Optimized Cure Times for Rubber Processing – National Instruments BridgeVIEW™ and DAQ Boards Make In-Mold Control of Vulcanization a Reality

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The Challenge: Replacing the inefficient industrial standard of fixed cure time recipes for rubber vulcanization, which fails to account for process and compound variation, and thus results in lowered throughput, high scrap rates, and inconsistent part quality.

The Solution: Using the PCI-MIO-16E-4 National Instruments DAQ board in a PC-based control system with software developed entirely in BridgeVIEW™ for in-mold monitoring for optimized cures.

Introduction
Using BridgeVIEW to support all software functions and NI DAQ and signal-conditioning hardware, Signature Control Systems has commercialized an impedance-sensing technology in a control system called SmartTrac. SmartTrac provides an important new means for rubber product manufacturers to improve the quality of their products while simultaneously reducing cure times. The technology uses in-mold impedance sensors to measure and control the vulcanization of rubber products in real-time. Moreover, the system is capable of detecting the effects of temperature and compound variations on the vulcanization process and responds to these variations by automatically adjusting the cure time in order to efficiently produce more consistent products.

The Variables in Rubber Manufacturing
Traditionally, rubber manufacturers have relied on methods such as torque rheometry testing, engineering calculations, and operational trial and error to generate set, or fixed curing parameters for their manufacturing processes. Likewise, within these curing parameters, a safety margin, or additional time, is typically added to accommodate rubber compound and processing variations. Still, even with safety margins in place, variability is a costly compromise to both productivity and quality. From run to run, the additional cure time is often unnecessary and can reduce throughput by ten percent or more; and variations in compounds, mold conditions, injections speeds, and other determinants can lead to significant fluctuations in product quality.

In-Mold Solution
SmartTrac control systems generate data similar to that of having a torque rheometer permanently mounted inside the process, thus eliminating the need for fixed curing parameters. It uses sensors to gather feedback directly from the rubber as it vulcanizes. However, instead of measuring mechanical properties such as a torque rheometer, these sensors measure subtle changes in the electrical impedance of the rubber, which changes proportionally to the degree of vulcanization. SmartTrac’s control methodology is accomplished by placing an impedance sensor in the mold, where it comes into direct, yet non-invasive contact with the compound. The technology creates an electrical circuit with the Signature Control Systems’ sensor acting as one plate of a capacitor, while the opposite side of the mold acts as the other plate of the capacitor. The product, sandwiched between the sensor and mold wall, completes the circuit.

A low-level AC voltage is generated by the PCI-MIO-16E-4 NI DAQ board, which is in turn amplified by 5B Series signal conditioning modules. This current excites the sensor, resulting in a complex current flowing through the material to the grounded mold surface. We can measure conductance (loss factor) and capacitance (permittivity) of the material. During the cure, the electrical properties of the material change, and the resulting changes in capacitance and conductance can be monitored.
For each product type, we develop a **rule base** that describes the optimal cure characteristic. A rule base is simply an algorithm that we use to interpret the sensor data. The sensor data is analyzed and displayed in user-friendly software developed entirely in BridgeVIEW (see Figure 1), and the information is correlated with T-90 times and mechanical properties to determine the optimum cure for each heat. We can then program the control system to automatically open the press, based on certain key characteristics, or we can program the unit to extend a press cycle by recognizing an under-cured condition. The system can then optimize cure times for every cycle, creating significant improvements in both productivity and quality, as the cure time is dynamic and based on the product’s actual state of vulcanization.

![Fig. 1: SmartTrac’s UserFriendly Operator-Press Interface Screen Developed in BridgeVIEW](image)

**Quantifying Improvement in the Process**

A first-tier automotive supplier used SmartTrac to cure parts made from three batches of a nitrile compound. Moreover, each batch of the compound was identical except for the accelerator levels. The material was examined both during cure and historically, using impedance data generated from a NI DAQ board and viewed with the historical trend viewer interface in BridgeVIEW (Figure 2). The analysis established correlative relationships between the impedance data and the cure state of the material. We also used the impedance data to construct a rule base, or intelligent control algorithm, while performing tensile testing of the parts to confirm their consistency. Based on rheometry data, the material was normally cured for three minutes at 180 °C, and fixed cure time parts were also produced for comparison against the parts generated using impedance technology.
The compound had accelerator levels of one, two, and three (actual accelerator levels were not provided by the supplier). Also, the supplier varied the mold temperature to the levels of 175 °C, 180 °C, and 185 °C. Finally, the cure time was changed from 2.5 minutes, to 3 minutes, and finally to 3.5 minutes. Each cure was monitored with the Signature Control Systems impedance sensor, and the data was retained in the SmartTrac software package for analysis.

The parts produced from the three batches of HNBR were compared to parts produced using the standard fixed cure time and temperature. Tensile strength was measured to provide a relative gauge of part consistency between SmartTrac’s technology and the fixed time method. Signature Control Systems technology reduced product variability by more than 35 percent (Figure 3), with a simultaneous cure time reduction of 16.7 percent.

![Fig. 2: Impedance Data Seen in the BridgeVIEW Historical Trend Viewer](image)

![Fig. 3: Box and Whisker Plot – Distribution Comparison](image)
The Derived Economic Benefits
The use of this technology for control has produced much more consistent mechanical properties in cured parts. Likewise, many supplementary benefits are apparent to manufacturers. In addition to reduced cycle times and higher quality in manufactured goods, these benefits include significant scrap reduction, real-time indication of compounding problems, decreased work-in-process inventories, and reduced capital expenditures.