Pulsed UV Light
For Heat Sensitive Continuous Motion Applications

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Abstract

The inherent benefits of high intensity pulsed UV lamps - low heat, excellent depth of penetration, cool cures and energy efficiency - are well known. Traditionally these benefits were only available for indexing applications where the cure target is held in a fixed position in front of the lamp. Recent advances in lamp geometries, pulse rates and lamp wattages are making pulsed UV lamps the solution of choice for heat sensitive continuous motion applications such as wood coating. Illustrating the benefits of applying this technology to wood coating is Delle Vedove USA's new vacuum coating and roll coating equipment.

An old technology with some new twists

Pulsed UV lamp technology is not new. Xenon Corporation has been manufacturing and selling flash lamps for over forty years. While the basic technology is not new, it has continued to evolve. Recent advances in pulsed lamp technology and coating materials now make it possible to apply pulsed UV lamps in applications that traditionally required a continuously emitting source. Delle Vedove's newly introduced UV-X pulsed lamp oven pioneers the commercialization of these technologies in the wood coating industry.

The basics of pulsed UV lamp technology

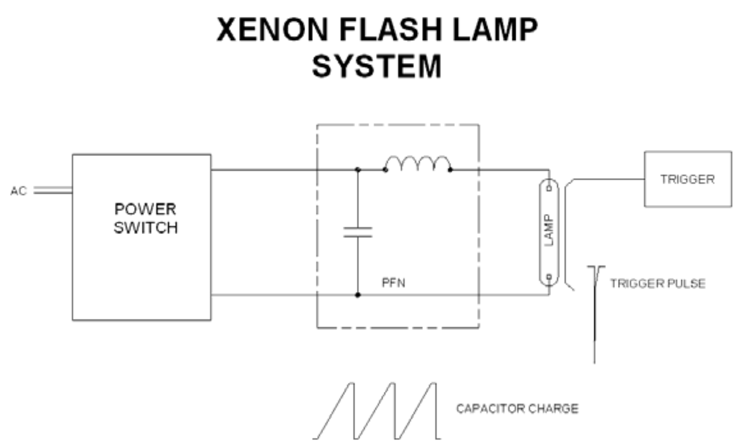

Figure 1

A modern high power xenon pulsed lamp system consists of four major elements, a power supply, a pulse forming network (PFN), a xenon flash lamp and a trigger circuit. The power supply called a “cap charger” acts as a current source converting AC power from the mains into a DC charge current. The PFN consists of a high voltage storage capacitor and an inductor. The capacitor is used to store the energy for each flash of the lamp. The inductor determines the pulse width, i.e. the duration of the flash. The flash lamp is fabricated from a quartz tube fitted with specially designed electrodes at each end and filled with high purity xenon gas. The trigger circuit initiates the ionization of the xenon gas within the flash lamp by applying a high voltage pulse to the lamp.

The following sequence is followed for each flash of the lamp. The power supply charges the storage capacitor to a preset voltage. When the capacitor is fully charged, the trigger circuit is fired initiating the ionization of the xenon gas within the lamp. The electrical resistance of the lamp drops as the xenon gas ionizes. The drop in resistance within the lamp allows the capacitor to discharge through the lamp creating an intense flash of light. After the flash, the ionization of the gas within the lamp is allowed to dissipate raising the impedance of the lamp. This process is repeated for each lamp flash.

Lamp Spectrum

The xenon flash lamp emits a broadband continuous spectrum with photon emissions from the UV into the IR.

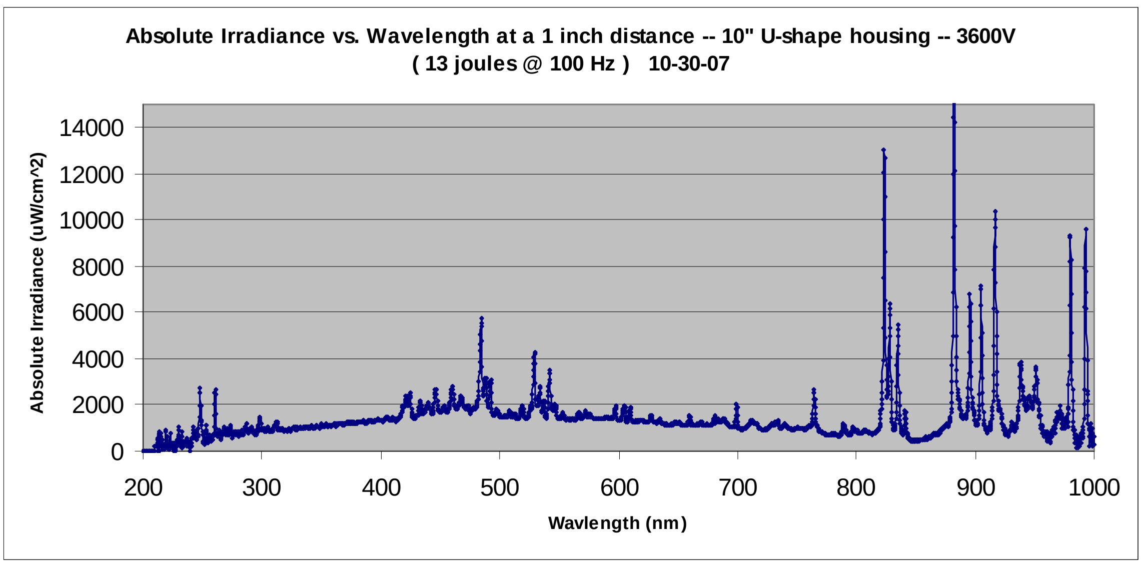

Figure 2: Typical Flash Lamp Spectrum

Peak Intensity

One of the significant differences between a pulsed UV lamp and a continuous mercury lamp as well as an LED array, is the peak intensity of the light. The peak intensity of a pulsed lamp is typically one to two orders of magnitude higher than that of a mercury lamp of similar wattage. These high peak energies are achieved by storing power in the high voltage storage capacitor and releasing this energy in a very short burst through the flash lamp. Pulse widths of 10us to 300us are common in today’s industrial flash lamp systems. Peak energy levels range from 300 kilowatts to over a megawatt.

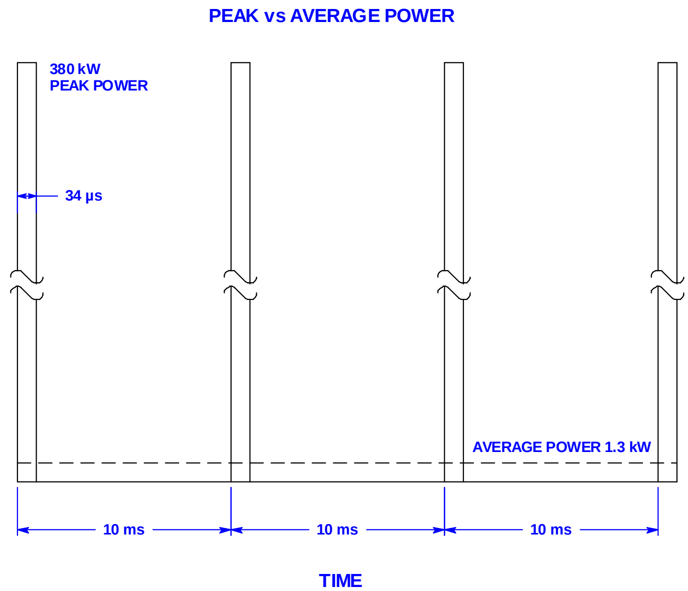

Figure 3: Peak and Average Energy of a pulsed UV lamp

Pulse rate

There are several factors that determine the maximum rate at which a lamp can be flashed. One of these factors is the ability of the power supply to fully charge the storage capacitor after each lamp flash. The minimum power supply rating can be calculated with the following formula.

Power supply rating = pulse frequency x energy per pulse

A flash lamp system operating at 13 joules per pulse and a flash rate of 100 pulses per second will require a power supply that is rated at 1,300 watts or higher.

Capacitor charging power supplies of 2kW, 3kW and more recently 6kW are now available.

A second important factor in determining the maximum pulse rate is the recovery time of the lamp. When the lamp flashes the xenon gas within the bulb becomes highly ionized. This ionization energy must be dissipated before the high voltage charge is again placed across the lamp electrodes. Xenon Corporation has developed a patent pending technology called InterWeave™ that aides in the dissipation of this residual ionization energy.

A third factor in determining the maximum pulse rate is the pressure of the gas within the lamp. When a lamp flashes, the temperature of the xenon gas and with it the pressure of the gas rises rapidly. This temperature and pressure must be dissipated between each lamp flash. A hot lamp will not flash.

Lamp Cooling

One of the fundamental differences between a mercury lamp and a UV flash lamp is the temperature at which the bulb must be operated. For efficient operation a mercury lamp is run as hot as possible. The temperature limit of these lamps is set by the softening point of the quartz envelope. The surface temperature of a UV mercury lamp typically operates at 950ºC to 1,000ºC. This high operating temperature makes cooling of the lamp fairly easy. It also makes it very difficult to manage the IR that is being emitted from the envelope of the lamp.

The pulsed UV lamp must be run as cool as possible. To insure that the pressure in the lamp is fully dissipated between each lamp flash, the temperature of the lamp is kept below 200ºC. To maintain this low lamp temperature, the lamp must be very aggressively cooled. Air cooling is generally applied. The obvious benefit of this low lamp envelope temperature is a very small IR footprint. Simply stated, a cool bulb gives a cool cure.

Lamp Geometry

Unlike UV mercury lamps, which are limited to linear and point source geometries, the UV flash lamp can be fabricated into an almost endless variety of shapes. Xenon's current offerings include, points, linear, "U", spiral, and pancake designs. Custom lamp geometries and unique reflector designs are used to insure optical efficiency and uniformity of cure.

Figure 4: Examples of UV Flash Lamps

The traditional benefits of pulsed light

The unique benefits of the UV flash lamp are well known. A flash lamp contains no toxic materials such as mercury. The lamps can be instantly turned on and off. In indexing applications, this fact alone can generate significant energy savings. The curing efficacy that is derived from the high peak energy levels and broadband spectrum can significantly reduce the total energy requirement in both indexing and continuous motion applications.

The high peak energy levels insure a significant depth of cure. The low IR footprint makes pulsed UV lamp technology ideal for use with heat sensitive substrates. Unique lamp geometries provide high optical efficiencies and uniform curing.

Figure 5: Spiral Lamp and reflector

These attributes have made the UV flash lamp the solution of choice for the optical disc market as well as many custom indexing assembly applications.

The challenges of pulsed UV/Visible technology

The challenges associated with pulsed UV light must also be recognized. Historically, these challenges have significantly limited the application of UV flash lamp systems. The UV flash lamp system is more complex than a typical mercury lamp system. This complexity is reflected in a steeper learning curve for the system integrator and a higher initial equipment cost for the end user.

Beyond cost and a general unfamiliarity with this technology, the most significant barrier to the application of the pulsed UV solution has been the difficulty in applying a pulsed lamp system to a continuously moving substrate. This problem is referred to as striping and is illustrated in figure 6. Striping will occur if the flash rate is not fast enough to prevent bands of cured and uncured coating.

STRIPING

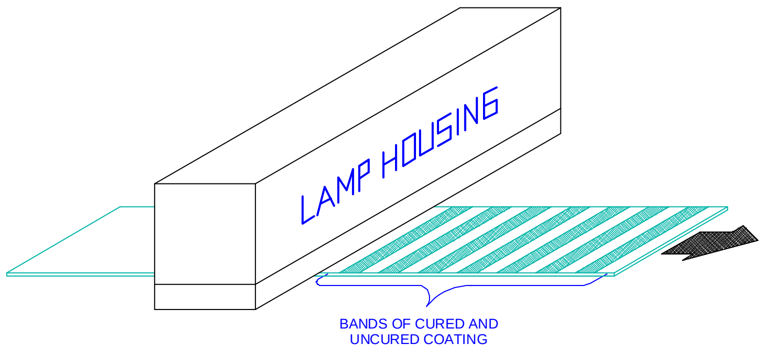

Figure 6

The solution

Xenon Corporation has pioneered a series of technical advances which in combination has opened the door to the application of UV pulsed lamps to continuous motion curing.

In 2006 Xenon increased the power rating of its standard product from 2kW to 3kW. In early 2008 the maximum system power was further increased to 6kW. Proprietary InterWeave™ circuitry enables a single power supply and controller to simultaneously operate two lamps, significantly reducing the initial equipment cost to the end user. This innovation enables higher flash frequencies, up to 100pps, by quenching the residual ionization within the lamps. Two new lamp types, the 10" (254 mm) and the 12" (508 mm) U-lamps, have been developed. These lamps expand the width of the optical footprint while maintaining the required high peak energy intensity on the target.

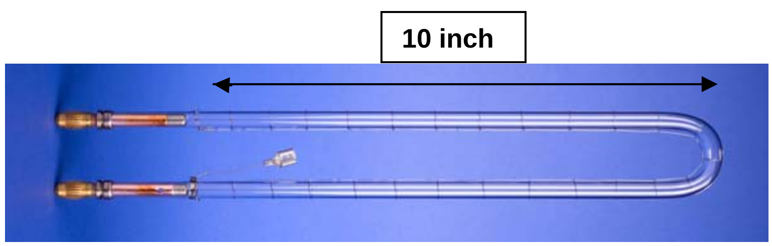

Figure 7: 10" (254 mm) U lamp

Dainippon Ink & Chemical, Inc. has matched Xenon's advances in pulsed lamp technology with the development of new coating materials. Dainippon Ink & Chemical, Inc. now offers two wood clear coat formulations specifically tuned to operate with pulsed UV light. Dainippon Ink & Chemical, Inc.VC-9 coating was developed for vacuum coat application. The RC-8 formulation was developed for use with roll coat applicators. Each of these formulations can be tuned to deliver a range of gloss levels.

Applying pulsed UV light to wood coating

Delle Vedove USA is championing the application of pulsed UV technology in the field of wood coating with the introduction of two new products, a Vacuum UV System equipped with a UV-X oven and a Roll-Coat System equipped with a UV-X oven.

Figure 8: Delle Vedove Vacuum UV System

Figure 9: Delle Vedove UV Roll-Coat System

Delle Vedove's UV-X oven can be equipped with two, four or six 10" (254 mm) U-lamps. When the UV-X oven is paired with a vacuum coater, all four surfaces of a board are coated and cured with one pass through the process. Typical line speeds for the four lamp system are 20 to 24 meters per minute. The six lamp configuration enables line speeds up to 45 meters per minute. The roll coater is designed to coat only the top surface of the wood. Equipped with a two-lamp oven, the UV Roll-Coat system can be operated at 12 to 16 meters per minute.

Sensors on the in-feed and out-feed of the pulsed lamp oven are used to start and stop the lamps when a piece of wood enters and leaves the oven. Energy is saved during each and every pause in production. The pause could be a half hour lunch break or a half second gap between two planks passing through the curing oven.

The instant-on instant-off feature of the pulsed UV lamp is only the start of the energy savings story. When the coatings were formulated to take advantage of the broad spectrum and high peak energies of pulsed UV lamps, the system wattage was dramatically reduced. A 5kW UV mercury lamp was replaced by a 2kW pulsed UV lamp, a 60% energy savings.

Temperature measurements taken by Delle Vedove have confirmed the low thermal footprint of the pulsed UV lamp. There is almost no temperature rise on the surface of the wood as it passes through the oven as shown in figure 10. This low temperature processing has enabled the commercial UV coating of white pine and other high resin woods.

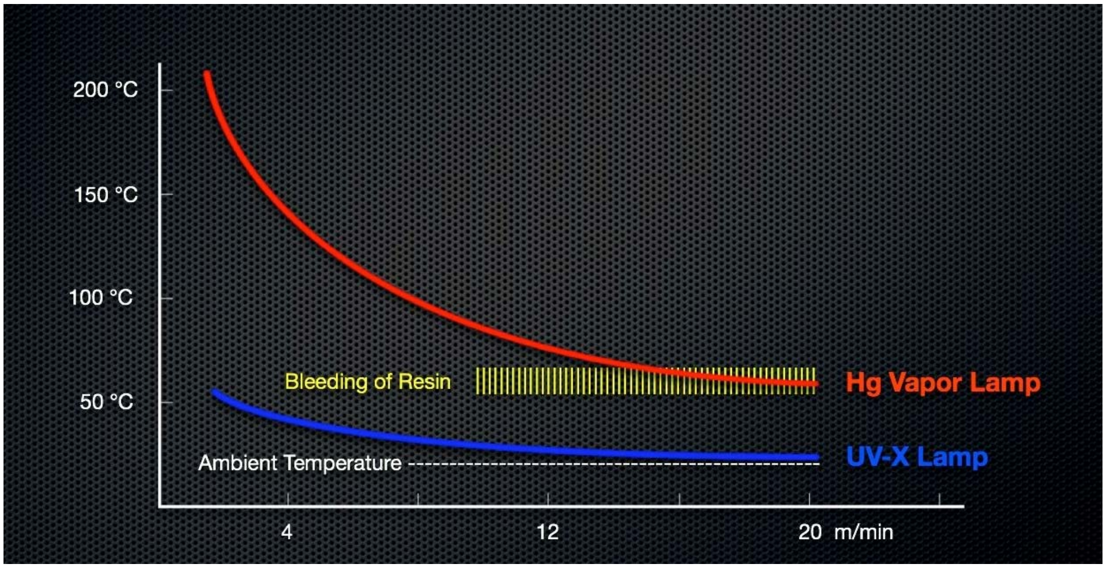

Figure 10 Provided by Della Vedove USA

A product jam in a conventional mercury lamp oven can quickly lead to over heating and a potentially a fire. The low heat load and instant-on instant-off features of the pulsed UV light system can be combined to eliminate this hazard.

Comparison of Pulsed and Mercury Lamp Systems

	UV Pulsed Lamp System	**Mercury Lamp System**
Energy Usage	2kW	5kW
Heat	Minimal IR	Significant IR
Safety	Risk Eliminated	Potential of Fire
Environmentally Friendly	No Hg and Less Energy	Hg and More Energy

Table 1

Future developments

The commercial introduction of Delle Vedove's Vacuum and Roll-Coat systems are the beginning and not the end of this story. Xenon plans to introduce a 30" linear lamp InterWeave™ system in Q2 2008. Delle Vedove's parent company Cefla Finishing Group, is designing a 1.5 meter wide pulsed UV lamp oven to cure wide wood panels. Dainippon Ink & Chemical, Inc. is developing a variety of tinted coatings. Trials are underway at Material Science Products & Engineering in Japan to quantify the benefits of pulsed lamp curing on plastic films and other heat sensitive materials.

Conclusions

The application of pulsed UV light technology to continuous curing processes is now possible. Advanced lamp technology developed by Xenon Corporation has eliminated striping. Dainippon Ink & Chemical, Inc. has developed coating formulations that take advantage of the broad spectrum and high peak power of the pulsed UV lamp. Delle Vedove USA has spearheaded the commercialization of these technologies with the introduction of two new wood coating systems. Ongoing technical advances coupled with the rapidly rising cost of energy and the expanding use of heat sensitive substrate materials make pulsed UV lamps the solution of choice for a growing list of applications.

Acknowledgments

The author wishes to acknowledge the many inputs and contributions of Mr. Vittorio Belluz and Mr. Massimo Di Russo of Delle Vedove USA Inc., Mr. Kazuo Murakami and Mr. Tony Pirro of Dainippon Ink & Chemicals, Inc. and Mr. Tomio Nakazawa of Material Science Products & Engineering.