Insight —Technical Overview 3.05

Distributed Dielectric Cure Monitoring of Wind Turbine Blades

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 5-1.

Distributed Dielectric Cure Monitoring for the first time allows the use of DEA to monitor many locations in very large structures like wind turbine blades and composite beams. 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.

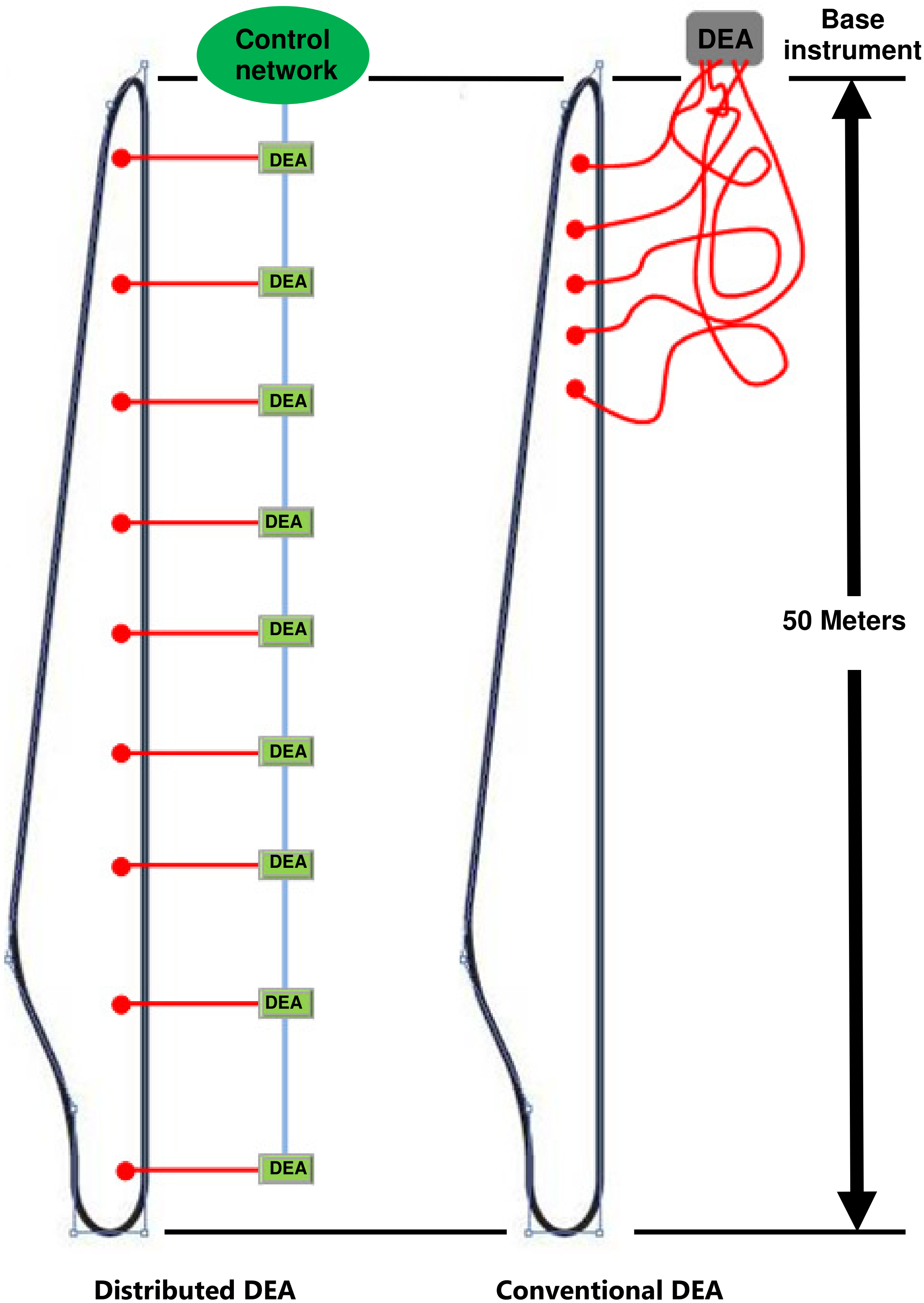


Figure 5-1
Distributed DEA compared to conventional DEA
(Wind turbine blade manufacture)

Distributed Dielectric Cure Monitoring with the LT-439

The LT-439 Dielectric Channel of Figure 5-2 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 5-3, the LT-439 Dielectric Channel enables Distributed Dielectric Cure Monitoring in all processing environments.

Figure 5-2
LT-439 Dielectric Channel for Distributed DEA

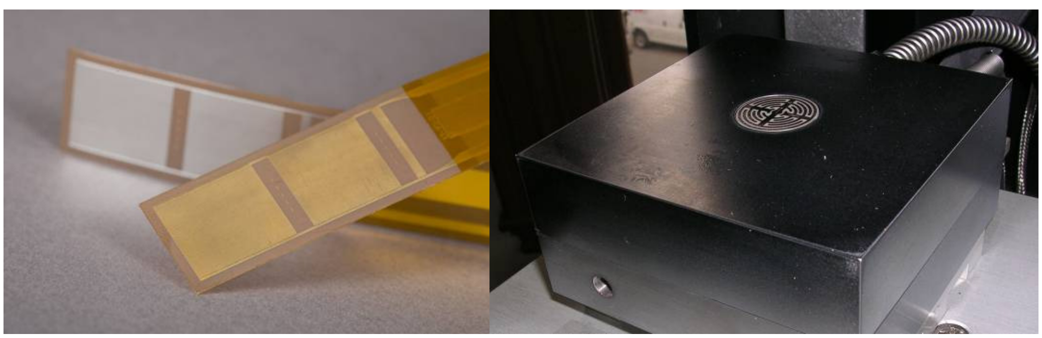


Figure 5-3
Disposable (left) and reusable (right) dielectric sensors

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.

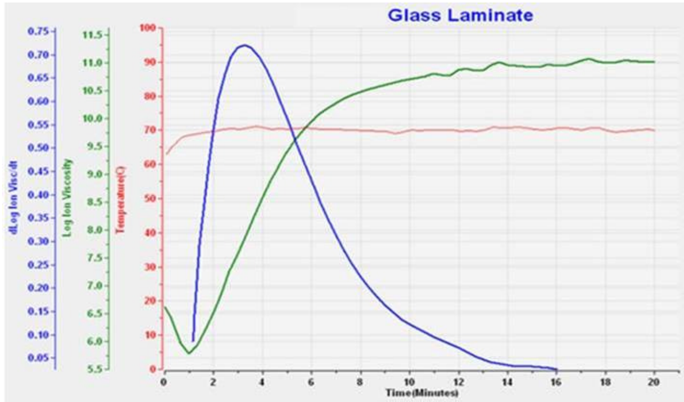
A convergence of cure monitoring technologies

For highly critical parts such as composite wind turbine blades, 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 currently measure only temperature as a very indirect and inaccurate way to infer the progress of cure. DEA, however, is a direct indicator of cure state. Dielectric cure monitoring is valuable for documentation because no other technique can observe cure state in manufacturing and in real-time.

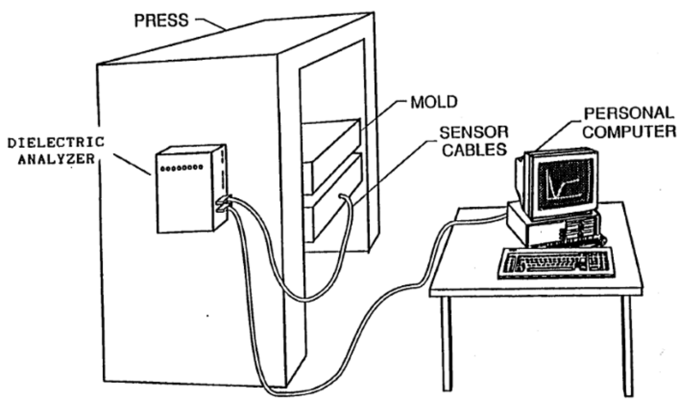
The next advance—DEA-based closed-loop control of large composite structures—is on the verge of becoming a reality. Two critical technologies of a large scale, closed-loop control heating system have existed for decades: dielectric cure monitoring, commercialized in the 1980s, and the demonstration of closed-loop molding control with dielectric cure monitoring in 1992.[1]

Most recently, Spirit AeroSystems of Wichita, Kansas developed the third critical technology: an intelligent, multi-zone heated tool that replaces an autoclave.[2] This tool allows complete control of the curing process with real-time monitoring and feedback, adjusting cure time for individual segments of a part—depending on its geometry and thermal requirements—and reducing cycle times, cutting production costs and decreasing energy use. Although the Spirit AeroSystems tool uses temperature for control information, it is only a small step to incorporate dielectric measurements for feedback about material state.

The convergence of these technologies comes at a time when the development of larger and larger wind turbine blades is crucial to the rapidly growing renewable energy sector. These blades, often more than 50 meters long, are fabricated in a mold. The thickness of the blade, the exotherm and the thermal environment vary along its length. Consequently, widely spaced locations cure at different rates. Manufacturers must use trial and error to determine the optimum demold time. Removing a blade too soon can damage it because of insufficient stiffness, and removing a blade later than necessary reduces throughput.



a. Dielectric cure monitoring (ca. 1980)



b. DEA closed loop feedback control (1992)[2]

c. Intelligent control of multi-zone heating (2018)[3]

Figure 5-4
Technologies for closed-loop control in the production of large structures

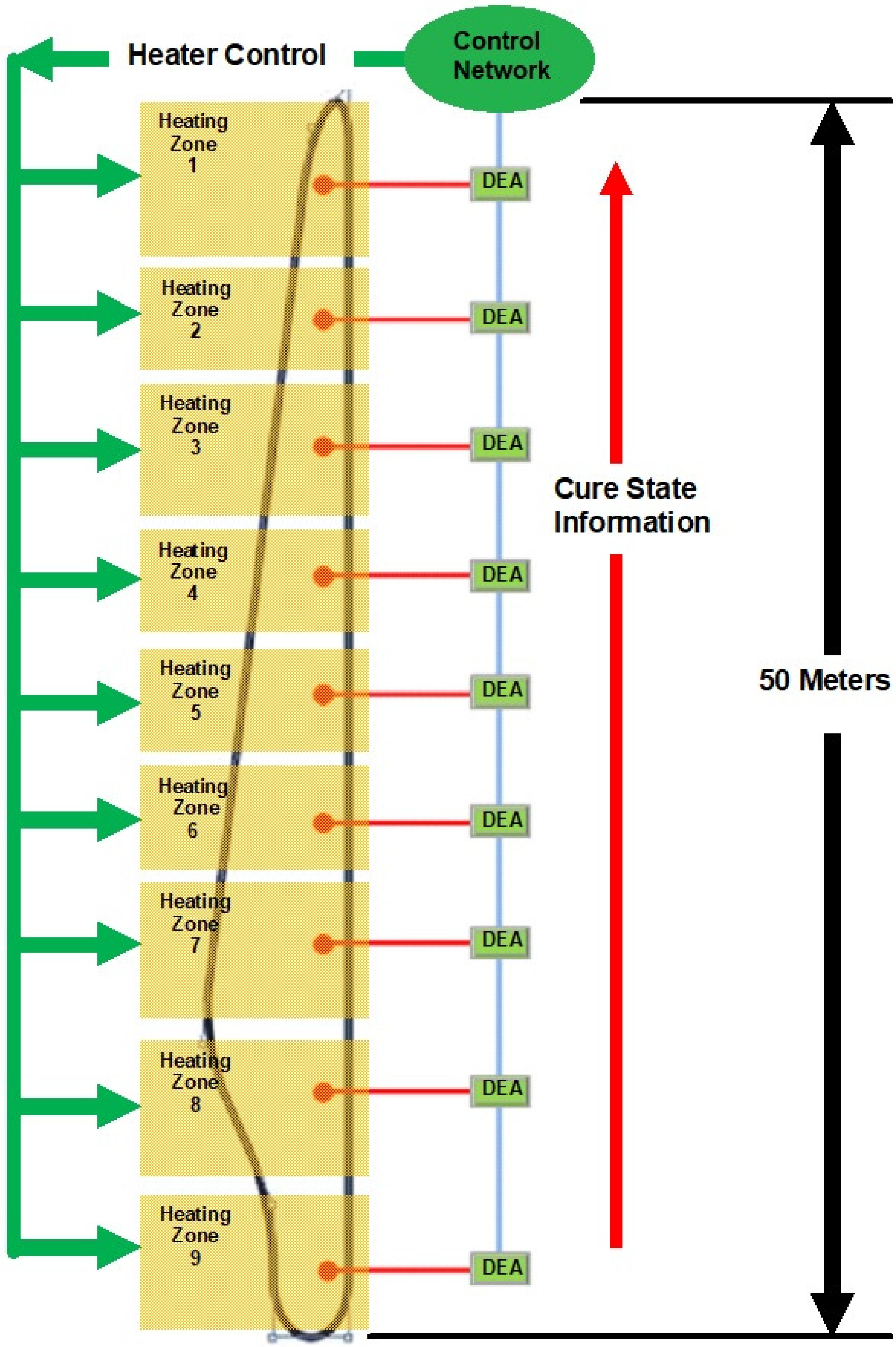


Figure 5-5

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

Dielectric sensors installed in the mold at strategic locations—every five meters along its length, for example—can determine when cure along the entire part has reached a desired point. Only at that time would the wind turbine blade be removed from its mold.

With the use of independent heaters and distributed DEA instruments, as in Figure 5-5, dielectric measurements would allow a closed-loop control system to adjust heating so the entire structure cures at a uniform rate for optimum throughput. As a benefit, if a factory ships even as little as one more blade a week, or reduces scrap by one blade a week, profitability increases.

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*.

2. Spirit AeroSystems, "Spirit AeroSystems Develops New Composites Manufacturing Technology," Press release, Dec 14, 2017. https://www.spiritaero.com/release/136953/spirit-aerosystems-develops-new-composites-manufacturing-technology

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