Visitor Research Report

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Area of Research: **Investigation of Open-Circuit Sensing of Material Phase Transformation (Curing)**

Period of Visit: **May 27, 2008 – December 31, 2008**

Goal:

The goal of the research is to use open-circuit wireless magnetic field sensors to successfully track the curing of thermoset composites, which is used as an aerospace structural material. Once the composite has cured, the embedded sensor then serves as a health monitoring system for that particular section of material.

The open-circuit wireless sensors have already been implemented in applications like fuel level detection and wheel rotation speed. In applications such as these, the sensor enables measurement of the desired variable without bringing electric current or wires into potentially dangerous situations such as around fuel vapor, where ignition can occur, or fast rotating machinery, where wires can be abraded. In implementing the sensors in material phase transformation applications, the physical properties of the composite can be tracked without disturbing the curing process. This enables the composite builder to accurately know how the material is behaving during the cure process without affecting the cure.

Once the cure is complete, the sensor is embedded into the composite. This is highly desirable as the sensors are then able to function in the embedded environment as a health monitoring system. If the material is altered, the sensor's response characteristics change. Each manufactured panel of composite has its own sensor; it is desirable to put multiple sensors at reasonably distanced locations to serve as an overall vehicle health monitoring system.

Strategy:

The sensors themselves are RLC series circuits. They are geometrically stand alone patterns of electrically conductive material. An antenna powers the sensor via induction. The alternating current sent through the antenna induces a magnetic field, which induces an alternating current in the sensor. The distance at which the antenna can excite the sensor is directly proportional to the power of the signal in the antenna. Once the sensor is excited, the antenna is shut-off as a transmitter and activated as a receiver. In this manner, the response characteristics (i.e., frequency, amplitude, and bandwidth) of the electric current in the sensor circuit can be measured. These variables relate to the inductance, capacitance, and resistance of the sensor circuit. The sensor circuit consists of the sensor and the parts of its environment that affect its RLC behavior, namely the curing thermoset plastic. The inductance of the sensor is constant once the geometry of the sensor is fixed. The capacitance and resistance of the sensor, however, are highly variable. They both change due to changes in the sensor circuit. For example, an increase in dielectric constant will cause the resonant frequency of the sensor to decrease, and an increase in resistance will cause the amplitude to decrease. Once the resonant frequency is identified, it becomes the excitation frequency sent from the antenna to the sensor once the receiving phase completes and the transmit phase begins.

A particular thermoset curing being investigated is a two part epoxy consisting of a resin and hardener. A sensor is suspended in the mold and the then the two parts are mixed and poured into the mold. An antenna is placed around the mold and the resonant frequency is found. The amplitude of the resonant frequency and the bandwidth are also measured. As the viscosity of the thermoset changes, its dielectric constant and resistance also changes. These changes are reflected in the resonant frequency, the corresponding amplitude and the bandwidth of the circuit. As the epoxy hardens, the dielectric constant will increase and the resistance will increase, resulting in a decrease in resonant frequency and amplitude. This pattern will continue until the epoxy has fully cured, when there will be no detectable change in these variables. The sensor is then embedded into the fully developed composite. Then, a hole, tear, or crack is created in the composite and the sensor's response is captured.

Accomplishments:

Curing was successfully tracked in the epoxy curing process. As the composite hardened, the resonant frequency decreased and the amplitude decreased. After the manufacturer's recommended set time, there were no noticeable changes in the resonant frequency or the amplitude of the signal. Once it was embedded, the sensor was also able to sense the presence of dielectric materials around the composite. The sensor's resonant frequency and amplitude changed in the presence of conductive materials and dielectric materials. For example, the proximity of metals to the composite panel caused an increase in resonant frequency and a decrease in amplitude.

Future Work:

The next phase of the research is to investigate the health monitoring abilities of the sensor. The composite will be intentionally damaged, and the transient and steady state response of the sensor will be studied.

The research has also lead to interest in investigating the sensor for applicability to high temperature vacuum curing processes. The particular challenge in this curing process is finding a material that can withstand the high temperatures involved. Flashing of the mold material is of utmost importance. Secondary considerations are the resistance and the dielectric constant as a function of temperature. As the temperature is increased, the electrical resistance also increases. Also, the mold materials being investigated have the property of decreased dielectric constant with increased temperature. Currently, at the high temperatures necessary to carry out the curing process, the signal becomes absorbed by the mold material, resulting in no discernible resonant frequency.

Pending Publications:

None.

Seminar Presented:

None.