Insight — Technical Overview 2.06

Distributed Dielectric Cure Monitoring of Composite Aerospace Structures

Introduction

Distributed Dielectric Cure Monitoring (D-DEA) is a new concept for the application of Dielectric Analysis (DEA) in manufacturing. Instead of a single expensive base instrument and many long extension cables, D-DEA uses multiple inexpensive instruments connected along a single RS-485 communications line, as shown in Figure 1.

Distributed Dielectric Cure Monitoring for the first time allows the use of DEA to monitor many locations in very large autoclaves like those used for composite aerospace structures. Distributed Dielectric Cure Monitoring also avoids the tangle of extension cables used for monitoring parts requiring multiple sensors, such as aircraft and spacecraft components.

Compared to conventional DEA instruments, Distributed Dielectric Cure Monitoring:

- Is less expensive
- Avoids long sensor cables which degrade signals to base instrument
- Uses short sensor cables which preserve signals to D-DEA units
- Integrates DEA into a standard RS-485 process control network
- Allows up to 256 DEA channels operating simultaneously
- Extends the distance of DEA channels to 4000 feet (1890 meters), the RS-485 distance limit
- Enables DEA monitoring and process control of very large structures

Dielectric cure monitoring uses the same sensors and measurements for research, quality control and manufacturing applications. Dielectric Analysis correlates with laboratory tests such as differential scanning calorimetry (DSC) or dynamic mechanical analysis (DMA). As a result, DEA can act as the “go between” that brings information from the research lab to the manufacturing floor, and from the manufacturing floor to the manager responsible for product quality.

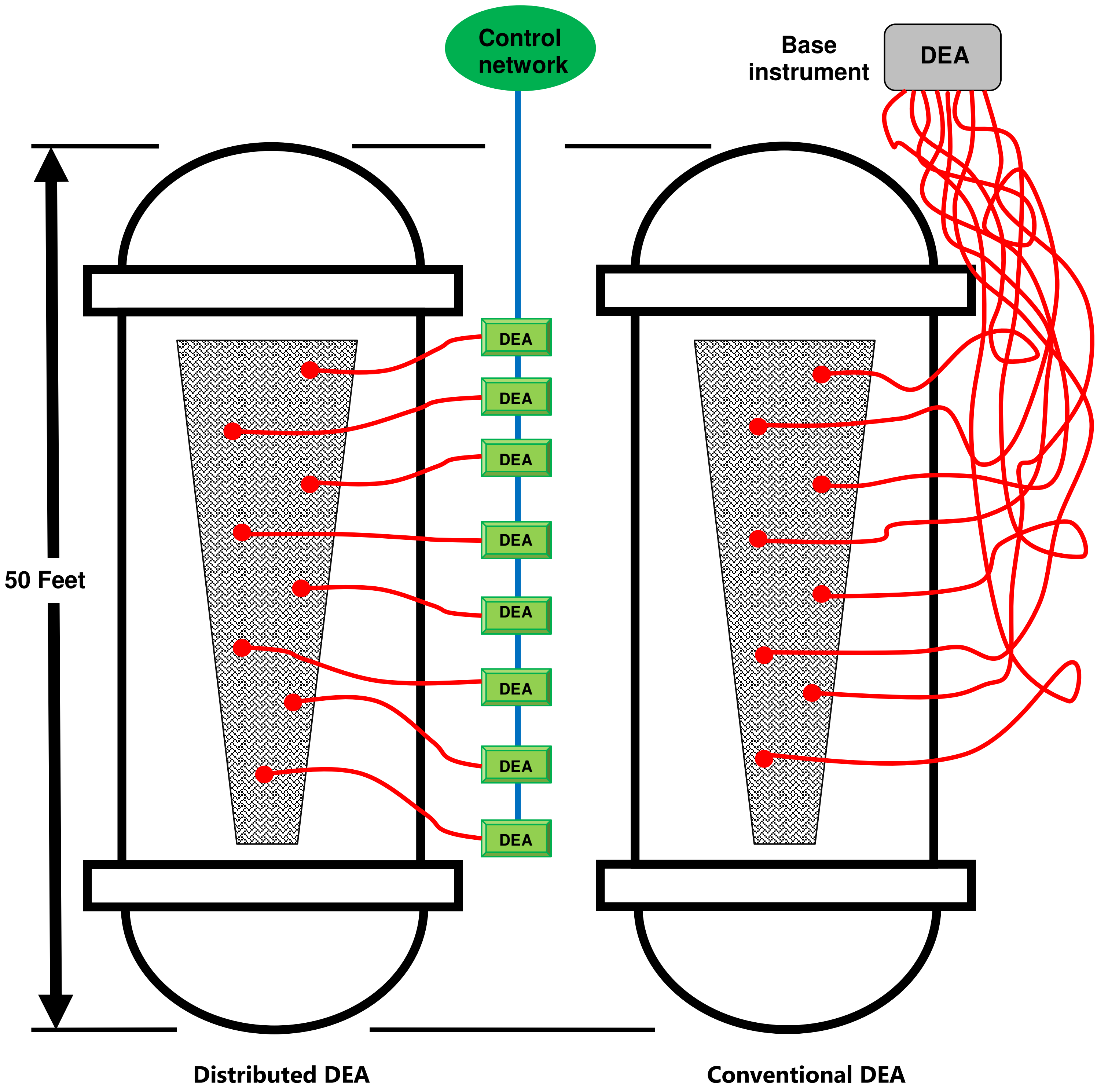

Figure 1
Distributed DEA compared to conventional DEA
(Composite wing in autoclave)

Distributed Dielectric Cure Monitoring with the LT-439

The LT-439 Dielectric Channel of Figure 2 is a cost effective, compact instrument designed for thermoset cure monitoring in R&D, Quality Control/Quality Assurance and manufacturing. When used with either disposable or reusable dielectric/conductivity sensors, like those shown in Figure 3, the LT-439 Dielectric Channel enables Distributed Dielectric Cure Monitoring in all processing environments.

Figure 2
LT-439 Dielectric Channel for Distributed DEA

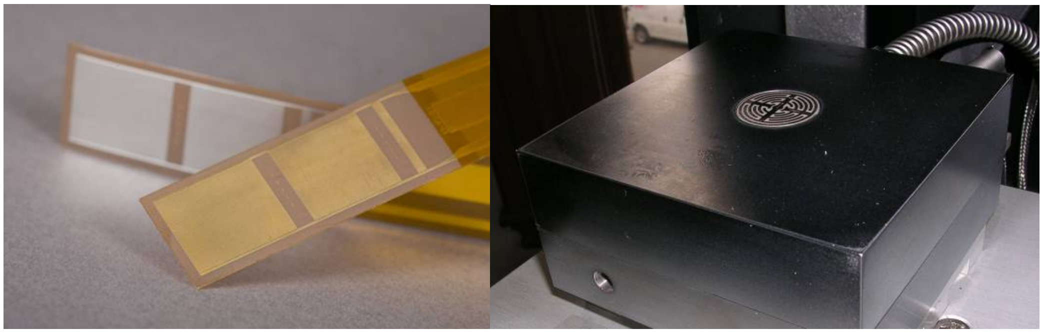

Figure 3
Disposable (left) and reusable (right) dielectric sensors

Measurements from the LT-439 may be interfaced to a control network through its standard RS-232 serial port or optional RS-485 serial port. Each LT-439 supports one dielectric sensor and one thermocouple. Up to 256 individual Dielectric Channels may be connected to a single RS-485 line. This low-cost flexibility eliminates complex cabling and allows simultaneous, multi-channel monitoring of cure state at any point in a large part.

The standard LT-439 Dielectric Channel has 10 Hz, 100 Hz, 1 kHz and 10 kHz excitation frequencies. An extended frequency option expands the range to 1 Hz – 10 kHz with additional frequencies within each decade.

DEA in manufacturing

For highly critical parts such as composite aircraft or spacecraft components, every step in manufacturing is documented, both to record that the part is made according to specification and for analysis in the event of failure. Many manufacturers measure temperature as a very indirect and inaccurate way to infer the progress of cure. DEA, however, is a direct indicator of cure state. DEA measures a property called *ion viscosity*, which is the frequency independent electrical resistivity. Dielectric cure monitoring is valuable for documentation because no other technique can observe cure state in manufacturing and in real-time.

During the manufacture of composite materials, parts are typically cured with a fixed schedule for time and temperature. Currently, DEA is most often used to confirm the consistency of parts. The nominal cure profiles of a carbon fiber reinforced prepreg (CFRP) might look like Figure 4.

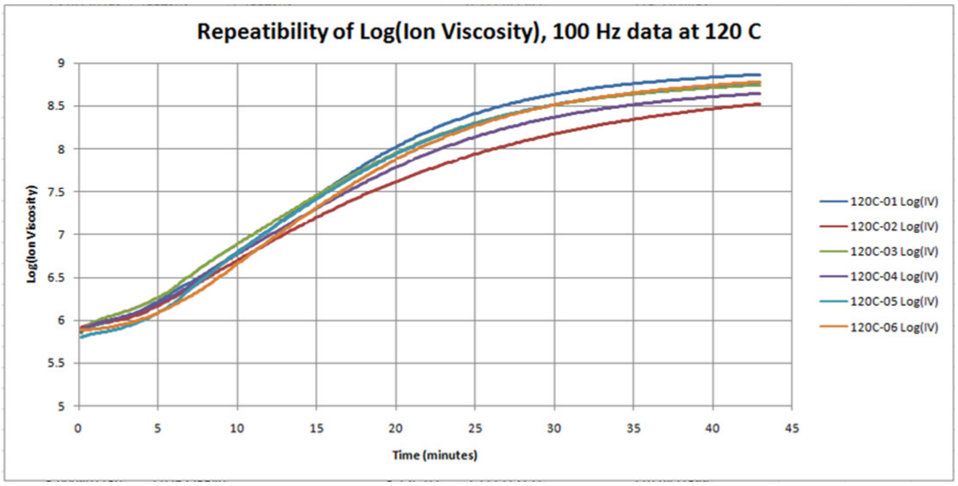

Figure 4
Nominal cures of carbon fiber reinforced prepreg

Dielectric cure monitoring can immediately improve productivity for high value composite fuselages or wings. These aerospace components, often more than 30 feet long, are fabricated in an autoclave. The thickness of the part and the exotherm during processing vary with location. Consequently, the rate of cure also varies, depending on location. Figure 5 shows how the time to a defined end of cure for CFRP depends on temperature. Removing a part too soon risks incomplete cure and deficient strength. Removing a part later than necessary wastes energy, increases costs and reduces throughput. As a result, manufacturers must use experience, extensive testing and guesswork to determine the optimum processing time.

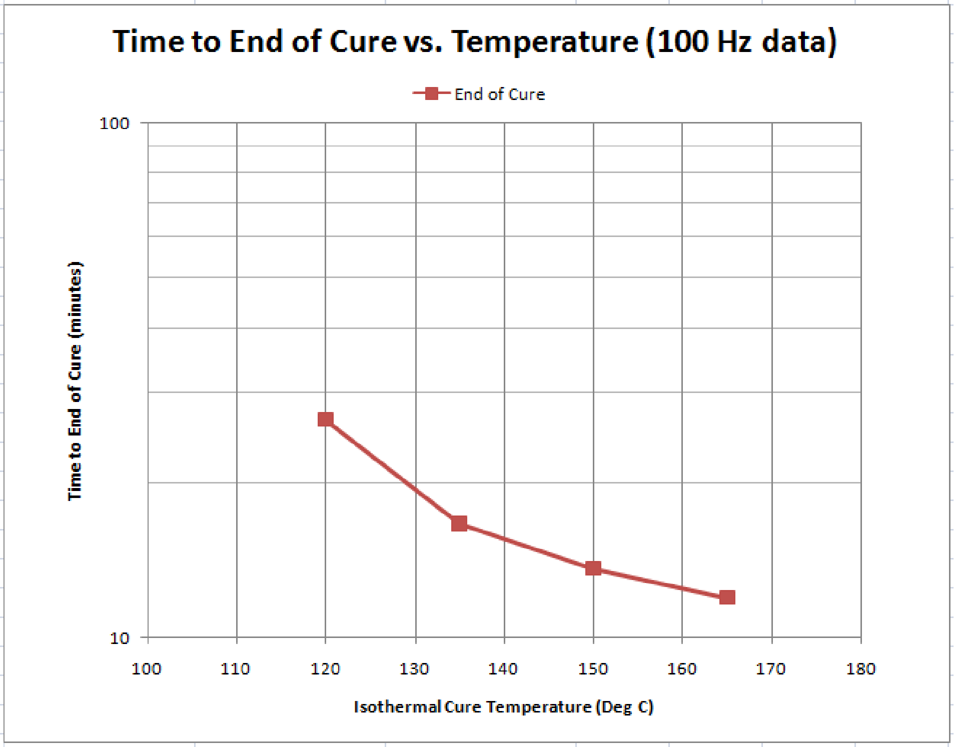

Figure 5
Variation of CFRP cure time with temperature

Dielectric sensors installed in at strategic locations can determine when cure along the entire part has reached a desired point. Only at that time would it be removed from the autoclave. By comparing cure profiles, every panel can be judged against a nominal family of curves. Results can be recorded for statistical quality control (SQC), and deviations beyond defined limits indicate the process has drifted.

Closed loop process control

Related to productivity is the possibility of closed loop process control. Figure 6 shows how Critical Points, which identify key events during cure, vary with temperature for sheet molding compound (SMC). Because the reaction is thermally driven, the time to end of cure decreases with higher processing temperatures.

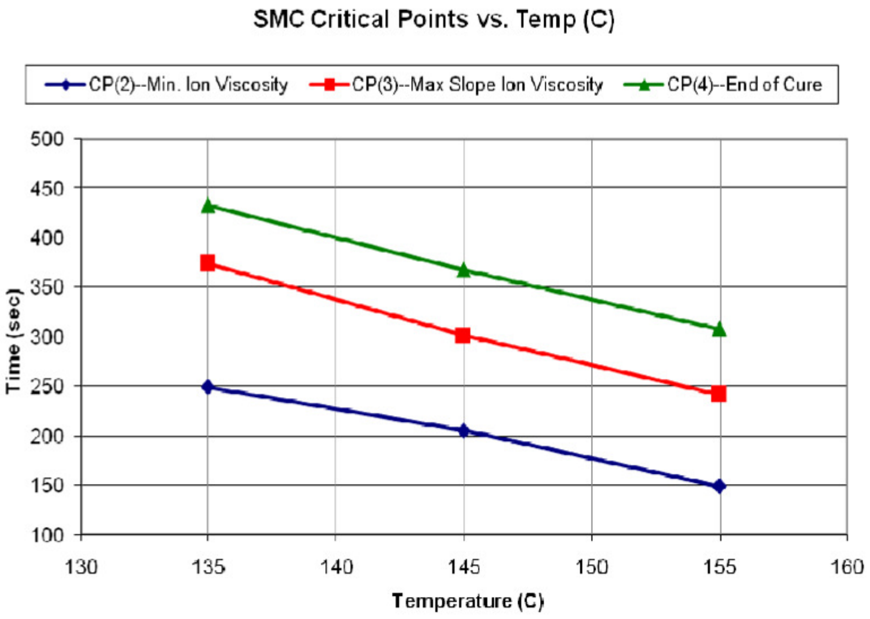

Figure 6
Variation of SMC cure time with temperature

Manufacturers of molded thermosets use timers to determine when products are cured and may be removed from a press. This standard practice must allow for normal variation in process temperature and other factors that affect cure. To be conservative, demold time is chosen to guarantee that all parts are good, with the result that some parts may be cured longer than necessary. Over many thousands of parts, the use of timers wastes considerable time, effort and productivity.

One study of closed loop process control used the hardware of Figure 7 at a company that manufactures commercial SMC products. A reusable dielectric sensor was embedded in the lower mold. The sensor was coated with mold release before each charge of SMC was loaded. Then the 2000-ton press was closed. Upon detecting end of cure, the dielectric cure monitor automatically issued a signal to open the press.

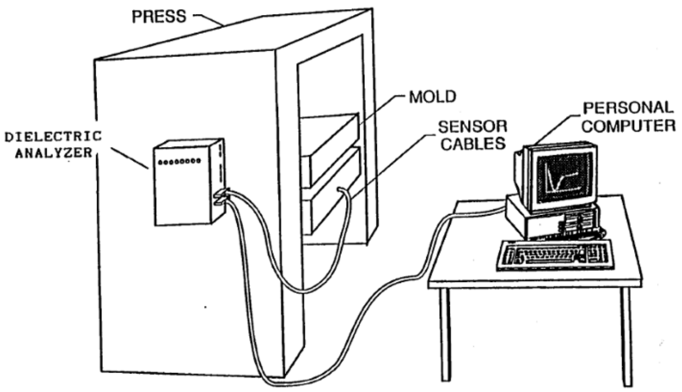

Figure 7
Closed-loop process control with dielectric cure monitoring (ref. 1)

Figure 8 shows the distribution of cure time during the production of about 1000 parts. A fixed timer setting would have been 60 seconds to ensure 100% good parts. In comparison, closed loop control with dielectric cure monitoring reduced average press cycle time to 50 seconds.[1] This 10 second reduction would have saved $70,000/year/press in labor costs alone.

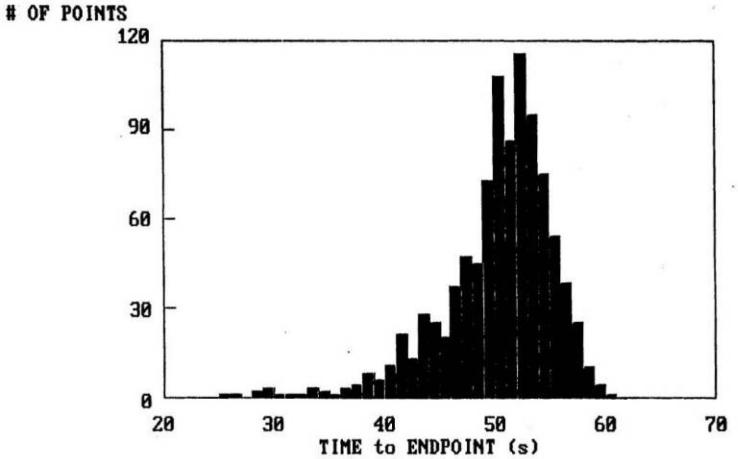

Figure 8
Distribution of SMC cure time for 1000 parts (ref. 1)

In large composite structures, such as an aircraft fuselage, wind turbine blade or bridge beam, different locations cure at various rates because of differences in thickness and thermal environment. If sections of a large part have independent heaters, as shown in Figure 9, then dielectric measurements can provide feedback for a control system. This system can adjust temperatures so all sections cure at a uniform rate for optimum throughput.

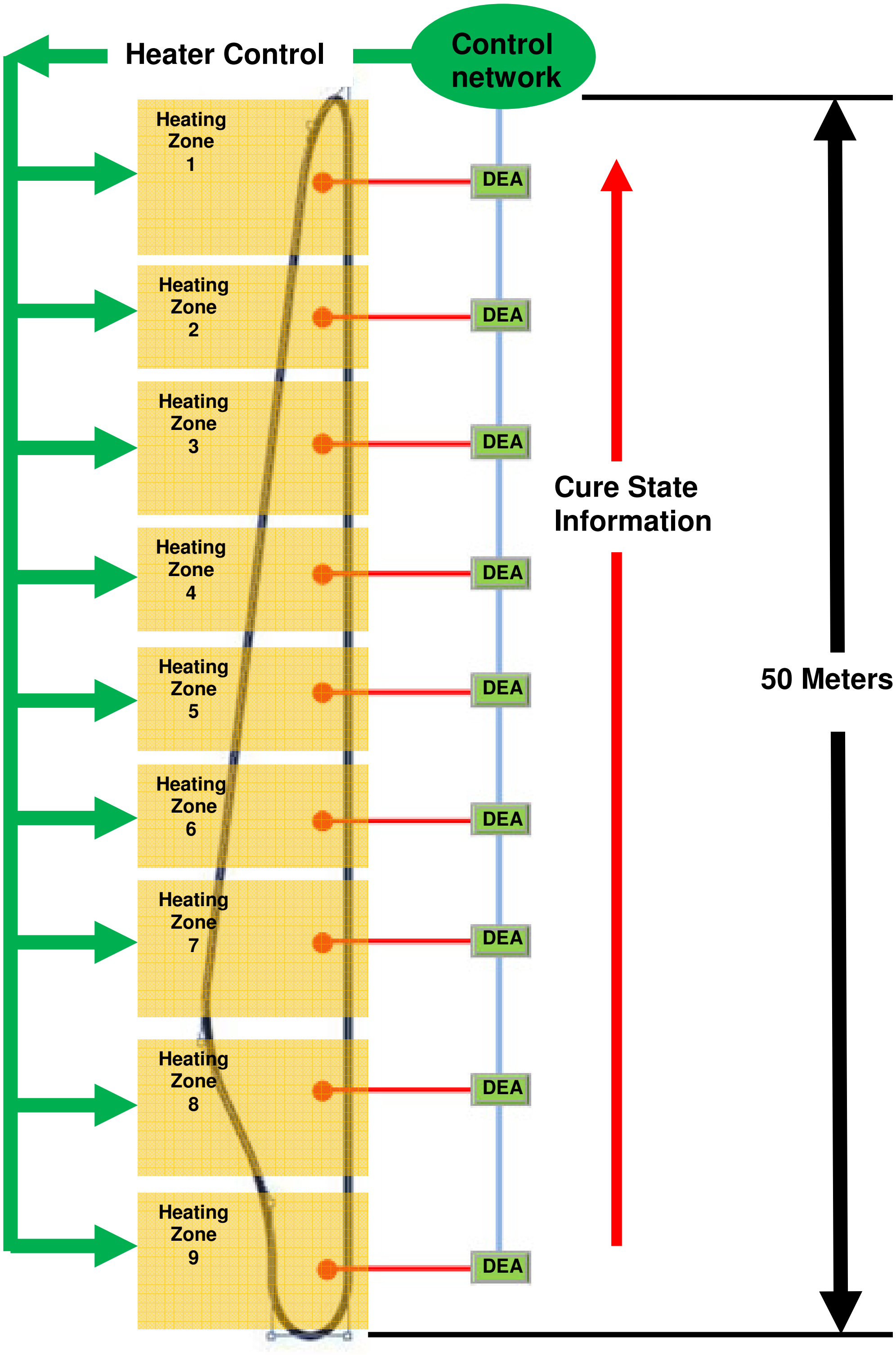

Figure 9

Distributed DEA for closed loop process control
(Wind turbine blade manufacture)

Conclusion

Distributed Dielectric Cure Monitoring (D-DEA) with the LT-439 Dielectric Channel is a new method of implementing dielectric cure monitoring for composite aerospace components and other large composite structures. By placing inexpensive, individual DEA instruments at desired points, D-DEA avoids long extension cables which can degrade the sensor signal. A process control network can communicate with up to 256 LT-439 Dielectric Channel Units, enabling cure monitoring of as many points as needed as far as 4000 feet (1890 meters) away from the base station.

Dielectric cure monitoring (DEA) is a simple electrical measurement that uses the same sensors and methods in research, quality control and manufacturing applications. Dielectric analysis correlates with measurements from purely laboratory tests, such as differential scanning calorimetry (DSC) or dynamic mechanical analysis (DMA). As a result, DEA can act as the "go between" that brings information from the research lab to the manufacturing floor, and from the manufacturing floor to the manager responsible for product quality.

References

1. Day, D.R. and Lee, H.L., "Analysis and Control of SMC Part to Part Variations," Session 13-C of *Proceedings of the 17th Annual Conference, Composites Institute*, *the Society of the Plastics Industry, Inc., Feb 3-6, 1992.*

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