VALIDATION OF REMOTELY POWERED AND INTERROGATED SENSING NETWORKS FOR COMPOSITE CURE MONITORING

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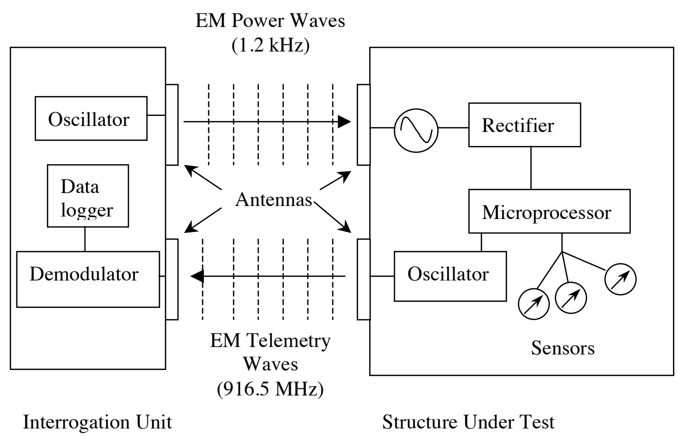
Introduction: Monitoring of a composite's thermal and dielectric profile during autoclave cure is important for the quality control of the cure schedule and ultimately, for the quality of the composite's mechanical properties. However, the wires typically used for thermocouples and capacitive sensors embedded in the composite and brought out through a protective bag can be a source of damage to the material due to steam penetration.

The ingress/egress of lead wires (or fiber optic "tails") present additional trimming costs and handling problems, and require external connections. These problems may be overcome by employing embedded sensors, powered by an external magnetic field, to measure temperature, dielectric constant, strain, crack extension, etc. without direct physical connections[1,2].

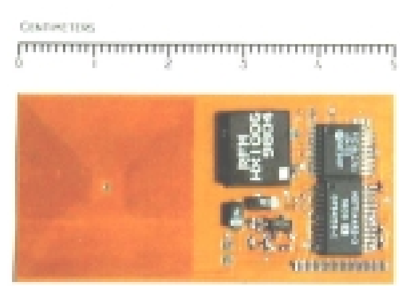
Methodology: We have developed a technique for remote powering and bi-directional communications with a network of micro-miniature, multi-channel addressable sensing modules (ASM's), which may be powered and interrogated via a non-contacting inductive link (figure 1)[3,4]. ASM's may be configured to operate with a variety of sensors, including thermocouples, strain gauges, magnetometers, and capacitive/inductive sensors. Because the nodes are addressable, multiple ASM's may be embedded in a composite and queried by a single external powering/interrogation system. In order to demonstrate the utility of embedded ASM's for composites monitoring, a validation was performed in a large steam autoclave used to produce high performance composite structures such as sonar bow domes (BF Goodrich Engineered Polymer Products, BFG/EPP, Jacksonville, FL). A test panel of thick fiberglass reinforced epoxy composite (approx. 1.5 meters square by 50 mm thick) was

Figure 1. Remote Powering & Interrogation System



prepared for cure within the large autoclave at BFG/EPP. Data from five embedded semiconductor temperature sensors (MicroChip Technologies, Chandler, Arizona) integral to a thin ASM "patch" (figure 2) were monitored through a non-contacting powering/interrogation

Figure 2. ASM patch transponder on polyimide



coil, this coil placed outside the protective bag. The powering/interrogation coil was connected to a 40 meter long sealed coaxial cable which exited through sealed openings in the autoclave for connection to a remote host for powering, communications, and PC based data acquisition. Simultaneous data were collected from a hard wired thermocouple system (Holometrix Micromet, Bedford, MA, USA), which were embedded in the composite panel adjacent to our ASM patch. The operating specifications for our ASM patch transponder are provided in Table I, below.

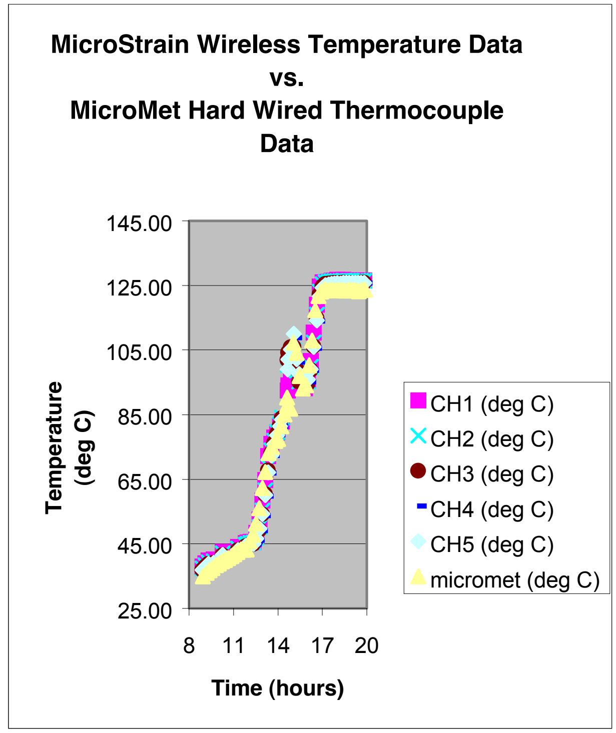
Table I. ASM transponder specifications:

Description	Specification
Amplifier gain	1-128; programmable
Filter	Low pass 1-250 Hz; programmable
Sensor inputs	5 pseudo differential; 3 full differential
RF Transmission Frequency	916.5 MHz
A/D resolution	10-16 bits (inversely proportional to low pass filter setting)
Output data rate	80 Hz for 5 channels of data; 220 Hz for 1 channel of data
Bit error rate	10 ppm w/ error checking
DC power required	9 mW typical
Temperature stability	10 ppm/C offset 100ppm/C gain

Results: The temperature profiles from all the embedded sensors and from both systems were plotted over the cure cycle (figure 3). The hard wired Micromet thermocouple system and the remotely powered/interrogated ASM system (ch 1-5) produced nearly identical temperature profiles.

Discussion: These test results support the validity of our remotely powered and interrogated sensing methodology, and demonstrate that our ASM's can perform in an autoclave environment at elevated temperatures. Our planned future work includes greater miniaturization of the embedded ASM network, as well as validation of specialized nodes for measuring a composite's dielectric properties during the cure cycle.

Figure 3. Autoclave composite cure temperature data, indicating hard-wired and wireless results



Smart composite panels and smart structures with remotely powered and interrogated sensors can be used for improved cure monitoring as well as in-service strain monitoring; and these data could indicate the need for repair, reinforcement, or replacement.

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[3] Townsend, C.P., Hamel, M.J., Arms, S.W., *"Remote Interrogation of Sensors Embedded in Composites"*, NSF Phase II SBIR progress report, Feb 2000, podium presentation SPIE's Int'l. Conf. on Smart Stuctures, San Diego, CA 1998

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