New-Generation EB Equipment—Lowering Customers' Operating Costs

By Urs V. Läuppi and Imtiaz Rangwalla

Since its introduction, the success of low-voltage electron beam (EB) processors (used mostly for curing inks, coatings and laminating adhesives for packaging applications) has been overwhelming. However, the packaging market is high-volume and extremely cost-driven. This market has challenged EB manufacturers to produce higher product speeds, better equipment performance and overall total lower operating costs. In response, the EB industry is developing a new generation of EB equipment to meet these challenges.

The overwhelming acceptance of a low-voltage, low-cost series of EB equipment has truly kept up with its expectation as the curing method of choice for many applications. Since its introduction in 2000, more than 125 of these types of EB systems have been sold—with greater than 90% of these applications in the packaging market, particularly food packaging (Table 1).

The advantages of EB curing have long been known, but historically it has been limited to large converters for high-value and niche applications.[1] Development of low-cost EB equipment increased market awareness toward lower-value, higher-volume applications. This development was further supported by environmental mandates put forth for package sustainability and lower carbon footprints, making energy curing (EB curing in particular) the curing method of choice[2] for a wider variety of applications.

Figure 1 shows the market penetration of EB use toward lower-value, higher-volume applications. This penetration has definitely increased the growth of low-voltage EB equipment. But at the same time the technology is maturing and being commoditized, there is increasing pressure from the market to reduce operating costs, improve performance at no added cost and meet the demands of the global marketplace. To meet these market challenges, the same technology platform that was used to develop the EZCure[3] series of equipment was further optimized.[4]

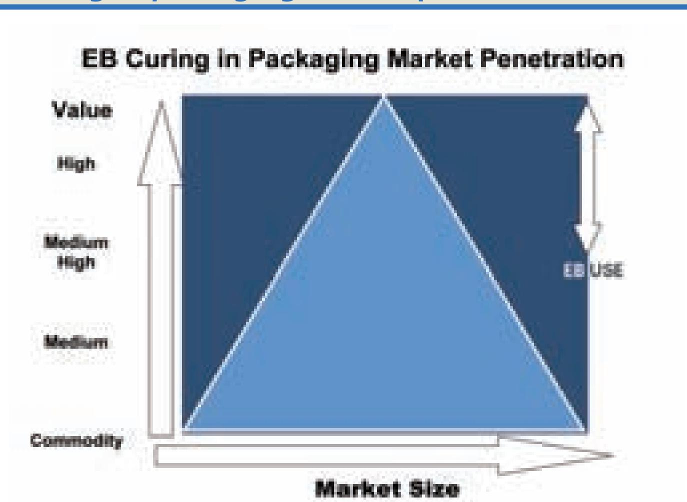
Table 1

Application of low-voltage EB units in packaging

• Curing of Inks
– Web offset inks
– EB flexo inks
• Curing of EB lacquers
– Replacing laminates
• Crosslinking high-barrier shrink films
• Curing of laminating adhesives

Figure 1

EB curing in packaging market penetration



adhesive curing applications. Ozone removal does remain an issue, but this is easily accomplished by using ozone exhaust. In this manner for these applications, nitrogen-operating expense is eliminated.

For these two reasons, it is important that the amount of oxygen in the process zone be reduced to 150-200 ppm during curing. To obtain this required concentration, one needs to supply the EB equipment with liquid nitrogen containing < 20 ppm oxygen. Usually, the nitrogen is supplied at three locations.

- **An entrance knife:** It's precisely designed and controlled with respect to the opening and angle with respect to the web. Nitrogen flows through it in a laminar flow designed to strip off the boundary layer oxygen that is brought in by the moving web at high product speeds.
- **An entrance blanket:** A line of holes just below the entrance knife (holes are toward the substrate).
- **An internal blanket:** Two lines of holes just above the titanium

Nitrogen Consumption

The process zone of EB equipment is purged by an inert gas, such as nitrogen, for two reasons:

1. Air contains 21% oxygen—high-energy electrons will ionize the oxygen in the air and create ozone.
2. Insitu free-radical polymerization for curing inks and lacquers will get inhibited by ionic oxygen present in the ambient process zone and result in an incomplete cure.

Note: Nitrogen is not required for film crosslinking and EB laminating

Table 2

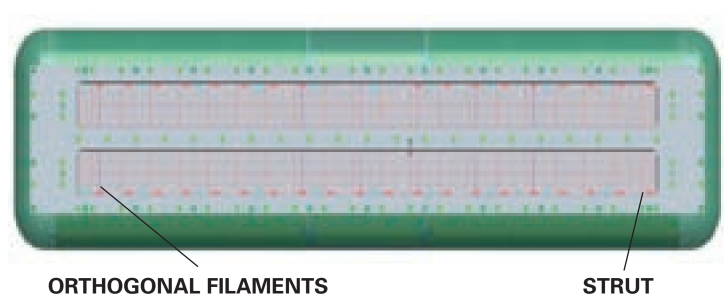
Nitrogen consumption data with passive knife

System: EZCure 110/135/1000
Product width: 130 cm
Substrate: White PE with EB coating flood coated
Data obtained after system stabilization and 30 minutes of running.

Run	Line Speed m/min	Oxygen Concentration PPM	Gas Flow Nm³/h			Total Flow Nm³/h	Web Temperature °C	
			Internal Blanket	Entrance Blanket	Entrance Knife		In	Out
Without Passive Knife	350	98	47	46	30	123	28	32
With Passive Knife	350	110	42	38	15	95	28	36

FIGURE 2

Parallel filament location with respect to window struts



foil (one line of holes is toward the titanium foil and the other one is toward the substrate). The function is to maintain nitrogen concentration in the process zone.

In addition to the above mentioned nitrogen inlet points, the following additions were made to reduce nitrogen consumption by reducing the exit of nitrogen from the process chamber. These additions are passive with no nitrogen gas flowing through them:

- A blade that comes up underneath the exit roller.
- A thinner blade that comes up to about 3.0 mm to the web as it approaches the exit roller.

As can be seen from Table 2, the nitrogen consumption is reduced by almost 25%, while at the same time maintaining product quality and not substantially increasing the web temperature. This reduction has a direct impact on the operating costs.

Improved Cross-Web Uniformity

It is important to obtain good cross-web dose uniformity to assure adequate cure of the product across its width. As the demand for some applications requires one to run at higher product speeds, it is necessary to lower the dose-to-cure. As the dose-to-cure is lowered by chemistry modifications, it is important to decrease the variation of dose both down and cross-web to maintain adequate cure and, thus, impart required product quality.

Inside the vacuum chamber of an electron accelerator is an electron gun. This gun is comprised of tungsten filaments that are heated to high temperatures (also known as the thermionic emission temperature). At these temperatures, electrons boil off

FIGURE 3

Cross-web uniformity as measured with dosimetry using straight parallel filaments

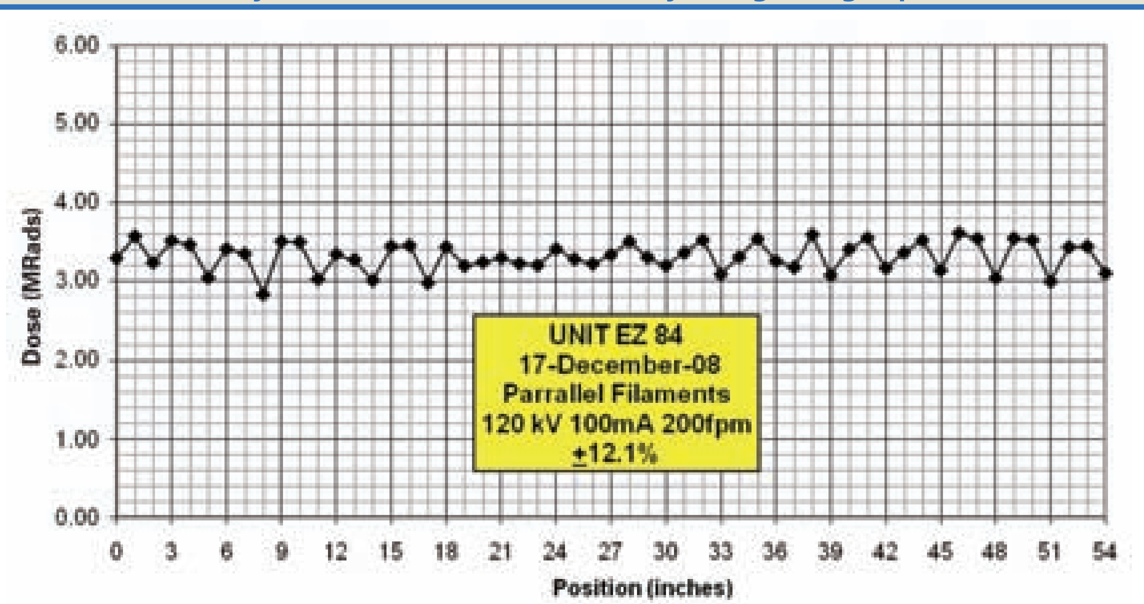
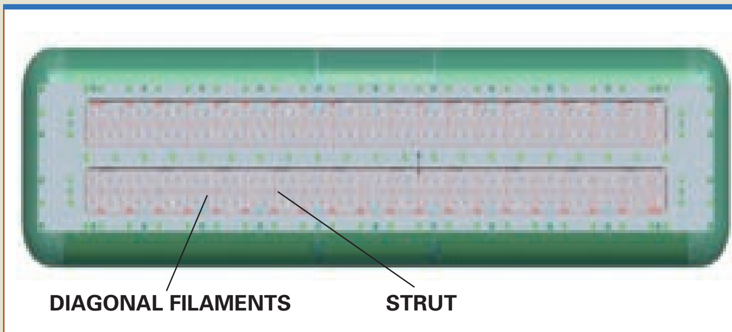


Figure 4

Diagonal filament location with respect to window struts



from the filament and create a cloud around them. These electrons are then extracted and accelerated by applying a series of positive grid voltages. The tungsten filaments are spaced every 76 mm across the entire width of the electron accelerator. So, for example, a 1,370 mm-wide EB processor would have 20 filaments about 200 mm long placed parallel to each other.

These accelerated electrons are traveling at close to 2/3 the speed of light and exit from the vacuum chamber into the process zone through a thin, 10-micrometer titanium foil that rests on a copper window body. The copper window body is comprised of 76 mm-wide window tiles with fin-shaped openings to provide required mechanical support to the foil as well as adequate heat transfer from the foil to the window body. At the same time, it is maintaining enough opening for the electrons to pass through. These individual window tiles are then electron welded to make the required accelerator width. The joining point of these individual pieces is called window struts and is 2.3 mm wide. There is the same number of struts as there are filaments. So, for a 1,370 mm-wide EB unit, there would be 20 of these struts. To provide a good cross-web EB uniformity, it is important to align these filaments precisely over the window struts to hide them and avoid high dose points and, thus, non-uniform EB distribution across the product width as shown in Figure 2. This alignment is very time consuming and, in spite of careful adjustments, cross-web uniformity as measured by dosimetry[5] is at the best around +/- 10 to 12% as shown in Figure 3.

As one can see, the high to low points are roughly about 76 mm,

Figure 5

Cross-web uniformity as measured with dosimetry using diagonal filaments

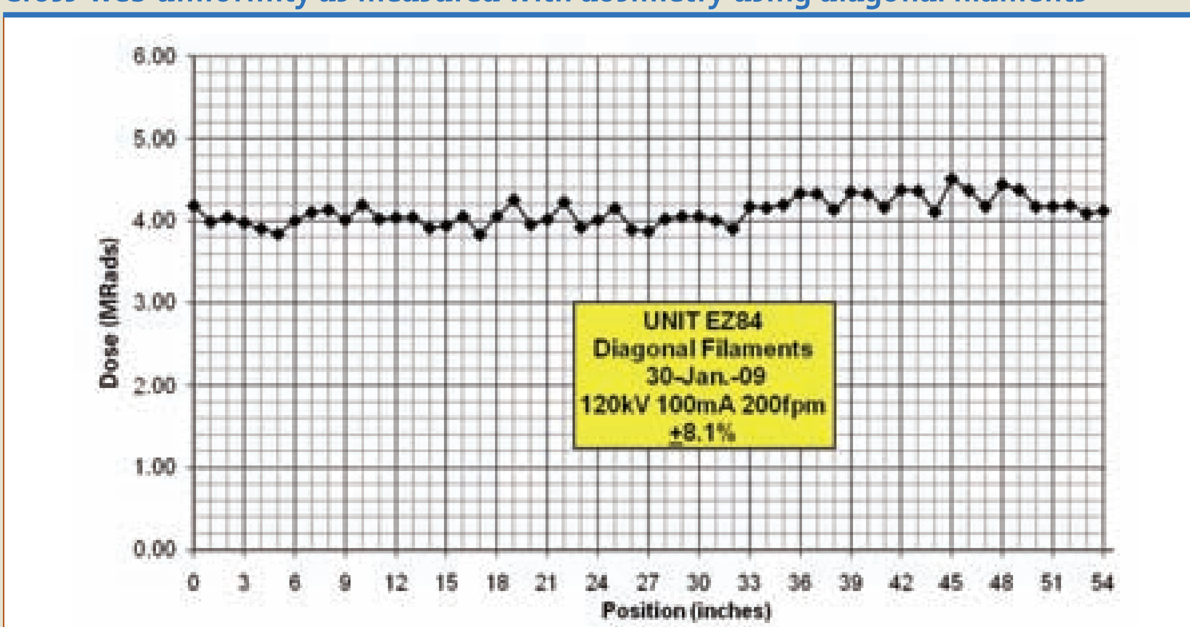


Figure 6

Two high-efficiency EZCure in series. Product operating speed 1,000 m/min

corresponding to the filament positioning in the gun.

To improve the cross-web uniformity, instead of using the tungsten filaments parallel to the window, they were spaced diagonally with respect to the window struts. Still, the spacing between them would be 76 mm, length increased to 240 mm. By placing them diagonally, it was not necessary to hide them behind the struts as shown in Figure 4. This change not only saved precise adjustments required by installation engineers, but it additionally provided better cross-web uniformity in the +/- 8 to 9% range as shown in Figure 5.

Improved Efficiency

As mentioned above, the electrons extracted and accelerated from the electron gun go through the thin titanium window foil resting on the copper window body. The entire window body design and choice of the foil are developed to provide maximum efficiency in terms of electron flux reaching the product plane, with least amount of attenuation. In addition, the electron gun itself needs to provide optimum focusing so that the maximum number of electrons pass through the window, and not hit the sides of the vacuum chamber. At the same time, the EB unit must be suitable for high-speed, 24/7-type industrial applications with minimum downtime for foil change or other maintenance.

Development in both gun focusing, proper choice of window foil, and window body development has resulted in improving the efficiency, reducing power consumption and increasing product throughput.

One example of these improvements is shown in Figure 6 in which two EZCure EB systems were installed in a series. This design will enable products to run at a record speed of 1,000 m/min curing coatings at a depth of 5-10 g/m^2 demanded for this high-volume packaging application.

Table 3 is a comparison of power, nitrogen consumption directly affecting the operating costs of 1,300 mm-wide EZCure, delivering 10 kGy at 1,200 m/min and new generation EZCure specified at the same condition currently under development. One should note that there is no sacrifice in the uptime, (i.e., even the new

Table 3

Operating cost comparison of 1,300 mm-wide EZCure and new Generation EZCure. Dose/speed 10 kGy at 1,200 m/min

	EZCure	New Generation EZCure
Power kWh	77	55
Cooling kWh	30	21
TOTAL kWh	107	76
Electric Cost $/h	8,56	6,08
N_2 Nm^3/h	123	95
N_2 Cost $/h	14,76	11,4
Total Operating Cost $/h	23,32	17,48

Note: Power cost used is $0.08/kWh and nitrogen cost used is $0.12/Nm^3

Figure 7

Low-voltage EB equipment capable of operating at a maximum speed of 200 m/min

generation EZCure will provide 98% uptime as its predecessor and cure coatings, inks and adhesives at a maximum penetration depth of 25 g/m^2).

Table 3 shows that a combination of nitrogen consumption reduction and the reduction in total power consumption reduces the operating cost by about 25%.

Development of Low-Cost EB Unit

As mentioned earlier, the use of EB curing is penetrating the mainstream markets of packaging. In emerging countries such as Brazil, India, China and other Asian countries, the norm is reverse printing with gravure and then adhesive laminating the printed layer with a sealant layer to provide a finished product. There could be significant value in eliminating the top layer of film with an EB-curable lacquer. The EB unit can be installed in-line with a gravure press, achieving the entire process in one step.

However, the issue is product speed. In these markets, very few printers are operating at 400 to 500 m/min. Most of them are operating at a maximum speed of 200 m/min. This reduction in speed results in lower volume production making long payback times for an EB unit designed to operate at 400-500 m/min. There is definitely a market need from the emerging countries to obtain a low-voltage EB unit capable of curing at a maximum depth of 10 g/m^2, product speed of 200 m/min, and product widths of 100 to 130 cm. Most importantly, the price of this equipment should be about half that of the standard low-voltage EB unit price.

Such equipment is currently under development and the engineering version of it is shown in Figure 7. This equipment will be a side-fire, low-voltage EB unit with a single window opening design. The power supply will be cable connected and high-voltage operation will be from 75 to 95 kV. The equipment will be available with machine widths of 760, 1,100 and 1,300 mm; the maximum speed will be 200 m/min at 30 kGy dose.

Conclusion

As EB-curing technology is maturing, optimization of various parts of low-voltage EB curing is helping to reduce operating costs. The development of new-generation EB units will result in reducing the operating costs of EB curing—which already was the most energy efficient curing method—even lower by almost 25%. This optimization has also enabled improved product performance by reducing beam uniformity variation. Finally, to meet global market demands, a smaller, less expensive version of EB-curing equipment is being developed for introduction by early next year.

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