

# UV Curing of 3-D Parts – What is the Best Lamp Arrangement?

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## **Abstract**

Curing of UV coatings on complex three-dimensional parts is a significant challenge. Factors such as productivity, part design, part size, and physical process limitations are a sampling of constraints that must be taken into consideration for UV process design and implementation. This paper will discuss various general solutions and provide examples of solutions chosen for production and the reasons for the specific choice.

## **Introduction**

UV coatings are applied to a number of substrates such as paper, glass, plastic and metals and touched by the consumer in many products such as packaging, personal electronics, digital media, home goods, and automobiles. Each one of these applications and substrate offer unique challenges, but one of the most challenging – from a UV curing perspective – is the curing of UV coatings on 3-D objects.

These coating applications require superior durability and aesthetic qualities in a high productivity environment with very low defect rates. The finishing process is at the end, or near the end, of the manufacturing process where the part has acquired its highest value. So, minimizing defect rates and maximizing the productivity from the finishing process is always a priority.

The major application for UV curing is headlamp manufacturing, also known as forward lighting. The largest component is the polycarbonate (PC) plastic lens. UV coatings are used on the lens to provide physical protection (scratch, mar, and chipping resistance) and also filter out UV radiation to minimize discoloration of the plastic. The adoption of UV-cured hardcoats for PC lenses has decreased the time to finish a lens from 2.5 hours for a thermally-cured hardcoat to 8 minutes for the UV hardcoat<sup>1</sup>.

Forward lighting reflectors are the second largest component and are molded from a thermoset plastic known as Bulk Molding Compound (BMC). This material consists of chopped glass-fibers compounded into unsaturated polyester resin. This material is utilized due to its superior mechanical and thermal stability. Reflector manufacturing utilizes the UV curing process to cure the coating applied to the molded reflector prior to the metallization process that forms the reflective surface. The coating has two primary functions - to provide a very smooth surface and seal the reflector so gases will not be

emitted, causing defects, when the part is placed under vacuum for metallization. In North America, almost 100% of reflector coatings utilize UV curing.

A similar application is used to seal Sheet Molding Compound (SMC) used for Class A automotive body panels<sup>2</sup>. This composite material is used to decrease weight and tooling costs for lower production vehicles such as the Chevrolet Corvette. One of the primary finishing defects in the assembly plant is a paint defect called “porosity popping”. This defect occurs when gasses are expelled from the SMC during the basecoat/clearcoat baking curing process in an assembly plant. The cost to repair these defects can be onerous and affect productivity. The use of a hybrid cured coating (UV + Thermal) has been able to eliminate this defect and is used in production.

The third primary application is clearcoats over molded-in-color parts. The primary application has been the use of a UV-clearcoat over body-side-moldings to protect the doors from chips, scratches, and dents. This specific application demonstrates that UV cured coatings can have superior physical toughness with extreme flexibility.

From the descriptions above, it should be clear that the UV coatings are used on a wide variety of complex geometric shapes and offers challenges for the process design team looking to implement the UV curing process.

The fact is that UV curing has moved from smaller parts such as cell phone covers to automotive body panels in excess of 25 ft<sup>2</sup> per part.



## UV Curing Process Considerations

There are many factors that need to be taken into account when designing the UV curing process and how it will be integrated into the finishing line. The four primary considerations that should always start the analysis are<sup>3,4</sup>:

- UV energy curing requirement of the coating – maximum and minimum
- Productivity
- Part size, geometry, and orientation
- Critical performance surfaces of the part

The following challenges are the primary concern of the UV lamp solution provider<sup>3,4</sup>:

- Uniform irradiation of the UV-curable coating on the substrate.
- Minimization of shadow areas.
- Uniform and stable UV spectral energy at wavelengths consistent with the coating formulation.

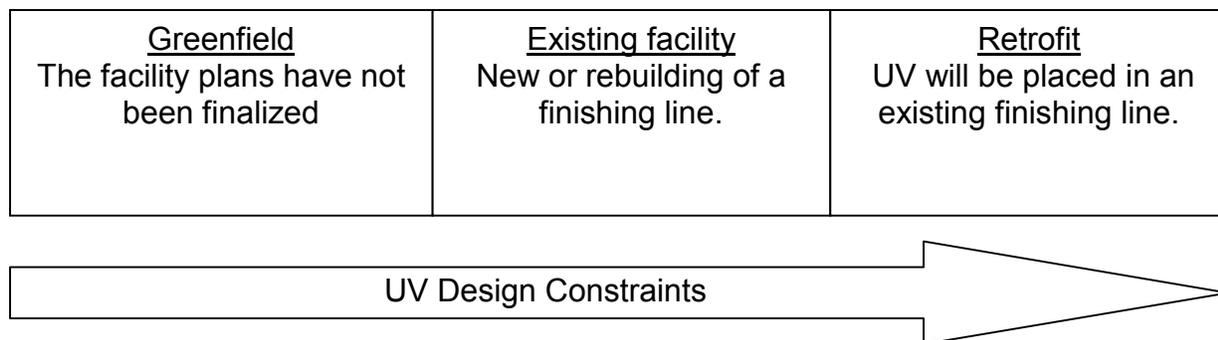
There are also a wide variety of other considerations that may have been defined that could have an impact on the UV curing installation<sup>3,4</sup>.

- New installation of retrofit on an existing line
- Physical Constraints –How much room is reserved for the UV section?

- Conveyor Type Options – Continuous chain, indexing, power & free, etc.?
- Part Arrangement – How will the parts be oriented? What are the limitations?
- Part movement – will the part have the ability to be moved during the curing process?

It should be clear that these factors are interdependent. To determine the most cost-effective solution, it is critical that the formulator, lamp supplier, finishing line integrator, and end-user should be brought together to discuss these factors as early as possible.

There are typically three distinct type of projects; a new manufacturing facility, a new or rebuilt finishing line, and fitting UV curing into an existing finishing line. As we move from a new facility toward a retrofit installation, the number of constraints obviously increase and decrease the options available for the UV curing installation.



When creating the UV curing process design, the primary concern is how the optics of the lamp relates to the geometry of the part to provide the UV energy required by the curing process window. Though this may be a complex problem, there are a number of standard solutions that are utilized. They can be broken down into the following group:

- Single lamp or one array of multiple lamps – this solution is used for simple shapes or for one or two-dimensional substrates.
- Multiple arrays of UV lamps – This is the most common and most flexible solution. You usually design the lamp array to provide UV energy to a defined part window.
- Automation of the lamp(s) – this can be as simple as a lamp, or an array of lamps, rotating about an axis or moving in a single plane. It can also be as complex as a UV lamp mounted on a robot.
- Movement of the part – Again
- Hybrid Systems – This is using a combination of fixed lamps with lamps that have some movement.

It should be said that coatings on convex surfaces are easier to cure than coatings on concave surfaces. However, concave parts such as headlamp reflectors exclusively utilize UV coatings. So, the most cost-effective UV curing process solution can almost always be determined through careful analysis of the various factors such as the coating's UV energy requirement, productivity requirement of the finishing process, geometry and orientation of the part, and the optical properties of the lamp.

## Examples

### Lamp(s) Over Conveyor

The simplest arrangement that is found is the use of a single lamp, or a simple array of lamps, over a conveyor. This is a common and cost effective solution for parts that have a low vertical profile, usually coupled with lower line speeds. Examples of applications that may use this type of arrangement are thermoformed plastic panels or panels with minimal vertical profile. Photo 1 represents is an example of this simple concept.

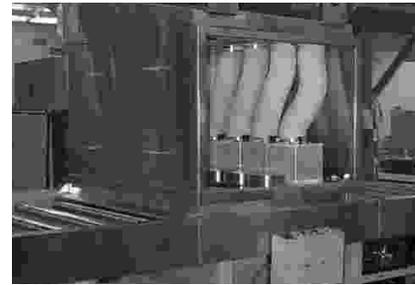
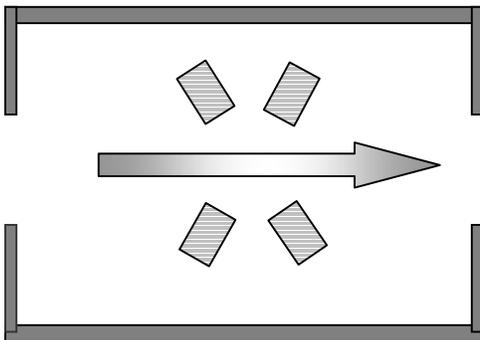


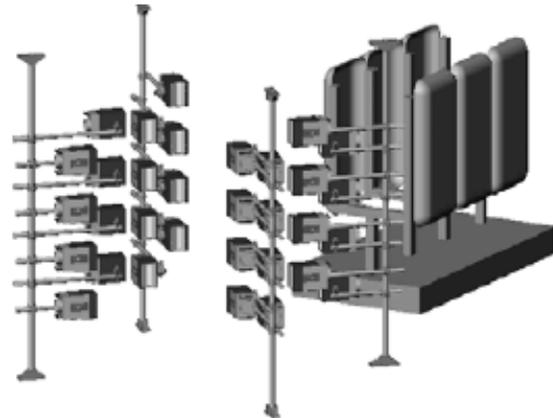
Photo 1

### Fixed array of lamps

Fixed array of lamps are the most frequently used solution. It provides the best combination of process simplicity to cure a defined part window with process robustness. The primary disadvantage is the number of lamps is determined by the critical surface that receives the least amount of UV energy. Graphic 1 demonstrates lamps oriented to cure parts racked in a vertical position where four an array of lamps are angled to irradiate the leading and trailing edges of the part. Graphic 2 demonstrates the similar concept on a much larger scale. In the case, there are multiple lamps mounted into 4 independent, vertical arrays. The lamps are positioned to maximize the UV energy to most difficult surface, the leading and trailing edges of the parts.



Graphic 1



Graphic 2

### Lamp Automation

The movement of lamps is a more complex situation. In the simplest terms, the trade-off is that automation minimizes the number of UV lamps but adds the cost of automation and adds complexity to the process. The responsiveness to the coating under the curing conditions under consideration must also be understood. Partial curing or pre-initiation of the coating may create defects or inferior performance of the coatings. Once again, the optics of the lamps, geometry of the part, and responsivity of the coating to UV energy must be considered.

Graphic 3 demonstrates automating the previous concept of fixed arrays to illuminate the leading and trailing edges. In this specific case, two of the vertical array of lamps is mechanized to rotate about the vertical axis as the part(s) pass through the lamps<sup>5</sup>.

Photo 2 shows a UV lamp mounted on a robot. This concept has been in service for a number of years in different applications. Special concern must be given to pre-initiation of the coating on parts that are larger than the aperture of the lamp. A careful evaluation of the UV coating to this type of exposure is required to eliminate any potential for coating defects.

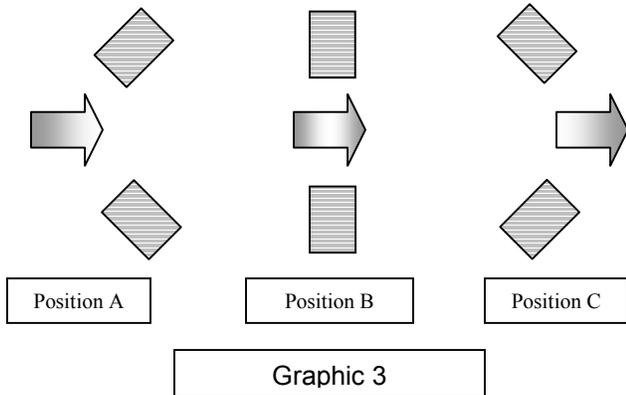


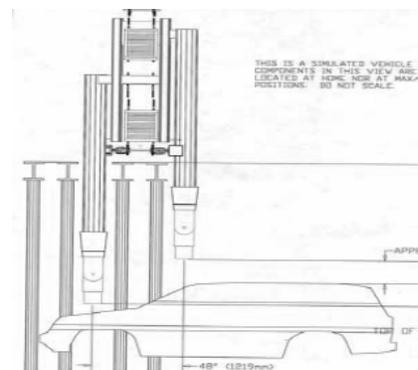
Photo 2

### Part Movement/Automation

A corollary to the previous description of lamps in dynamic motion is the movement or manipulation of the part in front of static lamps. This is used frequently in production. A primary example is the mounting of the parts on cylindrical racks and rotating the rack before UV lamps. Usually, this is used in an indexing system. This is a very common configuration for UV curing of automotive reflectors.

### Hybrid Solutions

Hybrid solutions that utilize both fixed lamps in combination with automated lamps. An example of this type of solution is the current concept to cure UV clearcoats on car bodies. The fixed lamps cure the vertical surfaces of the vehicle, while the horizontal lamps are mounted in a roof-beam that follows the profile of the vehicle as it moves under the lamps by moving in the vertical plane<sup>3</sup>. The lamps also have the ability to rotate about the horizontal axis allowing the lamps to illuminate the leading and trailing surfaces as the vehicle passes by the roof beam.

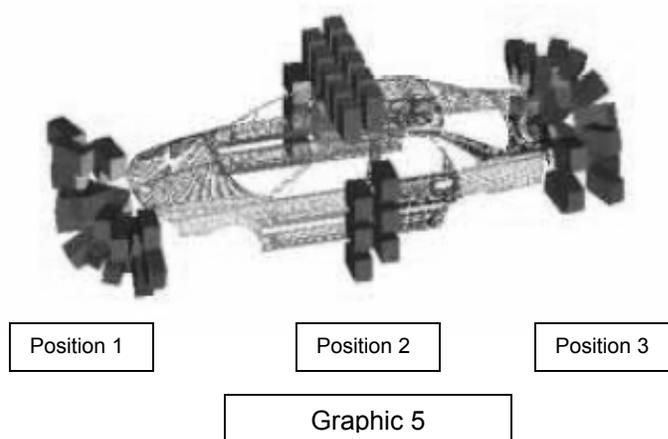


Graphic 4

### Simulation Software for 3D Curing

Simulation software<sup>6</sup> has been developed to simulate the UV curing step of the exterior surfaces of an automobile by utilizing digital representation of the vehicle, an optical model of a UV source, and the critical factors for the UV curing process. The benefits of the software was to significantly reduce

the time spent on UV process development, determine the number of lamps early in the design phase, and evaluate changes to the process relatively quickly. Graphic 5 demonstrates the position of lamps at three specific time slices. The position at the front of the vehicle shows the lamps at time slice 1 as the vehicle moves toward the lamps. The middle grouping of the lamps show their position at the second time slice at the midpoint of the vehicle. And of course, the third position represents the configuration of the lamps as the car passes by and leaves the UV curing zone.



## Summary

There are a multitude of potential solutions for curing of 3D parts. There is not a standard solution that fits all the needs, but there always is a best solution. The best solution is derived by a thorough analysis of the critical UV process factors - the UV energy process window of the coating, the geometry and surface area of the part, and productivity requirements for the finishing line - weighed against the constraints of the specific UV installation.

## References

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