SMALL

ELECTRON-BEAM ACCELERATORS

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1. FOREWORD

This presentation gives an overview of the current state of industrial electron beam development. It is not possible to present all of the technical details which one might wish because of the need to protect the proprietary interests of the firms engaged in the production applications and technology development. Still, the general view can be seen clearly.

2. INTRODUCTION

The use of Electron Beam Accelerators is a well-known and proven production technology, which has been used for more than 30 years. The electron beam accelerators are used in several new applications that put higher demands on the equipment. To meet the upcoming requirements compacter design have been developed to optimize performance and reduce running costs. While the basic of the technology remain in general, differ designs offer different advantages for specific applications.

The market is driving the equipment supplier to adapt and develop new types of Electron-Beam Accelerators to meet new demands like:

- Faster running equipment
- Smaller size
- Full control of curing parameters
- Traceability of process parameters
- Minimizing downtime
- Lower cost of ownership

This has to be done together with the user, the chemical supplier and the plant manufacturer to adapt the accelerator fully – not only during the planning phase but also during the design of the curing line and later during initial operation.

3. THE ACCELERATOR

Different types of accelerators is available on the market, with different system designs and layouts. The common factor is that they all use high voltage to accelerate the electrons in vacuum. The electrons pass out of the vacuum into the air through a titanium foil stretched over a water-cooled support grid. The product treatment area is in front of the titanium foil. The large area window has a standard length in conveyor direction of 50 mm to 250 mm. The working width is adjusted to correspond to the object to be irradiated.

To understand the acceleration of the electrons in the accelerator the best way to compare this with a normal Cathode ray tube used in the old TV. Fig 1.

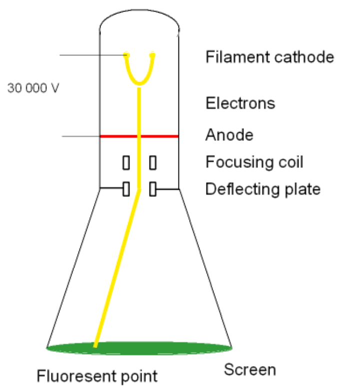


Fig. 1 Cathode ray tube

The production of free electrons in vacuum is properly familiar to us all from the cathode ray tube and the television tube. A classic triode system is used for generating and forming a beam. A tungsten cathode heated in high vacuum by an electrical current makes free electrons available on its surface and these are accelerated to the anode. In a TV set the electrons (negatively charged particles) are accelerated by a high negative voltage towards the anode and then deflected to the screen, or to the electron-beam exit window in the electron-beam accelerator. In the accelerator these electrons then emerge from the vacuum through a thin piece of titanium foil into the air or an inert gas where they can act upon the material.

3.1 Scanner system

In a scanner accelerators (fig.2) a tungsten heating cathode, Wehnelt cylinder and an anode -with focussing lens and electron-beam deflection system- together form one unit. Absolutely linear current signals controll the beam deflection in two perpendicular directions. Scanning frequencies are over 800 Hz. The electron-beam exit window is designed to have a large surface area. A 7 to 20 microns thick titanium foil is supported on the vacuum side by means of a special construction.

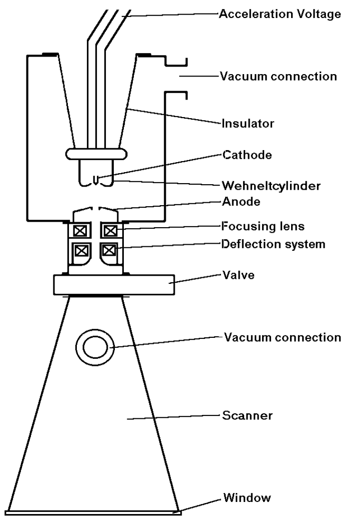


Fig. 2 Electron Crosslinking electron Electron accelerator Scanner type

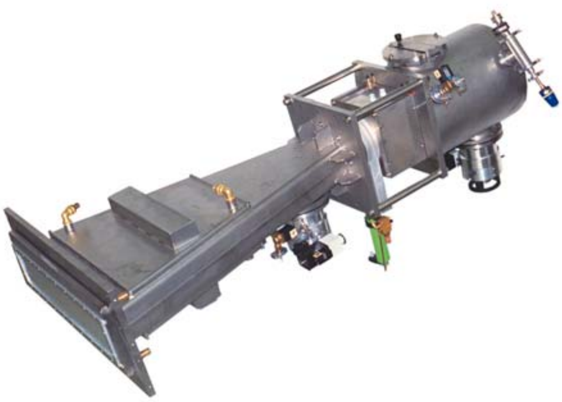


Fig3. Picture of Electron Accelerator 250 kV accelerating voltage and 1,25 m working width.

Operating characteristics EC-Scan

- Acceleration voltage	75 - 300 kV
- Electron current	0 - 200 mA
- Working width	- 2000 mm
- Throughput	9000 kGy m/min
- Distribution of dosage over working width	< ± 4 %

- No gas cooling of the electron exit window necessary.
- The accelerator can be installed in any position whatsoever.

This type of accelerator is running at 24-hours operation in many different types of applications. It is especially distinguished by low set-up times following initial installation and service. Its uncomplicated construction combined with a control system for automatic process control enables the operator to quick and easy replacement of cathode and exit window without assistance from the supplier. Replacing wearing parts requires less than one hour in total. Still work is ongoing to minimize the cost of ownership for the system.

Cooling is effected by means of water and convection through this supportive copper plate. No additional window cooling from the outside is necessary by blowing either air or inert gas. This considerably simplifies window cooling and the inerting of the process.

Scanner accelerators have the highest accuracy in dosage and distribution but are less powerful in emitting electron current. Their exactness makes these types ideal for product development and experimental use as well for production.

3.2 Linear or multi-cathode system

Linear or multi-cathode electron accelerators (fig. 4) utilize cathode systems with several cathodes across the working area. A control grid accelerates the electrons and guides them out of the electron exit window of titanium foil. These accelerators can easily be manufactured from small (0,1-0,3) m up to larger working widths (2,5-3 m). The linear accelerators provide a large electron current but are less accurate in the dosage and distribution, especially at low doses.

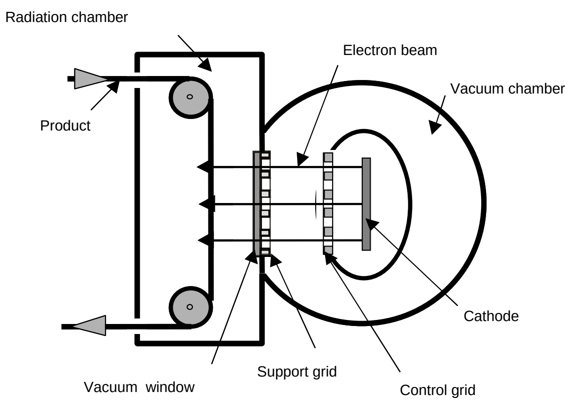


Fig 4. Electron Crosslinking electron beam accelerator Linear type

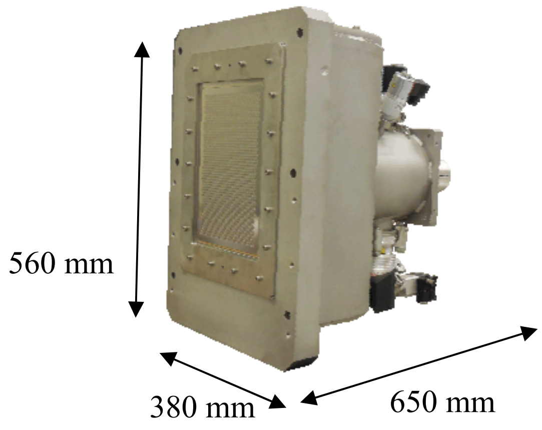


Fig 5. Electron Crosslinking EC-Beam working width 0,3 m.

Operating characteristics EC-Beam

- Acceleration voltage	70 - 150 (180) kV
- Electron current	0 - 50 mA
- Working width	100 - 300 mm
- Throughput	14000 kGy m/min
- Distribution of dosage over working width	< ± 10 %
- No gas cooling of the electron exit window necessary.	

Fig 6. Electron Crosslinking EC-Beam working width 2,3 m.

Operating characteristics EC-Beam

- Acceleration voltage	75 - 250 kV
- Electron current	0 - 2000 mA
- Working width	400 - 3000 mm
- Throughput	14000 kGy m/min
- Distribution of dosage over working width	< ± 10 %
- No gas cooling of the electron exit window necessary.	

Fig 6. Electron Crosslinking EC-Print working width 600 mm

Operating characteristics EC-Print

- Acceleration voltage	70 - 110 kV
- Electron current	0 - 200 mA
- Working width	100 - 600 mm
- Throughput	6000 kGy m/min
- Distribution of dosage over working width	< ± 7 %

- No gas cooling of the electron exit window necessary.
- The accelerator can be installed in any position whatsoever.

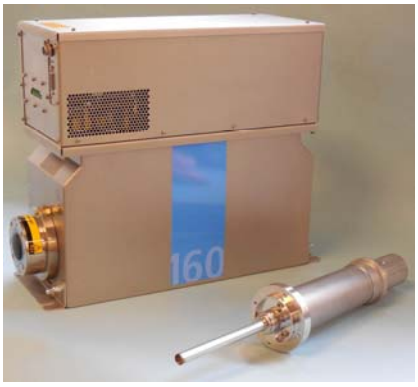


Fig 7. Electron Crosslinking EC-Tube system working diameter 20 mm

Operating characteristics EC-Tube

- Acceleration voltage	70 - 140 kV
- Electron current	0 - 2 mA
- Tube diameter	20 mm
- Max diameter	ca 80 mm

- No gas cooling of the electron exit window necessary.
- The accelerator can be installed in any position whatsoever.

4. APPLICATIONS

In all industrial applications the Electron Beam Accelerator itself is the same but the handling system differs for:

- Laboratory equipment
- Solid form materials, as sheet, board, panels, etc.
- Flexible material, roll to roll

4.1 Laboratory equipment

Laboratory scale serves as a basis to develop an in-depth fundamental physical and chemical understanding of the process, to investigate a wide variety of materials and methods for producing crosslink in materials, and to develop more effective, optimized treatments.

Pilot plants are small processing systems that are operated to generate more detailed information required for scale up to production plant. A detailed analysis leads to optimization of the process parameters.

Selection of material, paint and process design etc. should be based on the laboratory data from large-scale experiments in a laboratory Electron beam accelerator.

The EC-LAB 400 is a compact multi-purpose laboratory electron beam with a variety of possibilities and applications. These include web transport with drum and batch applications and there is option for continuous roller transport for adaptation in other processes and system for continuous irradiation of cables, fibres and composites that will open many new possibilities. The highly modular design it can easily be customized to meet unique needs and ambitions. The EC-LAB equipment is suitable laboratory use or pilot scale production, to develop new processes or to insure quality in production. [30]

Process parameters and data from the EC-LAB 400 can be directly translated to a production unit.

Typical data for EC-LAB 400

Accelerating voltage:	80 – 300 keV	Cassette speed:	5 – 30 m/min
Electron current:	0 – 30 mA	Max size (LxWxH):	600 x 400 x 250 mm
Working width:	max 400 mm	Web speed:	0 – 150 m/min
Throughput:	4500 kGy m/min	Max web width:	450 mm
Exit window:	Titanium		
Thickness:	7 – 20 µm		

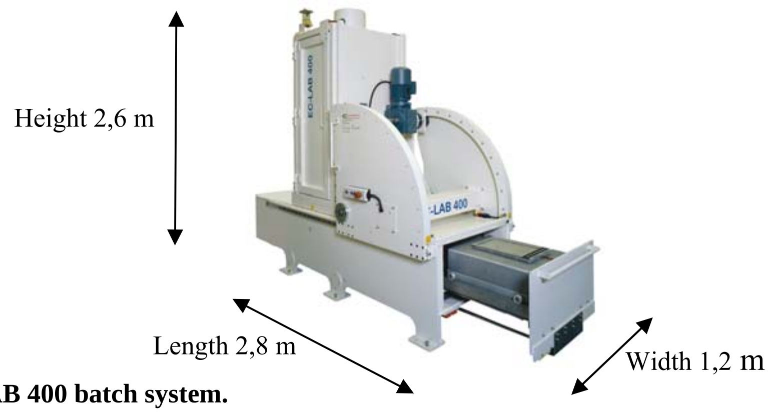


Fig. 10. EC-LAB 400 batch system.

4.2 Solid materials

In the surface converting of solid materials the EB-technology is successfully used in the following operating fields:

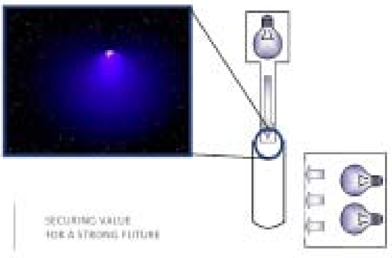
Curing of top lacquer on doors [1], [2]
All-around curing of coated profiles [3], [4]
Curing of the coating on raw boards in the wood industry [5], [6]
Curing of the coating on architectural claddings for outside applications [7], [8]
Curing of the coating on wood-cement boards for outside and inside application [9]
Curing of impregnation and top lacquer on laminated boards
Curing of coated edges and panels in the wood and laminate industry [10]
Curing of coatings on MDF boards (Medium-Density-Fibre-board) [11], [12], [13]
Curing of coatings on three-dimensional parts e.g. rims and pumps housings.
Surface sterilization and disinfection

One example of the use of small Electron-Beam Accelerators is the production of PET-bottles in filling lines for the drinking industry.

Sterilization method for bottles

- Krones develop new Sterilization method „ from the power connection"

- Based on Electron Beam from CROSSLINKING



- Electrons are produced in the Electron emitter
  - The gloving cathode produce an electron cloud
  - The electron are accelerated with high voltage
  - The electrons are projected against the treated surface

- Today Krones realize the exchange of chemical system to Sterilization with Chemical free Electron emitter system.

Sterilisation of PET bottles is done by the EC-Tube on the inside of the bottle and the outside by the EC-Beam to achive Sal 10^{-6} degree and is a safe and fast way compared to method with steam and chemistry.

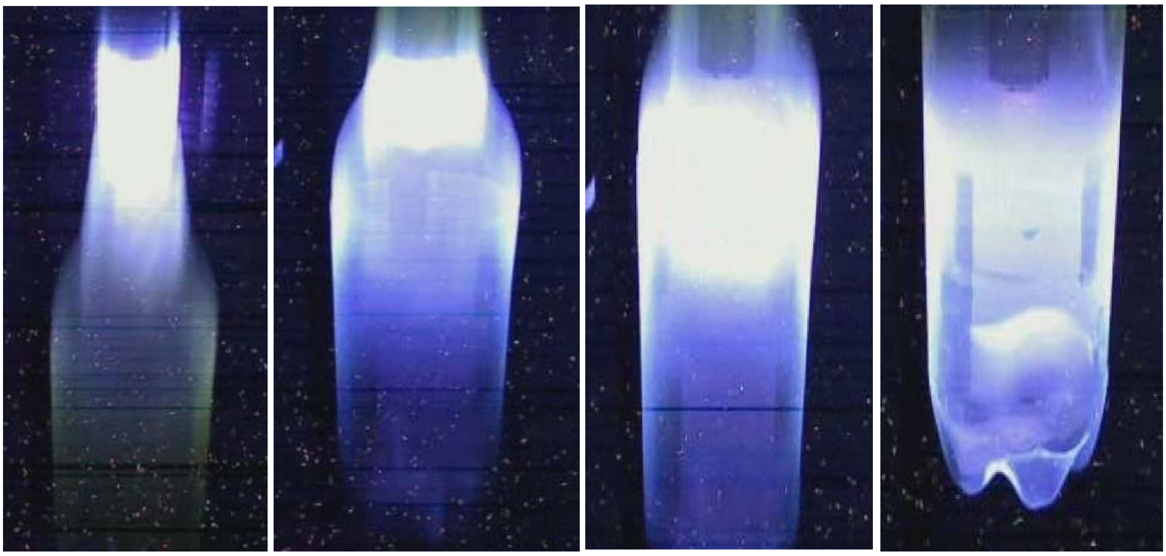


Fig. 14 Irradiation of Pet-bottles (Krones)

Operating characteristics EC-tube (inside bottle)

- Acceleration voltage	70 - 120 kV
- Electron current	0 - 2 mA
- Bottle type	PET 1,5 L
- Sterility Assurance Level (SAL)	10^{-6}

Operating characteristics EC-Beam (outside bottle)

- Acceleration voltage	70 - 150 kV
- Electron current	0 - 50 mA
- Bottle type	PET 1,5 L
- Sterility Assurance Level (SAL)	10^{-6}

Capacity for a sterilization system is in bottles per hour

Size	Capacity
33 cl	24.000 bph
50 cl	24.000 bph
75 cl	22.000 bph
100 cl	18.000 bph
150 cl	12.000 bph

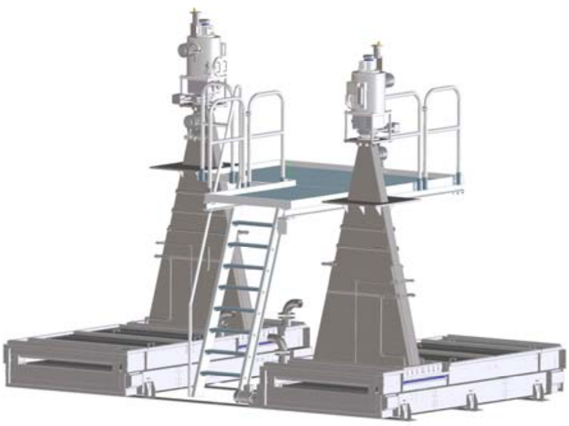


Fig. 11 Accelerator for door line

Operating characteristics EC-scanner

- Acceleration voltage	80 - 250 kV
- Electron current	0 - 200 mA
- Working width	100 - 1350 mm
- Throughput	4500 kGy m/min
- Transport speed	0 - 50 m/min
- Production size (wxh)	1230 x 2600 mm
- Distribution of dosage over working width	< ± 4 %

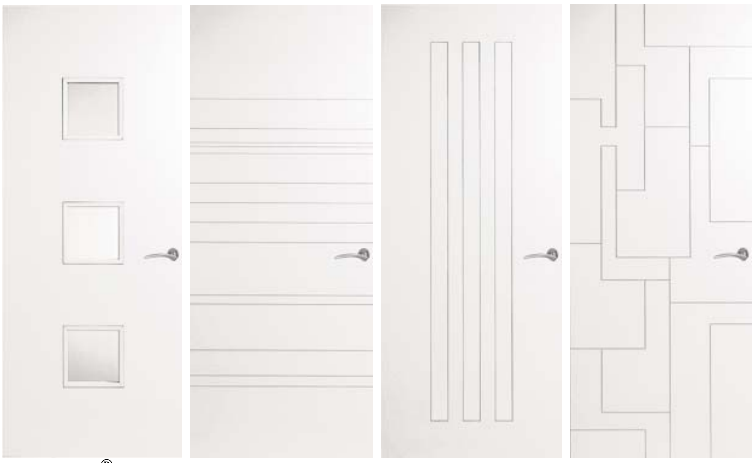


Fig. 12 Typical doors Svedex®

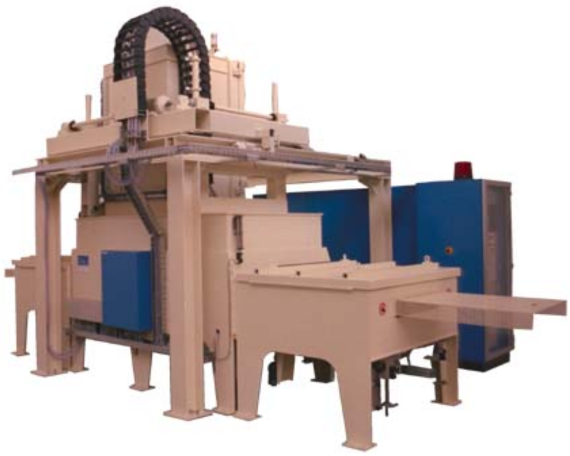


Fig. 13 Picture flat line

Operating characteristics EC-scanner

- Acceleration voltage	80 - 300 kV
- Electron current	0 - 100 mA
- Working width	100 - 600 mm
- Throughput	9000 kGy m/min
- Transport speed	0 - 35 m/min
- Production size (WxH)	600 x 600 mm
- Distribution of dosage over working width	< ± 4 %

4.3 Flexible materials

In the surface converting of flexible materials the EB-technology is successfully used in the following operating fields:

Vulcanisation or Crosslinking of pressure-sensitive adhesives [14]
Curing of high-gloss coating of special paper (e.g. photographic paper) [15], [16], [17]
Curing of release coatings
Curing of web offset printing inks, finishing varnishes [18], [21]
Crosslinking of films and foils
Production of antistatic finish
Crosslinking of flock adhesives
Curing of intaglio prints [18], [19], [20]
Post-Crosslinking of binding agents of magnetic materials
Metallizing of paper, e.g. curing of basic lacquer and adhesives for selective or plane transfer metallizing as well as curing of overprints
Curing of metal coating from roll to roll (coil coating) [24]
Stabilisation of rubber raw materials by partial vulcanisation
Crosslinking of laminating adhesives
Crosslinking of thin insulation of wire and cables
Colouring of textiles
Surface Sterilization

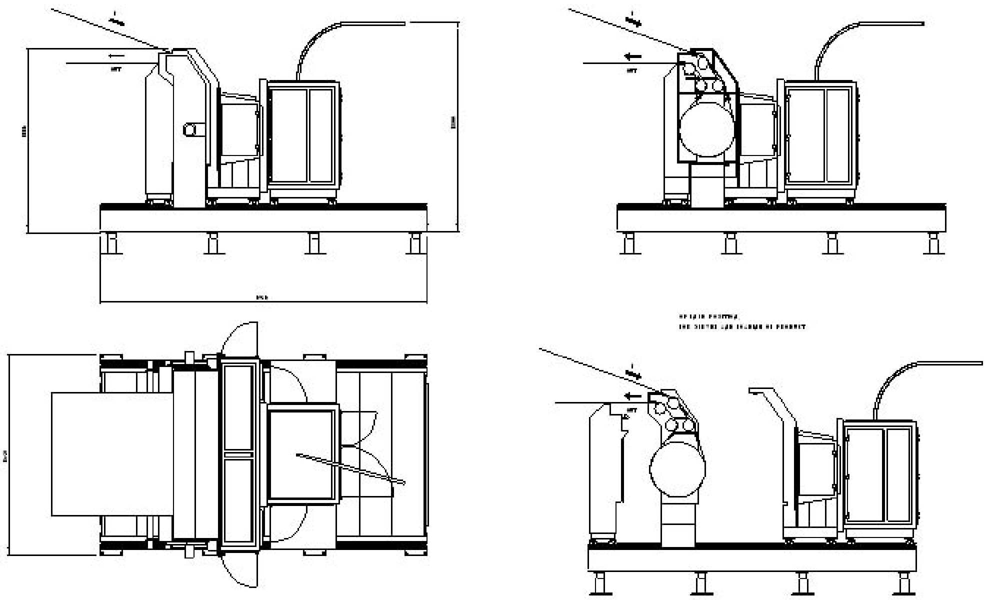


Fig 15. Typical layout for flexible products

4.3.1 EC-beam printing system

EC-print 110 is a compact Electron beam accelerator Linear type suitable for all Flexo-, Screen- and Roll offset- printing applications up to 600m/min or more.
The costs for the HV transformer and screening can be reduced through lower accelerating voltage. The advantage of reducing the accelerating voltage is well known. This has however not been implemented as there have not been any thin foils available in corresponding sizes for the printing industry. The window foils of titanium used until now are manufactured by through rolling mill. Because of the high mechanical stress when making thin foil “pin holes” can be obtained. New techniques make it possible to manufacture thin foils without pinholes.

Fig 16. Picture EC-print for Web width 600mm

Typical data for EC-print 110-600

Accelerating voltage:	70 – 110 keV
Working width:	max 600 mm
Throughput:	6000 kGy m/min
Web speed:	0 – 600 m/min

4.3.2 EC-Beam 80-250kV

Electron beam suitable for curing and surface converting of a variety of substrates, e.g.:
- Wood materials such as floor coverings, doors, wall plates, all-around curing of lacquers on mouldings
- Façade plates for outside application, direct coatings of paper and foils
- Paper and synthetic foil coatings (furniture foils, lacquered foils for laminated boards in application for high requests like floor coverings or table surfaces)
- Vulcanizing of pressure sensitive adhesives

The PLC system of the equipment control and supervise the high voltage (penetration depth of electrons) and electron beam (dose / throughput of material).
The unit can be equipped with inert gas recovery and recirculation.

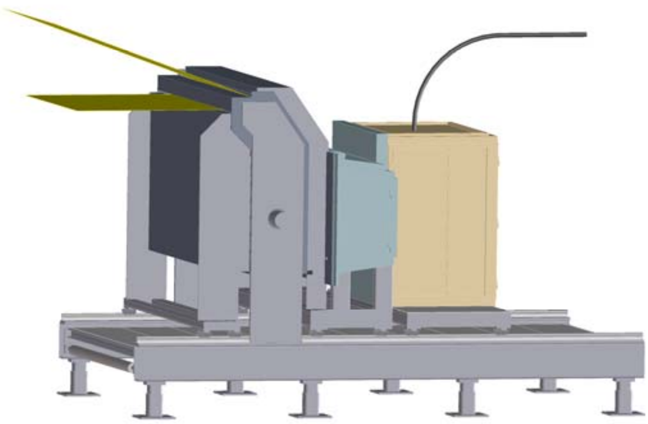


Fig. 17. EC-beam 250kV Product width 2300 mm

Typical data for EC-beam 250kV

Production unit made for 24/7 operations at 250kV

Accelerating voltage:	80 – 250 keV
Working width:	- 3000 mm
Throughput:	13000 kGy m/min at 150 keV
Web speed:	10 – further m/min

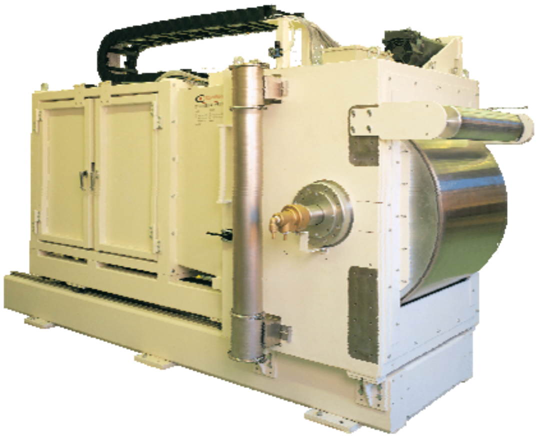


Fig. 18. EC-scan unit for from roll to roll. (120 kV, 220 mA, 0,6 m)

Typical data for EC-scan 120kV

Production unit made for 24/7 operations at 250kV

Accelerating voltage:	80 – 120 keV
Beam current	0 - 200 mA
Working width:	max 600 mm
Throughput:	9000 kGy m/min at 150 keV
Web speed:	10 – further m/min

4.4 EB –Package sterilisation

The documentation of the radiation sterilization process rests on the ability to measure dose in all steps of the validation and routine control.

4.4.1 Aseptic packaging.

Consumer products such as aseptic packaging for food or cosmetics, which have to be microbe free, can be sterilized by radiation.

Sterilizing the inside of the package packaging production plant moves a considerable part of the aseptic process from dairies and other beverage companies back to packaging production. The sterilization is performed with electron beam inline treatment, which is a safe method with a low environmental impact. This process has no effect on material properties like strength or colour, nor does it generate any detectable odours. The package is sterilized throughout, and the irradiation process follows the ISO standard for medical products, thus ensuring defined package sterility levels.

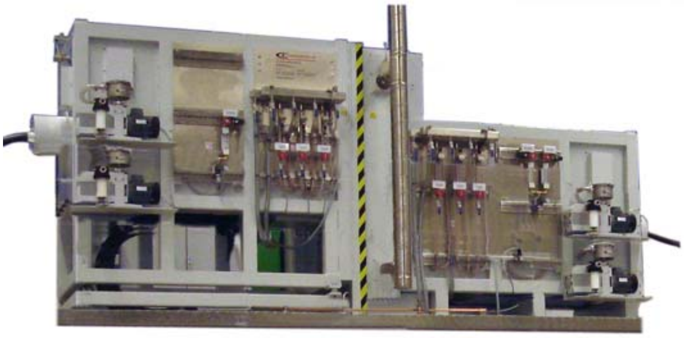


Fig. 19 EC-scan 250 kV **Fig 20. Ecolean® Air Aseptic**

Typical data for EC-scan 250kV

Production unit made for 24/7 operations at 250kV

Accelerating voltage:	80 – 250keV
Beam current	2 x 120 mA
Working width:	max 400 mm
Throughput:	9000 kGy m/min at 150 keV
Web speed:	10 – 300 m/min

4.4.2 Medical Device.

EB 300-120 MD
Electron accelerator manufactured according to GAMP [29].

Producers of medical devices have a responsibility to ensure that their products are free from viable microorganisms. Sterile medical devices meet a Sterility Assurance Level (SAL) of 10^{-6} or less, i.e. the probability of a single viable microorganism being present is less than 10^{-6}.
A minimum irradiation dose of 25 kGy is considered sufficient to validate the sterilization of a medical product [27]. An irradiation dose of 15 kGy is acceptable when bio burden is lower then 1,5 cfu [27].

Accelerated electrons in voltage ranges of 150 - 250 keV with penetration depth see Fig 8 (in material of density) 1 of 70 - 300 µm are particularly suitable for
- Surface sterilization
- Germ reduction in the depth of the packaging material.

A key aspect for Medical device equipment is well written procedures. Procedures should be clear, concise and easy for employees to follow. Well-written procedures should not leave any room for misinterpretation. They should be written in such a manner that anyone who is properly trained and knowledgeable in the field could follow them as they are written should be clear, concise and easy for employees to follow. Well-written procedures should not leave any room for misinterpretation. They should be written in such a manner that anyone who is properly trained and knowledgeable in the field could follow them as they are written.

Fig. 21 EB 300-120 MD

5. SUMMARY

EB is the abbreviation for an environmentally safe, heat and solvent free technique: **E**lectron-**B**eam curing and sterilization.

Advantages of Electron Beam curing and sterilization is:

- Environmentally friendly due to a 100 %-solid system. EB generates no emissions.
- In sterilization eliminates the use of chemistry.
- No or low substrate heating.
- Low energy consumption.
- Substantial production increase compared to conventional heat-treatment methods.
- Immediate further treatment of converted products.
- Low space requirement. Integration into existing production processes without any problems.
- Exact repeatability of production conditions is obtained due to high dose accuracy. There is also no wastage when starting up and shutting down the plant.

The use of EB technology is a very fast, energy efficient and environmentally friendly method that provides exact repeatability of production parameters.

Laboratory scale serves as basis to developing process, materials and methods for producing with EB.

Still in order to carry this technology on to success, good cooperation between customer, chemistry and plant manufacturers is necessary.

1. Literature

[1] Fa. Svedex, Türenfabrik, NL-7050 Varssefeld
[2] Fa. Theuma N.V.S.A., Türenfabrik, B-3260 Bekkevoort-Assent
[3] Profilleisten-Lackirung mit Rundum-Elektronenstrahltrocknong, HK-International 5/92
[4] A. Lindbladh, From Idea to Industrial Plant with EB-technique, RadTech Europé '93 Mediterraneo, Conference Preceedings
[5] Fa. Hamberger Industriewerke GmbH, D-83101 Rosenheim
[6] Fa. Scannery Holztechnik GmbH, D-16928
[7] T. Alpar, Elektronenstrahlhärtung bei der Oberflächenveredelung von Zementspanplatten, 13. Münchner Klebstoff-und Veredelungs-Seminar, 1988
[8] C. Chaix, N.Handegard, Electron beam coatings on polyester panels, Composites-NO 14-mars- 1996
[9] U. Tenorth, Planung und Realisierung einer modernen ESH-Anlage zur Beschichtung von Holz-Zement-Platten und Holz-Spanplatten, beta-gamma 1/90
[10] Dekorative Platten mit verbesserten Oberflächeneigenschaften, Hoechst AG, Europäische Patentschrift 0 166 153
[11] Fa. Glunz GmbH, D-49716 Meppen, Interzum Köln 1993
[12] Lack-Design-Verfahren für Holzwerkstoffplatten, HK-International 1/94
[13] Fa. Astrid, I-33033 Codroipo (UD), Interzum Köln 1993
[14] P. Holl, Elektronenstrahler zur Vernetzung und Vulkanisation von Hot Melts,16. Münchner Klebstoff-und Veredelungs-Seminar, 1991
[15] H.D. Diesel, H. Giegold, Folienveredelung mit Hilfe der ESH-Technik, 7. Münchner Klebstoff- und Veredelungs-Seminar, 1982
[16] H. Haller, 15 years of EB-Technology with WKP, RadTech Europé '93 Mediterraneo Conference Preceedings
[17] Fa. Taubert GmbH, D-46047 Oberhausen, Patentanmeldung P 42 19 446.6, Verfahren zum Auftragen einer dekorativen Schicht auf ein Trägermaterial.
[18] Fa. Tetra Pak, S-22186 Lund
[19] EB lights the way to better film printing, Packaging Digest, April 1991
[20] P. Klenert, K-H. Krauß, H. Langguth, S. Rummel und R. Mehnert, Strahlenhärtung von Druckfarben und analytische Charakterisierung, IOM – Institut für Oberflächenmodifizierung, D-04303 Leipzig
[21] P. Holl, E.Föll, Electron-Beam for Controlled Environmentally Friendly Through-Curing of Lacquers, Foils and Adhesives, RadTech Europé '93, Mediterraneo, Conferrence Proceedings
[22] H. Neuhaus-Steinmetz, Penetration Depth of the Radiation Dose and Dose Yield for Low Energy Electron Beam Accelerators, Radtech '93 Mediterraneo, Conference Proceedings
[24] Anthony J. Berejka Ionicorp , Electron Beam Curing of Coil Coatings, Radtech report September/October 2003
[27] EC standard EN ISO 11137: 1-3 2006
[28] EC regulation No 1935/2004 Directives 80/590/EEC and 89/109/EEC
[29] GAMP5® International Society for Pharmaceutical Engineering
[30] B. Laurell, E. Föll, New multi purpose laboratory Electron Beam Equipment, Radtech 2007
[31] B. Laurell, E. Föll, Dosimeter overview and the use of D_{μ}, Radtech 2009
[32] B. Laurell, E. Föll, Electron-Beam Accelerators for new applications, Radtech 2011