yarns were successfully embedded in woven composite panels, demonstrating the AMCOS technology’s compatibility with composite manufacturing processes for automotive applications. Electrically conductive fiber sensor yarns were embedded and an test coupon and electrically and electronically monitored real-time continuous sensor readout. Their responses to external events, like strain, impact, and temperature changes, were experimentally measured. The results showed that the sensing fibers repeatedly and accurately detect strain, impacts, and temperature changes, and that calibration procedures can be used to establish a quantitative relationship between resistance and strain. Changes in temperature were measured directly and distinguished from other events, such as temperature changes.

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