Prospects and Challenges for the Industrial Use of Electron Beam Accelerators

Tony Berejka, Ionicorp+
Huntington, New York, USA

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Industrial Electron Beam Markets

>1400 high current EB manufacturing installations
EB Market Segments Require Different Energies

<table>
<thead>
<tr>
<th>Market Segment</th>
<th>Electron Energy</th>
<th>Typical Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Curing</td>
<td>80 – 300 keV</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>Shrink Film</td>
<td>300 – 800 keV</td>
<td>2 mm</td>
</tr>
<tr>
<td>Wire &amp; Cable</td>
<td>0.4 – 3 MeV</td>
<td>5 mm</td>
</tr>
<tr>
<td>Sterilization</td>
<td>3 – 10 MeV</td>
<td>38 mm</td>
</tr>
</tbody>
</table>
Industrial EB Processing
Demands Beam Current

\[ Dose = k \times \text{current} \]

\[ \text{line speed} \]

\[ k = \text{proportionality factor} \]

Product through-put dependent upon beam current
EB Equipment Development

Coolidge (GE) – 1920s
Westendorp (GE) – 1940s
Van de Graaff and
Emanuelsen (HVE) – 1960s
Cleland (RDI/IBA) – 1960s
Jongen and Abs (IBA) – 1990s
Low-energy EB Equipment Development

Quintal and Nablo (ESI) – 1970s
Farrell (RPC/PCT) – 1970s
Avnery (AEB) – 1990s
EB Equipment Development

Coolidge’s Electron Tube with Foil Window
First External Beam Electron Accelerator
EB Equipment Development

Raychem 1957 Use of GE Resonant Transformer
EB Equipment Development

Low-energy ESI Unit

[Diagram showing components like Vacuum Chamber, Beam Control Assembly, Linear Cathode, Foil Window, Electron Curtain, To Power Supply, Process Zone, Product In, and Shielding.]
EB Processing in Industry

Arthur Charlesby
EB Processing in Industry

Paul Cook establishes Raytherm (1957) and then the Raychem Corporation (1960) now Tyco Electronics = greatest kW EB capacity, used for wire and heat shrinkable products.

Bill Baird visits Cook and then develops the Cryovac process for manufacture of heat shrinkable food packaging films (1958) = greatest number of EB units in production.
EB Processing in Industry

Paul Cook – July 2007
Heat Shrinkable Tubing

Used to cover/protect wire and cable splices
EB Processing in Industry

Cryovac 500 keV Self-shielded Unit
Heat Shrinkable Food Packaging

10 EB units in one factory used to crosslink heat shrinkable film
EB Processing in Industry

Low-energy Applications

Bill Burlant at Ford uses low-energy EB to cure automotive coatings (1960s). Ford EB curing decorative coatings on plastic parts at \( \sim 10^7 \) pieces/year in early 1970s.

Dan Carlick at Sun Chemical pioneers UV/EB curable inks (1970s).
EB Processing in Industry

RDI Low-energy Cable Connected Dynacote™ EB

Multiple Scanned Beams
EB Economic and Environmental Impact

+ Many diverse, profitable end-use applications
+ Efficient manufacturing adds product value
+ EB is a very efficient means of energy transfer
+ Elimination of volatile organic compounds (VOCs) enhances air quality and reduces greenhouse gas emissions
## EB Pollution Prevention

### Low-energy Applications

<table>
<thead>
<tr>
<th>System:</th>
<th>Solvent</th>
<th>EB Curable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating solids:</td>
<td>60%</td>
<td>100%</td>
</tr>
<tr>
<td>Dried coating, g/m²:</td>
<td>20 g</td>
<td>20 g</td>
</tr>
<tr>
<td>VOCs/m², grams:</td>
<td>12 g</td>
<td>0 g</td>
</tr>
<tr>
<td>(0.9 density solvent)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ from solvent/fuel:</td>
<td>37 g/m²</td>
<td>none</td>
</tr>
<tr>
<td>(solvent incineration)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## EB Energy Efficiency

### Low-energy Applications

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<thead>
<tr>
<th>System:</th>
<th>Solvent</th>
<th>EB Curable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating solids:</td>
<td>60%</td>
<td>100%</td>
</tr>
<tr>
<td>Energy to dry, kJ/m²:</td>
<td>328 kJ</td>
<td>0.86 kJ</td>
</tr>
<tr>
<td>(solvent = 27.3 kJ/g; EB output = 70% input; dose = 30 kGy)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy, watt-hours per square meter:</td>
<td>91 w-h</td>
<td>0.24 w-h</td>
</tr>
</tbody>
</table>
Equipment Trends

+ Down-sizing of low-energy EB accelerators

+ Development of high-power EB accelerators making X-ray conversion practical
Low-energy EB Downsizing

Advanced Electron Beams
Application Development Unit
Low-energy EB Downsizing

Advanced Electron Beams

Two-module Pilot Line Beams
Low-energy EB Downsizing

Energy Sciences Incorporated

EZ-Cure III™ Accelerator
Low-energy EB Downsizing

PCT Engineered Systems

Broadbeam™ LE Series
Low-energy EB Downsizing

Getinge Linac STERSTAR™ System
Low-energy EB Downsizing

Getinge Linac STERSTAR System Schematic
Low-energy EB Downsizing

Major New End-use Application

+ Surface decontamination of substrate materials before entering aseptic packaging

Concerns:
  Determination of bioburden
  Low-energy dosimetry
Mid-energy EB Downsizing

IBA Industrial Incorporated Easy-e-Beam™

800 keV, 100 ma
Development of High-power EB

IBA Industrial Incorporated

5 MeV, 300 kW

Dynamitron®

7 MeV, 700 kW

Rhodotron®
High-power EB X-ray Conversion
High-power EB X-ray Conversion

5 and 7 MeV Rhodotron EB Sourced X-ray Targets – Operational since 2002
Market Prospects – 1979 View

*SRI International Study*

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**WORLDWIDE DISTRIBUTION OF INDUSTRIAL EB INSTALLATIONS (1979)**

- **Shrink Film (25%)**
- **Shrink Tube and Tape (18%)**
- **Auto Tires (10%)**
- **Miscellaneous (14%)**
- **Wire and Cable (33%)**

*Source: SRI International*
Market Prospects – 1987 View

IMRP 6 Panel

Mr. Anthony J. Berejka
moderator; Consultant, Huntington, New York, USA

Mr. Urs V. Läuppi
Energy Sciences, Inc., Geneva, Switzerland, now with Betacon, Sa, La Rippe, Switzerland

Mr. Chester C. Thompson
Radiation Dynamics, Inc., Melville, New York, USA

Mr. David Lyall
Viritech, Ltd., Swindon, Great Britain

Mr. Ken-Ichi Mizusawa
Nissin-High Voltage, Ltd., New York, USA

Dr. Marshall R. Cleland
consultant, Englewood, Colorado, USA, now with Radiation Dynamics, Inc., Melville, New York, USA
### Market Prospects – 1987 View

**IMRP 6 Panel Input**

<table>
<thead>
<tr>
<th>Application</th>
<th>1979 Forecast for 1988 Market</th>
<th>1987 Market Size and Shares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrink Tubing and Wire and Cable</td>
<td>161–210</td>
<td>185 39%</td>
</tr>
<tr>
<td>Shrink Film</td>
<td>50–75</td>
<td>105 22%</td>
</tr>
<tr>
<td>Tire Components</td>
<td>32–49</td>
<td>30 6%</td>
</tr>
<tr>
<td>Surface Curing</td>
<td>40–60</td>
<td>100 21%</td>
</tr>
<tr>
<td>Service Centers</td>
<td>13–20</td>
<td>25 5%</td>
</tr>
<tr>
<td>Other Applications</td>
<td>24–36</td>
<td>35 7%</td>
</tr>
<tr>
<td><strong>Total Accelerators</strong></td>
<td>320–450</td>
<td>480 100%</td>
</tr>
</tbody>
</table>
Market Prospects – 1987 Summary

- Low voltage, self-shielded equipment has taken off in the converting and web processing industries, complemented by a significant growth in the available radiation curable coating materials.
- Medium voltage accelerators continue to be the mainstay of the industry with growth in repeat orders to established markets like wire, cable, heat shrinkables and tires, with the capability of opening up the potential market to remove flue gas contaminants.
- High voltage, high current accelerators have been extended in capability so that they are now being more extensively used in the sterilization of medical disposables.
- Finally, there has been a resurgence in development work on higher current, very high energy (10 MeV) linear accelerators.
Market Prospects – 22 Years Hence

Positive Developments

+ Low-energy EB continues to grow at a fast pace with the downsizing of equipment making EB more affordable.

+ Mid-energy EB remains the mainstay of the entire industry but in historic markets.

+ Very high-power EB accelerators have made X-ray processing practical.
Market Prospects – 22 Years Hence

Areas Hindered by Lack of Demand

− Large-scale environmental applications have yet not generated market demand.

− Conversion of sterilization from gamma to EB is gradually improving.

− Food irradiation has not developed.

Non-technical societal and market barriers curtail areas of technical accomplishment.
1. **The need to address the market in a coherent manner.** The EB market is inherently diverse in equipment and in applications.

   The metrology used in EB processing, dosimetry, lacks coherence and a unified approach to measurement.
Market Challenges in 2009

2. The need to be more selective in the choice of areas for applications development.

Considerable technical resources have been devoted to areas, which, while proven to be feasible and appealing in themselves, face non-technical societal barriers.
Market Challenges in 2009
Include Risk Assessment for Societal Benefits
Market Challenges in 2009

3. The need to emphasize energy efficiency.

Energy transfer efficiency is inherent in the practical use of ionizing radiation. When compared to EB, all thermal processes are very energy inefficient.
4. **The need to develop trained professionals.**

Trained personnel are needed to explore new areas. This can be achieved by greater use of industry-academia partnerships, through fostering, but with industry guidance, of academic endeavors involving EB processing.
Market Challenges in 2009

Timeline for Technology Introduction
Market Challenges in 2009

5. The need for enhanced industry wide communication.

Out-reach complemented by closer communications within the industry is needed. Such out-reach should be extended to developing economies which have not yet invested in the more effective EB technologies.
Challenges in 2009

Challenges facing the EB processing industry:

• to address the market in a coherent manner
• to be more astute in the selection of areas for applications development
• to emphasize energy efficiency
• to develop trained professionals
• to enhance industry wide communication