OUTPUT CONSISTENCY OF COMMERCIAL LED INSTALLATIONS

EFSEN
UV & EB TECHNOLOGY

Index:

Summary

The LED technology is modern, stable technology, with a low degradation and long lifetime. As a result, many LED installations are assumed to have a constant performance over time, with no monitoring procedures in place. This paper aims to explore what need there is for continuous monitoring. The output consistency of a number of commercial LED installations at different ages will be presented. Manual and automatic procedures for monitoring and diagnosing LED systems output will be showcased, and a number of real examples of where monitoring would be of great help will be mentioned.

Introduction

How we perceive the performance of a product is of key importance when we are about to commit to an investment. Commercials and sales representative paints a vivid picture of the product, highlighting its features, while not necessarily shedding light on the downsides.

LEDs are often praised for an exceptional lifetime, high output, consistent performance and low energy consumption. And the fact that it is mercury free is a nice touch, something that will be a critical feature in the long run. These advantages with the LED technology is without a doubt what makes it worthwhile, with the promise of the LED lamp to be the future of our industry. Energy prices this last winter was through the roof in Europe. Just as those who invested in solar panels for their house are getting great returns for their investment, so are the factories who switched over to UV-LED, seeing savings in the 100 000s of dollars annually.

Just as with LED for commercial lighting, you pay a higher price, but get a product that has a more than tenfold lifetime. Consistency and stability over this very long lifetime is essential, but can we take it for granted?

Aging of UV-LEDs

The aging of LEDs are can generally be divided into catastrophic failure and gradual degradation. When we talk about lifetime, we are usually focusing on the gradual degradation, as the cases of catastrophic failure tends to happen during the first few 100 hours, meaning it most likely falls under the warranty. The gradual degradation is determined by the driving current and temperature, which over time causes defects in the crystal matrix.

The lifetime of LEDs are usually given with an L70 value. This will give the number of hours it takes for a light-source at 100% power until the output has been reduced to 70% of the starting output.

These L70 values, measured in laboratory conditions, are generally in the 30 000h + range for 395 nm LEDs, and we can see from commercial production unit output that LEDs can indeed provide a stable performance in a production environment for a very long time if properly maintained. On the contrary, LEDs that are not properly integrated, monitored and serviced might end their productive days well before the established L70 estimate.

It is important to remember that the L70 values are determined in a controlled environment, where it is more convenient to ensure that relevant parameters are kept consistent. Thus those values will give us an idea of what is possible to reach in terms of lifetime, but we have to ensure that the LEDs will not suffer from the sometimes harsh environment of commercial production lines. In order to get the most out of our LEDs, we need to understand how to take good care of them. All the way from system design, through integration to maintenance protocols, we get several opportunities to give our LEDs the best chances of lasting long.

The lasting performance of LEDs, as with many other electronics, is dependant the thermal management functions. In the never-ending quest for the highest output power LEDs, water-cooling has been the cooling of choice for units aiming to produce the highest peak irradiance. A consistent flow of cooling media, whether it is water or air, is a requirement for a functioning system. Thus efficient flow channels and sufficient cleaning of filters and cooling media is a necessity. Build up of dirt, growth of algae, leaks and clogged filters must be avoided at all costs. Clever design and maintenance processes are required to successfully cope with this, to ensure a steady flow of clean water through the water-cooled LEDs or of clean air for air-cooled LEDs.

In contrast to the single bulb of a mercury arc lamp, there are several thousands of small light sources in an LED unit, that will age differently. As the lamp is not changed every 1500 hours as the arc lamp is, this change will become more and more pronounced as the production hours tally up. To keep track of these variations can prove very valuable, as this will give the opportunity for preventative maintenance for maximized effective production time, it will ensure that you catch any deviations directly, rather than after batches have been produced with inconsistent curing.

What influences the choice when selecting a new LED unit for a process?

First and foremost, the curing requirements of the process will be the highest priority, determining what UV power you will need from your LEDs. High speed printing presses might require a high output system to deliver the required dose at speeds well over 100 m/min. For some of those processes, a water-cooled LED might be required. It is important to keep in mind, however, that despite the endless chase for higher peak irradiance, the vast majority of processes depend on a sufficient dose for a successful cure, with the purpose of high irradiance being to reach that does requirement as the speeds increase. Thus modern air-cooled units will meet the output requirement for many applications. For wood coatings for example, where line speeds are generally below 50 m/min, air-cooled LEDs will provide enough output for most applications. Even systems for the graphical industry is now changing over from water-cooled to air-cooled.

When it comes to industrial grade LEDs, they will generally provide a peak that exceeds the threshold (after which there is not any added benefit with increasing the peak, but the importance is the resulting dose). As humans, we are hardwired to look for the best. We often look for the highest performance, whether it is the highest power LED, the highest reactivity coating or the highest speed of our production line. But UV output is just one of the factors of importance for selecting the best LED. In addition providing sufficient UV output, the LEDs should provide a stable long term solution, preferably with the running costs and initial investments kept at a reasonable level. Thus rather than looking at the absolute highest performance in terms of output, it makes sense to focus on the combination of price and performance. Ensuring that curing requirements are met with a reasonable margin, but minimizing the energy consumption and maximizing LED lifetime. Because of this, it is critical to understand the process and the coatings cure requirements, and how the candidate LED systems meets those requirements, in order purchase and LED system that is dimensioned correctly.

One of the conclusions for my talk during the 2020 conference, on the topic of “the importance of measuring LED” was that with continuous measurements, you will not be required to “overdose”. Always knowing the status of your modules enables a tight specification for the coating. In contrast to this, it is common to lean on a higher power output across the whole unit in processes where the UV is not monitored. This in order to make sure that even if a few of the segments age faster than predicted, the higher output will ensure that the output is still within specification. This does, however, result in an energy consumption higher than necessary, a more expensive LED system than actually required, that might even have to be run at the maximum output from the start, which will make them age faster. A similar situation will be the case when curing products that are not designed for LED curing, or that has just undergone minor adjustments for LED curing. The dose required for cure would require high power (and possibly multiple LEDs), which leads to higher energy consumption and a negative impact on the life time. Thus it can be concluded that it is critical that the chemistry is adapted for LED curing and that the LEDs are continuously monitored (both of which should be mandatory for a modern production process) to ensure a stable process without over-dimensioned the setups for UV curing.

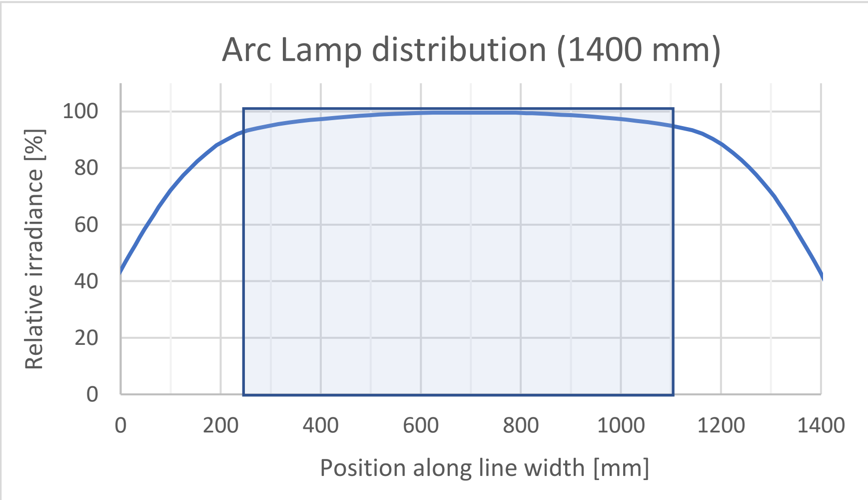
A case from a few years ago illustrates this very well. An LED solution was provided for a customer according to cure specifications of the coating manufacturer. The specification called for a dose of 200 mJ/cm^2 and a peak of 5500 mW/cm^2, established for the coating at 40 m/min. The line in question was running significantly slower, 15 m/min, which would make it much more convenient to achieve the dose. A standard LED at 50% would do the job. However, due to the high peak requirement, the LED had to run at 95%. Not only does this almost double the energy consumption, but it also impact the lifetime significantly. Values for this case is summarised in the table below, for easier comparison.

	Filter	Peak	Dose	Speed	Power	Consumption
		mW/cm2	mJ/cm2	m/min	%	kW
Lab values, high speed	UVA2	5586	200	40	95%	6,5
Installed line, 4 years ago	UVA2	5586	530	15	95%	6,5
Same coating, current lines	UVA2	2000	280	15	50%	3,4
Actual requirement?	UVA2	1400	200	15	35%	2,4

Monitoring UV

In order to run a tight specification, we need to monitor the UV output, and monitoring the UV will provide several additional benefits, such as process stability and reduced downtime.

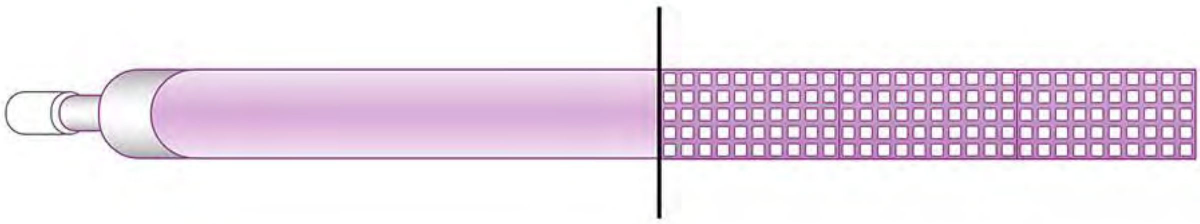
Mercury lamps are one bulb, and we know quite well how the output varies along the width, unless the bulb or reflector is damaged or deformed. It usually looks something like this:



UV output	Cure width	
95%	800	57%
80%	1100	79%
Lamp width	1400	

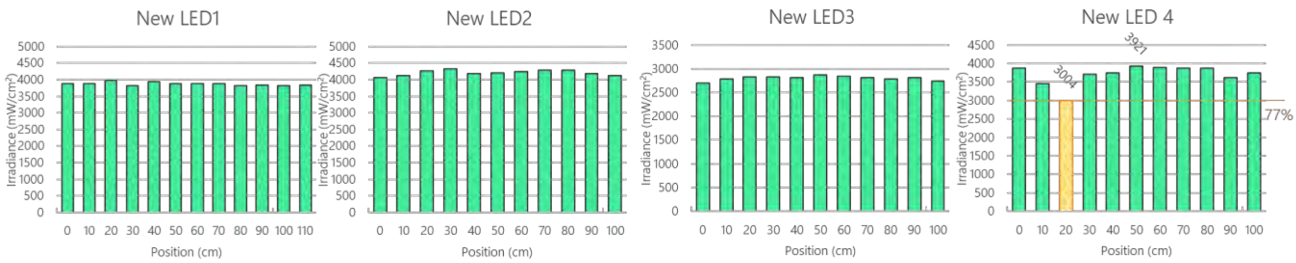
While it does not provide a homogenous distribution along the width, it does follow a distinct profile. For these lamps, it is standard procedure to measure at the start of each shift, a measurement that should be performed at the same position length wise, to accurately collect data for comparison with previous data.

This procedure does not make sense for LED arrays however. As it is an array of thousands of individual diodes, measuring in one position leaves us oblivious to the performance of all the other segments of the array. Thus a more appropriate procedure when it comes to manual measurements, is to measure several positions along the width of the lamp, optimal would be to measure each segment. This can be rather time consuming when done manually. Some factories and even some machine suppliers claim that the LED technology is stable enough so that measuring is not necessary.

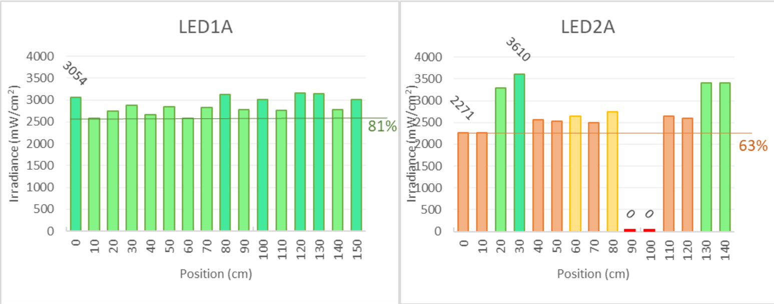


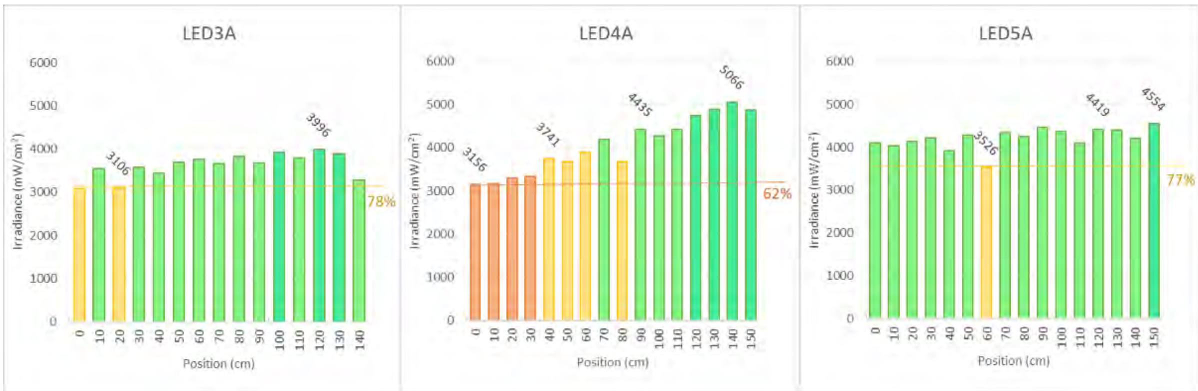
Manual measurement of commercial LED lines

To get some more insight into the performance of LEDs that has aged in a production environment, a series of manual measurements were conducted in different LED lines with LEDs of various age. Keep in mind, that the measurements presented here are not a select few, but the whole data set. We have not selected the most interesting out of a wide selection of lines, but instead show all lines we measured in this way.



Measurements in the picture above is performed manually with EIT LEDCure, with about 10 cm interval along the width of water-cooled LED lamps after 200 running hours in a factory. LED1-LED3 shows a deviation of about +/- 3%, which is reasonable. However, LED4 shows a significant deviation, with one segment performing at 70% of the highest powered segment. While this segment will still provide enough cure power, as the output of these specific LEDs were selected with high margin, this might be an issue in the long run. As time goes by and the LEDs age, this segment will eventually provide too little output to meet the specification. This might then be after the warranty period expired, and as these are full-width water-cooled LEDs, rather than modular units, the whole lamp would have to be sent for maintenance. With modular air-cooled LEDs, the module of the underperforming segment could swiftly be switched with a spare module off the shelf, continuing production whilst the defective segment is sent for repair. And more importantly, by measuring the LEDs we caught the issue within the warranty period. Without measuring, we would get the information about this defective segment first when lacking performance is lacking, resulting in unexpected production stop, and a costly repair.





The above examples are from a 3 year old line with air-cooled, modular LEDs. Some of the modules have been renovated. We can see a clear difference for the rightmost modules of LED4A being roughly 40% stronger. With continuous monitoring and segment control, the new modules could be adjusted to run in line with the others, and you would get precise information regarding when the older modules would need to be replaced.

Most surprising, however, is LED2A. Not only does it show significant inconsistency, but a couple of segments are completely out. For burnt out segments, where there is no temperature or power consumption registered, an error message is to expect from the unit, but apparently not in this case. The saving grace here, ironically, is that a mercury lamp was put in after this lamp due to requirements from the new coating supplier (as the product did not provide the same performance with LED as the previous supplier's product).

Another line installed four years ago, shows the that all the LEDs lacks uniformity to some degree. LED1 and LED3 might still provide an output meeting the requirements, but LED2 however has some segments that are way overdue for replacement or renovation.

Status of automatically monitored LEDs

In addition to manually measuring these LEDs, we followed up on a line featuring 7 W-LED, equipped with ICAD® for automatic measuring of LEDs. This wood coatings line of Freda in Lithuania has been running for about 3 years, and the W-LEDs have been operating 17000 hours. Running 40-50 meters per minute, this is a fast line by wood coating standards, and still after those 17000 hours runs with one air-cooled LED per station, at 80% power (with the exception being the top coat, which runs the same setup as from the start with 3 mercury lamps to give the top coat full resistance).

ICAD® is a proprietary in-line sensor that travels under the LED array during production, to continuously monitor each LED segment. This also allows for collecting curing history for efficient documentation of cure data. Any deviations will be automatically detected and adjusted to the right level where possible. Alarms or automatic line stops can be set to trigger whenever the minimum output level cannot be reached.

ICAD in action, measuring an LED array.

Conclusion

It is apparent that while LEDs are stable light-sources (especially in comparison with arc-lamp technology) but relying on them giving a stable and uniform output during the lifetime in a production environment is not realistic. There is a need for measuring them continuously, to understand the status of the different segments of each module, ensuring they provide the required output.

Continuous measurements is a vital tool for keeping the production going. Tracking how the output changes over time gives valuable information to anticipate and optimize maintenance, repairs and upgrades, to minimize the downtime. This ensures that the strengths of the LED technology is leveraged; providing a efficient, modern curing solution with a high consistency and long lifetime.