Advances in Low Energy Electron Beam Equipment Technology

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Electron beam (EB) technology has been used in industrial applications for more than 30 years. The use of EB is driven by a number of factors including: improved product performance, product consistency, high throughput, energy savings, and environmental advantages. The nature of EB technology can also enable unique applications that are not possible by other means. Recent advances in equipment technology are helping to expand the applications for electron beam systems that now range from 15 kV to 175 kV.

Most of the recent developments in EB equipment have focused on "low energy" systems. These systems typically operate in the range of about 70 to 150 kV. This equipment is well suited for curing of inks and coatings used in package printing applications and can also address a variety of non-printing converting applications. However, users and potential users of EB technology continue to ask more from the suppliers of this equipment. Requests include:

- Lower capital costs
- Improved reliability
- Lower cost of operation
- Easy and inexpensive maintenance
- Wider ranges of voltages
- Customization for new applications
- Larger range of web widths
- Non-web product handling

New applications are demanding smaller more efficient systems that can integrate directly into existing and new process lines. Equipment providers are responding to these requests and are introducing innovative new designs that leverage advances in technology and years of experience with industrial EB systems.

This paper summarizes new low energy EB equipment developments and compares these developments against the needs of the market.

Ultra-Low Energy Electron Beam Systems

Traditional low energy electron beam equipment uses an electron gun within a vacuum chamber. The electrons are accelerated though a thin titanium foil window to allow treatment of materials at atmospheric pressure. In order to minimize energy deposition in the foil most EB equipment operates at a minimum voltage of about 70 to 90 kV. A new innovative electron beam technology is now available for curing/treating materials within a vacuum chamber. Since the electrons do not need to penetrate a foil layer they can be accelerated in an "ultra-low" energy range of 15 kV to 25 kV. The ultra-low energy EB systems are designed to be installed directly into a vacuum coating chamber. A representative ultra-low energy EB unit (installed in a vacuum test fixture) is shown in Figure 1. Applications for ultra-low energy EB include curing coatings that are vacuum deposited or roll coated on a web within the vacuum chamber. These coatings can be used in combination with metallization or other processes within the vacuum chamber. The EB equipment is designed to operate in the 10^{-5} torr range used in many vacuum coating processes.

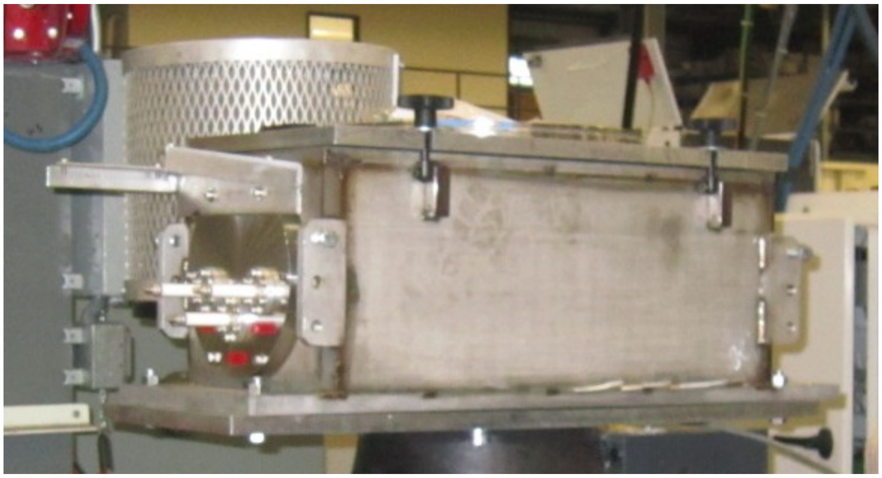

Figure 1. Ultra-Low energy electron beam for vacuum applications (electron gun within vacuum test fixture).

A dept/dose curve generated from a Monte Carlo simulation for an EB unit operating at 15 kV in a 10^{-5} torr vacuum is shown in Figure 2. This curve shows that 15 kV electrons can penetrate coating weights up to about 4 g/m^2 (4 microns for coatings with a density of 1.0 g/cm^3). Ultra-low energy electron beam systems are available to accommodate product widths from 20 inches to over 90 inches. The ultra-low energy systems include digital operated power supplies which offer high efficiency and precise control.

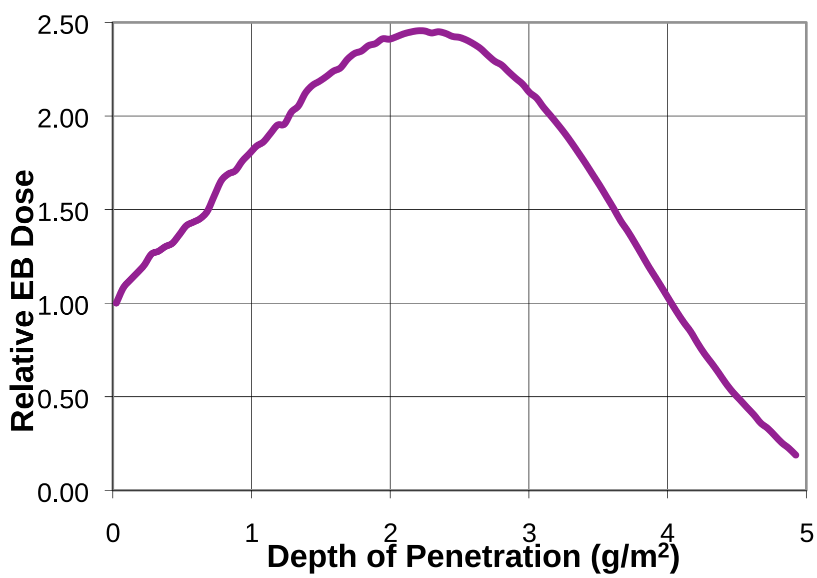

Figure 2. Depth/dose curve for 15 kV EB operated in 10^{-5} torr.

Integrated Shield Roll

All EB systems require shielding to protect personnel from the x-rays that are generated by the interaction of the electrons with materials in the equipment. Low energy EB systems can be self-shielded such that all of the required shielding is integral to the system. The amount of shielding material required varies with the energy level of the machine.

Chill rolls have been utilized in EB systems for many years. When a chilled roll is used to support the material as it is exposed to the electrons the distance between the material and the window where the electrons are emitted is precisely fixed. This ensures that any variations in the amount of energy delivered to the material are minimized. Even small changes in this distance will have a significant effect on the amount of energy when operating at low voltage levels. Supporting the material with a chill roll also is beneficial when processing plastic films. This design minimizes any potential for temperature rise in the material. It also facilitates the use of heat sensitive films such as films used in the production of shrink sleeve labels.

An innovative new design has been introduced that uses an integral chill roll as the shield roll for proper radiation shielding. This technology can be used for EB systems up to 300kV. This patented (US 8,106,369) design uses a temperature controlled roll to support the material while the roll simultaneously serves as a functional portion of the required shielding. The roll is precisely fit to the mating surfaces. The results are reduced size and materials, minimization of the volume that must be inerted with nitrogen, and easy access for threading and cleaning. The exposed roll surface is also ideal for integrating other processes such as coating heads, extruders, nip rolls, etc.

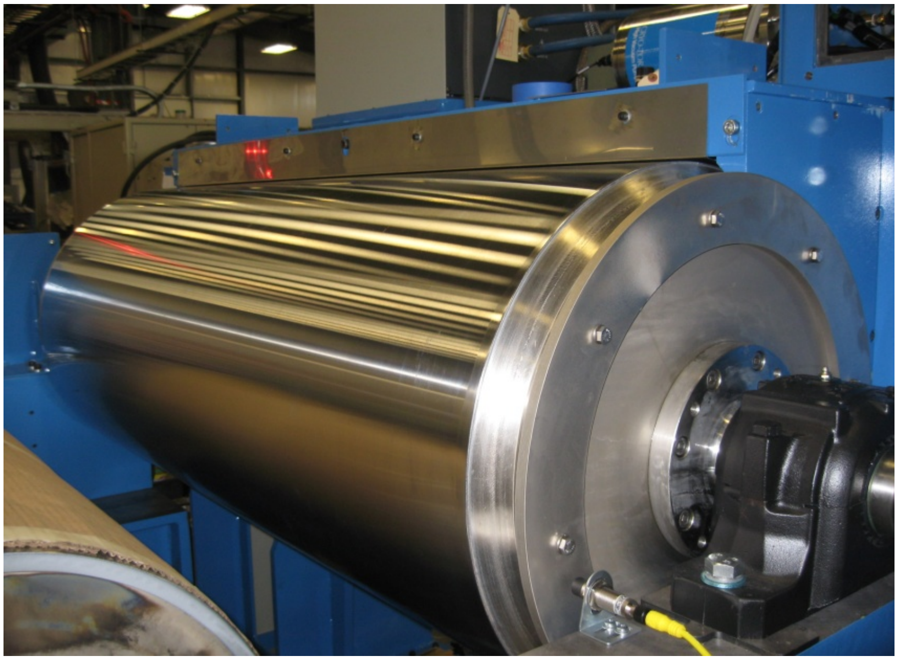

Figure 3. Integrated shield roll EB system.

Low Profile

Advances in printing press technology targeted at the flexible package market have opened more opportunities for EB systems. An important package printing technology is the use of variable sleeves on web offset presses. This style of press requires the EB system to accept a low web entry height. The web height will also vary as the sleeve diameters change. The latest EB system designs accommodate these web handling requirements and maintain a “side fire” orientation. The “side fire” orientation is preferred for the maintenance access that is required to perform a window foil change. The small size of this design also facilitates easier retrofits onto existing production lines starting at a press exit height of 24 inches (600mm).

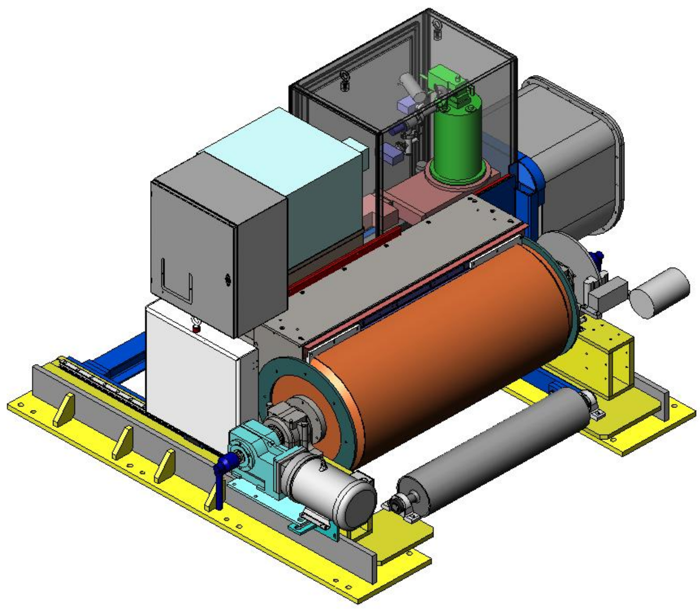

Figure 4. Low profile EB system.

Extended Voltage Low Energy Systems.

The first generation of more compact, lower cost EB equipment was introduced about 10 years ago. This equipment operated in the range of 80 to 125 kV which was suitable for curing relatively thin layers of inks and coatings. Curing or crosslinking of thicker materials required industrial EB processors operating from 150 to 300 kV. Recently new compact equipment was introduced operating at up to 150 kV. This range has now been extended up to 175 kV. These higher energies allow one-side treatment of materials up to 150 g/m^2 (150 microns for materials with a density of 1.0 g/cm^3). The ability to have these designs extend up to 175 kV allows the use of electron beams in applications such as crosslinking of film or pressure sensitive adhesives at prices that generate an attractive rate of return on investment. An example of a compact lower cost EB unit operating up to 175 kV is shown in Figure 5. This unit also incorporates the integrated shield roll technology discussed above.

Figure 5. Extended voltage (175 kV) electron beam equipment.

Digital High Voltage Power Supply

The high voltage power supply is a significant component in an EB system. The power supply technology used impacts the equipment's reliability, controllability, and energy consumption. EB systems have been introduced that now use high frequency switch-mode power supplies. The high frequency switching of the power transistors minimizes the voltage ripple to give a power factor above 0.90. This contributes to reduced electrical power consumption. This style of power supply is also digitally controlled providing arc response times of 50 microseconds. The digital controls can be easily integrated with the EB system controls via Ethernet connections.

A power supply rated for outputs above 30 kV will use an insulating material in the transformer section. Some power supply designs use sulfur hexafluoride (SF_6) gas for this purpose. SF_6 has been identified as a greenhouse gas air pollutant by the U.S. EPA. It has a global warming potential 23,900 times greater than CO_2. This latest generation of power supplies uses silicone fluid for electrical insulation. The silicone fluid also results in a cost savings compared to the higher cost SF_6 gas.

Figure 6. High voltage power supply

EB Systems Based on Sealed Tube Emitters

Sealed tube EB emitters have been in the industry for several years. Recent advances in the reliability and configurations now allow these emitters to be applied in more industrial applications (RadTech Europe 2011, Comet AG Technical Paper 4.2). Integration of these emitters into appropriate shielding configurations allows processing of a wide variety of materials including webs, flat materials, and three-dimensional (3-D) objects. Current sealed tube emitters are 16 inches (400 mm) wide and allow processing at speeds up to 100 m/min (30 kGy dose) with voltages ranging from 90 to 180 kV.

Web applications for EB systems based on sealed tube emitters may include narrow web printing, coating, and crosslinking. Potential applications for narrow web printing include:

- The curing of thick and / or high density ink layers
- Supplemental curing of current UV inks
- Curing of EB inks and coatings designed for food packaging
- EB adhesive lamination
- EB cold foil transfer

Narrow web configurations can incorporate integrated shield rolls for precise material handling and temperature control during the curing process (Figure 7).

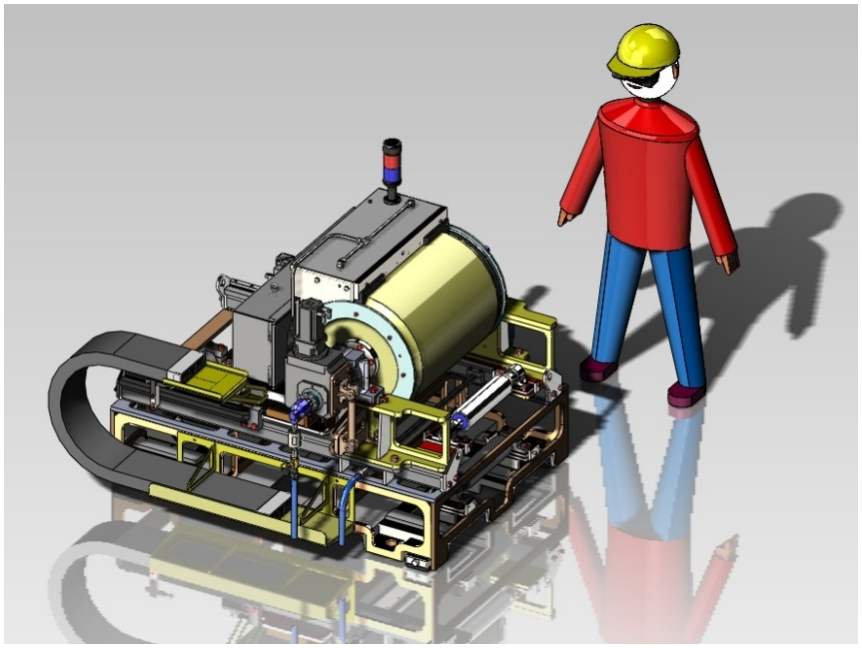

Figure 7. Narrow web EB sytem with sealed tube emitter and integrated shield roll.

Historically low energy self-shielded EB applications have mainly been limited to processing webs and flat materials. With the advent of reliable small format sealed tube emitters 3-D applications are now possible. One or more emitters may be configured along with automated product transport to allow curing on the desired surfaces. An example of a system designed for 3-D curing is shown in Figure 8.

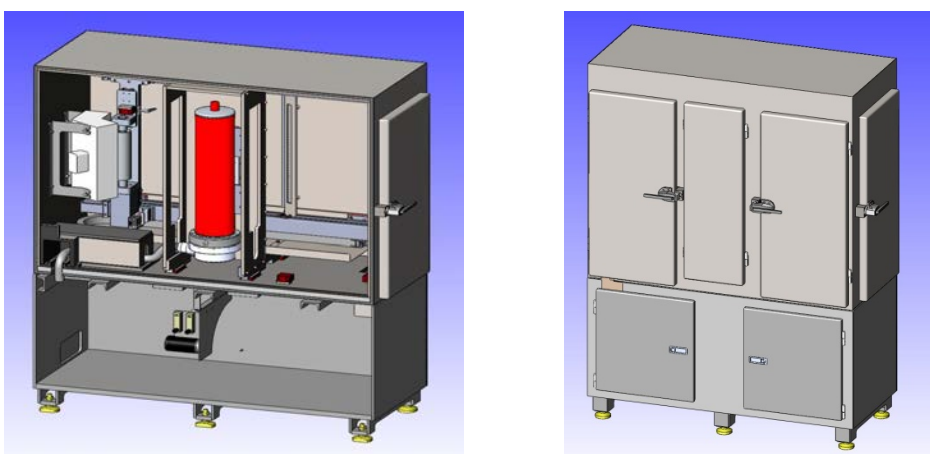

Figure 8. Custom 3-D curing application with a sealed beam emitter.

Conclusions

There are a number of new developments in low energy EB equipment that have been recently introduced. Table 1 shows that these developments are well suited to address the needs of the market for EB equipment. These developments in equipment technology will continue to facilitate the growth of new EB applications.

Table 1. New Low Energy EB Equipment Fit with Market Needs

	Market Need					
Development	Capital Cost	Reliability	Operating Cost	Maintenance	New Applications	Environmental Compliance
Ultra-low energy EB	X	X	X	X	XX	X
Low Profile	X			XX	X	X
Integrated Shield Roll	X	X	XX	XX	XX	X
Extended voltage	XX	X	XX	XX	X	X
Sealed tube emitters	X	X	X	X	XX	X
Digital High Voltage Power Supply		X	XX	X		X