Smart Manufacturing Needs Smart UV Curing: The Intelligent Irradiator and Advanced Monitoring System Work to Deliver Less Downtime

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Abstract

Manufacturers today are utilizing "smart" manufacturing to improve their product quality, production rates, and lead times while lowering production costs by more closely monitoring every aspect of their supply chain, production process, and product delivery. And manufacturers using UV curing processes to cure inks, adhesives, and coatings are no exception. However, until recently, users of microwave-powered UV curing systems had little ability to monitor their UV curing system in real time which sometimes led to premature replacement of consumable parts, troubleshooting delays, or unexpected downtime. This paper discusses the benefits of real-time monitoring, and describes how new sensor technology integrated into the irradiator (lamp head) combined with software enables manufacturers to monitor and analyze their UV system

Keywords: Irradiator; UV; intelligence; monitoring; lamp head; diagnostic; real-time; AIMS; UV curing; bulb; magnetron; air pressure; microprocessor; magnetrons; humidity; thermopile; Industry 4.0

1. Introduction

Real-time monitoring of a microwave-powered UV curing system enables process and production engineers to increase process reliability and production rates. Especially important for production lines with a narrow UV curing process window or where downtime is very costly, closely monitoring and analyzing the UV curing system operating parameters can reduce scrap rates, enable planned maintenance, and reduce unexpected system failures. The result is reduced unexpected downtime and increased production rates.

With real-time operational data, maintenance personnel can troubleshoot more quickly, avoid premature replacement of consumable parts, and improve preventive maintenance. This results in lower maintenance costs and reduces unexpected downtime due to UV curing system failures.

Even quality managers can analyze operational data to improve root cause analysis when curing issues arise, adjust operating process control parameters, and improve product quality efforts.

2. Intelligent Irradiator

Previous and current versions of power supplies have very limited feedback from the Irradiator. A typical configuration would have a series of safety interlocks which when activated shut down the system. These interlocks include a phototransistor, cable interlock and an analog pressure switch.

The Lighthammer® MK2 and MK3 power supplies are a digital replacement to Heraeus Noblelight America's (HNA) legacy ferro-resonate power supplies. The new power supply was built with Industry 4.0 in mind.

The MK series Intelligent Irradiator system has an embedded microprocessor. This microprocessor transfers data from the Irradiator to the power supply's microprocessor for storage and presentation on the front panel display.

3. Sensor choices

The choice of sensors was drawn from a wish list from customer input over the years. There were multiple challenges adding sensors inside a very hostile environment. Inside the irradiator reside two magnetrons each generating 3000 watts of RF energy to energize the plasma that creates the UV light. The bulb temperature when energized could reach temperatures as high as 1000°C. HNA has UV lamps that generate 600W/cm² of UV light. Exposure to this intense UV light can be very damaging to a variety of materials. The design required choosing reliable components and wiring which could perform inside the Irradiator. Each printed circuit board is fabricated with special materials to withstand the scattered UV light that exists inside the irradiator when the lamp is on. Each board has special circuitry to resist the RF fields generated by the two 3KW magnetrons running at 2.54GHz. And each of the sensors are conformally coated for protection from debris and dust. Thousands of hours in lifetest and testing ensured the addition of sensors to be effective and reliable.

Sensors to monitor irradiator performance

- Magnetron temperature sensors
- Bulb temperature using a thermopile
- Relative UV sensor
- Analog pressure sensor (real time differential air pressure sensor)
- Humidity sensor
- Inlet temperature sensor
- Ambient temperature sensor

3.1 Magnetron temperature Sensor

It is well established that magnetron performance suffers when they overheat. Placing a temperature sensor as shown in **Figure 1**, between the fins on each magnetron is a very effective location for measuring the magnetron temperature. The sensor monitors the heat and, if the heat exceeds the temperature threshold, a warning is displayed on the front panel indicating it is probably time to change the magnetron.

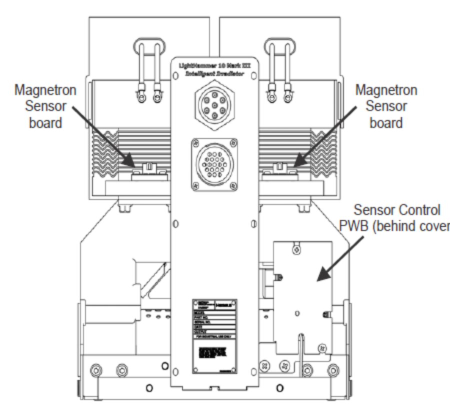


Figure 1

3.2 Sensor Control Module

The Sensor Control Module (SCM) as shown in **Figure 1**, is the brains of the Intelligent Irradiator. Cables from each sensor are daisy chained and connected to the SCM. On board is a microprocessor and several sensors including the analog pressure sensor, and an ambient temperature sensor. All the data from the disparate sensors is collected on the SCM. The data is then sent via communication cable to the power supply.

3.3 Analog Pressure Sensor

Proper cooling of the irradiator has probably the most significant impact on the lamp's performance and life. The biggest problem with the previous air pressure switch sensor was it did not offer continuous air pressure monitoring, and that it simply acted as an operational interlock. The new **analog pressure sensor** provides continuous monitoring of the air pressure inside the irradiator. As the power supply output demand increases, the air pressure matches the demand by increasing the speed of the integrated blower. This approach clearly establishes the relationship that more power demand to the bulb requires a greater volume of air to ensure proper cooling. And the converse is true, less power requires less air volume to prevent over cooling.

3.4 Thermopile and UV Sensor

The **bulb temperature thermopile** and relative **UV sensor** share the same housing and look at a single point on the bulb, see **Figures 2 and 3**. Monitoring the temperature and relative UV output of the bulb serves two purposes. First, the thermopile monitors the temperature of the quartz bulb. High temperatures outside normal operating parameters could suggest a potential bulb failure. Second, the relative UV sensor provides insight to users as to what UV value ensures a good cure. The relative UV sensor will highlight when the UV output is not enough. The lower UV output could be addressed by increasing the power to the bulb or it may be time to replace the bulb. The UV sensor is not a replacement for a radiometer because the sensor measures only the *relative* UV output. However, it does enable the user to know when the UV output is out of specification for their process reducing scrap rates and improving production quality.

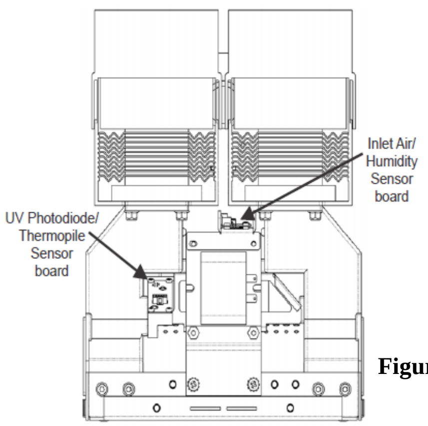
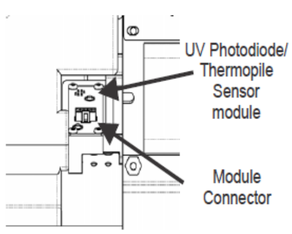


Figure 2

Figure 3



3.5 Inlet Air and Humidity Sensor

The **inlet air** and **humidity sensor** are mounted on a bracket as shown in **Figure 2.** The UV curing system is designed to operate at ambient temperatures from 25°C to 50°C. If the ambient temperature is below or above our working temperatures, the user will see a warning. Too cold could impact the bulb lighting and too hot could impact the life of the bulb. There are customers who have applications running in humid environments. Under these humid conditions when the lamps are off, there could be a buildup of atmospheric moisture which could collect in the air ducts. Moisture buildup inside the lamp could prove harmful to the lamp. A humidity sensor will notify customers when extreme humidity is present in the lamp.

4. AIMS

This smart UV curing system now provides a large stream of data that reflects the real time performance. This data can be sent to the customer's PLC, or the data can be presented through our **AIMS** (Advanced Intelligent Monitoring Systems) software.

The **AIMS** software requires a dongle that accepts I²C data and translates that data to USB which is plugged into a Microsoft platform PC. One single **AIMS** application can monitor 30 different microwave-powered UV curing systems. Users who integrate the new Intelligent Irradiator with the AIMS system software gain the added benefit of receiving email notifications for all warnings and failures. The user no longer must rely on an operator standing nearby the UV curing equipment to notice a warning or failure. The customer is not compelled to watch for an event. The nature of the warning and the specific UV curing system affected are sent in the email notification. It is up to the customer to choose who should receive the email notifications.

The **AIMS** software provides users with a variety of clear and concise dashboards for presenting the UV curing system sensor data. The collection of data is useful only when it can be presented clearly and concisely. Users can choose the dashboard format most convenient for their use see **Figure 4, 5, and 6**. It is possible for the customer to extract any data and export it in CSV format for review and analysis in EXCEL spreadsheets. Parameter data can be extracted to the PLC via Devicenet™, Profibus®, Profinet® or Ethernet™.

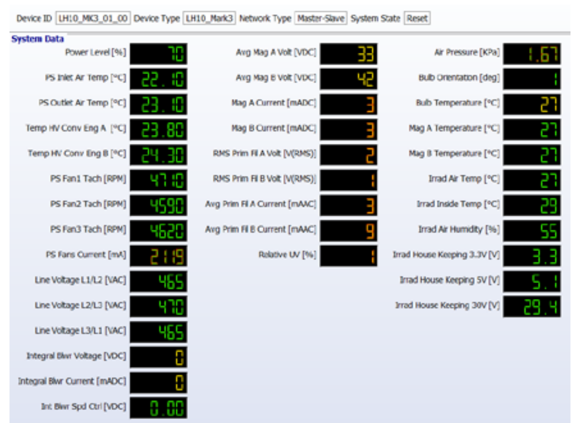


Figure 4, Parameter View

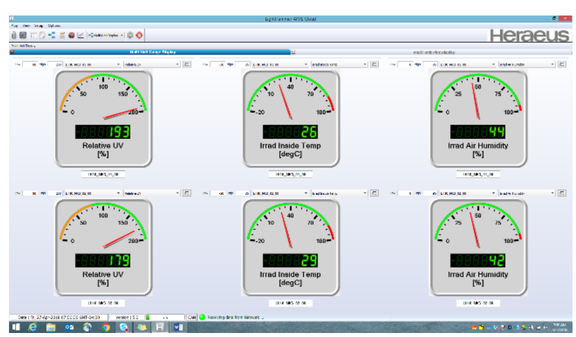


Figure 5, Analog Dial View

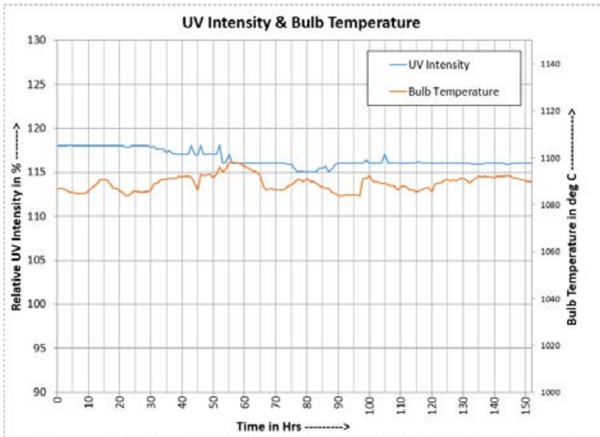


Figure 6, Spreadsheet View

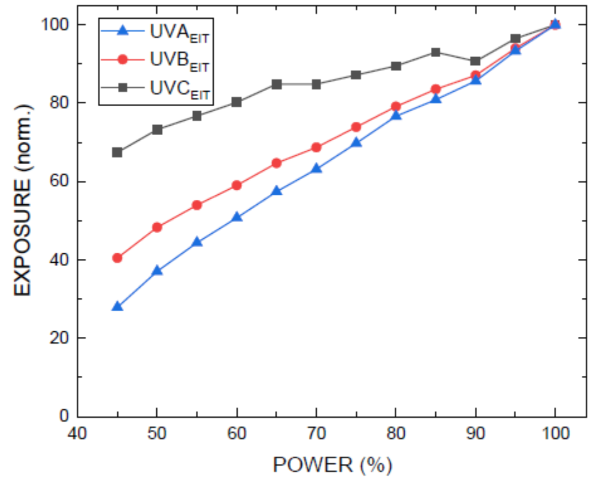


Figure 8

5. Sensors and Strong Dependencies in a UV System

Being able to monitor critical components in a UV system is a clear benefit. There are however dependencies:

- Magnetron temp sensors provide lifetime indication and air flow validation
- Inlet air temp/humidity sensor enables measurement of external conditions
- UV Sensor enables relative UV measurements
- Analog air pressure enables variable cooling function
- Ambient temperature sensor enables measurement of internal environment

The UV output for additive bulbs (D, V) are dependent on the cooling performance of the system. **Figure 7** illustrates raw data the EIT radiometer for the various UV bands. Radiometry when cooling level adjusted

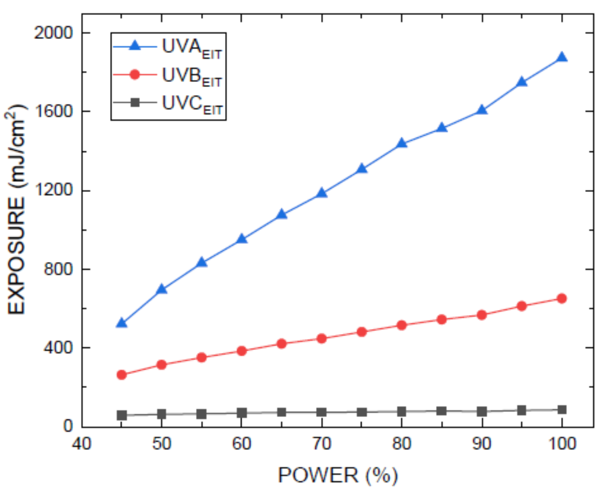


Figure 7

Figure 8 Illustrates the normalization for each band or maximum.

Figure 9 illustrates the benefit seeing behaviors to avoid blind spots. Customers with tight processes will be preempted to track these problems.

Strong dependencies:

- Magnetron Current
- UV Sensor
- UVB output
- UVA Output

Weak dependencies

- UVC
- Bulb temperature

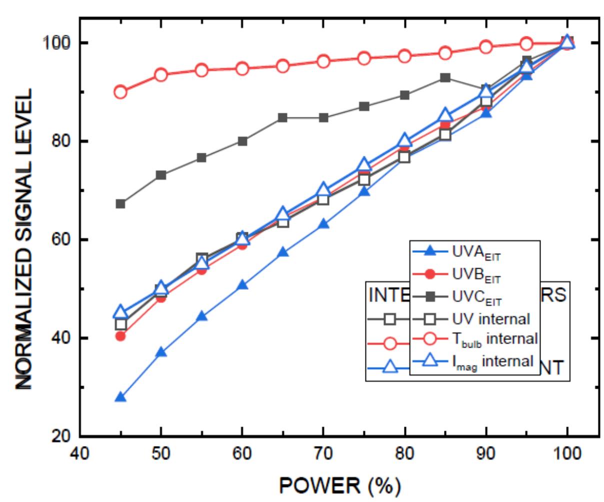


Figure 9

6. UV Output vs Power (Cooling Constant)

See **Figure 10**, the UV Sensor inside the Irradiator tracks well with UVA and UVB. Please note the **UV** sensor measures the relative UV output. The sensor should not be considered a replacement for a **radiometer**.

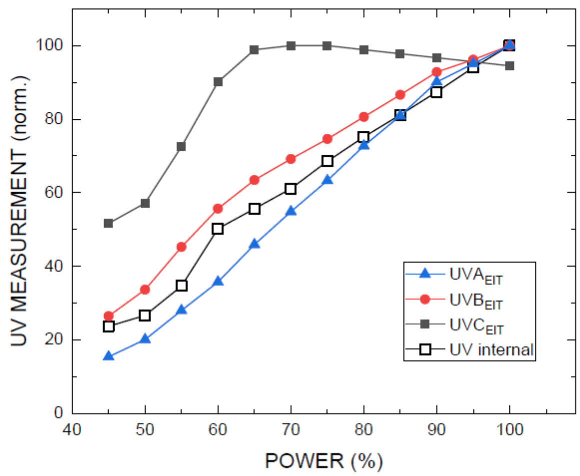


Figure 10

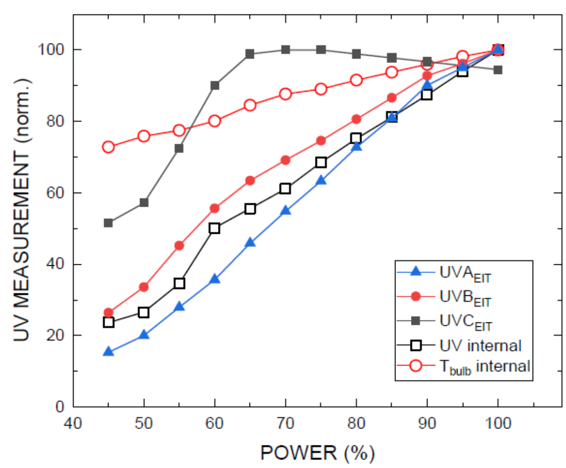


Figure 11

As you increase the power to the Irradiator you can see the Stronger dependencies:

- Bulb temperature
- UV Sensor
- UVA, UVB output

No dependencies

- UVC output

7. Conclusions

Adding intelligence to an industrial **UV** system is possible. Understanding the strong dependencies offers a complete picture of the interrelationships of different components inside the irradiator. Weaker dependencies cannot be ignored, they help us to identify blind spots in the system. Collecting and verifying the data from the sensors offers the customer the levers to determining predictable results. For the first time users of **microwave-powered UV** curing systems can benefit from smart technology that provides real-time monitoring capability to reduce unexpected downtime, increases in production rates and limit scrap.

8. Acknowledgments

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9. Author

William E. Johnson III is responsible for the global product management of microwave-powered UV curing systems for Heraeus Noblelight America LLC. Has over 25 years of design experience including electrical and mechanical design for PCB's, for devices and systems. William studied Mechanical Technology at Farmingdale State College, is an IPC certified Designer, and has six patents related to UV curing products.

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