Sealed Electron Beam Emitter for Use in Narrow Web Curing, Sterilisation and Laboratory Applications

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Abstract

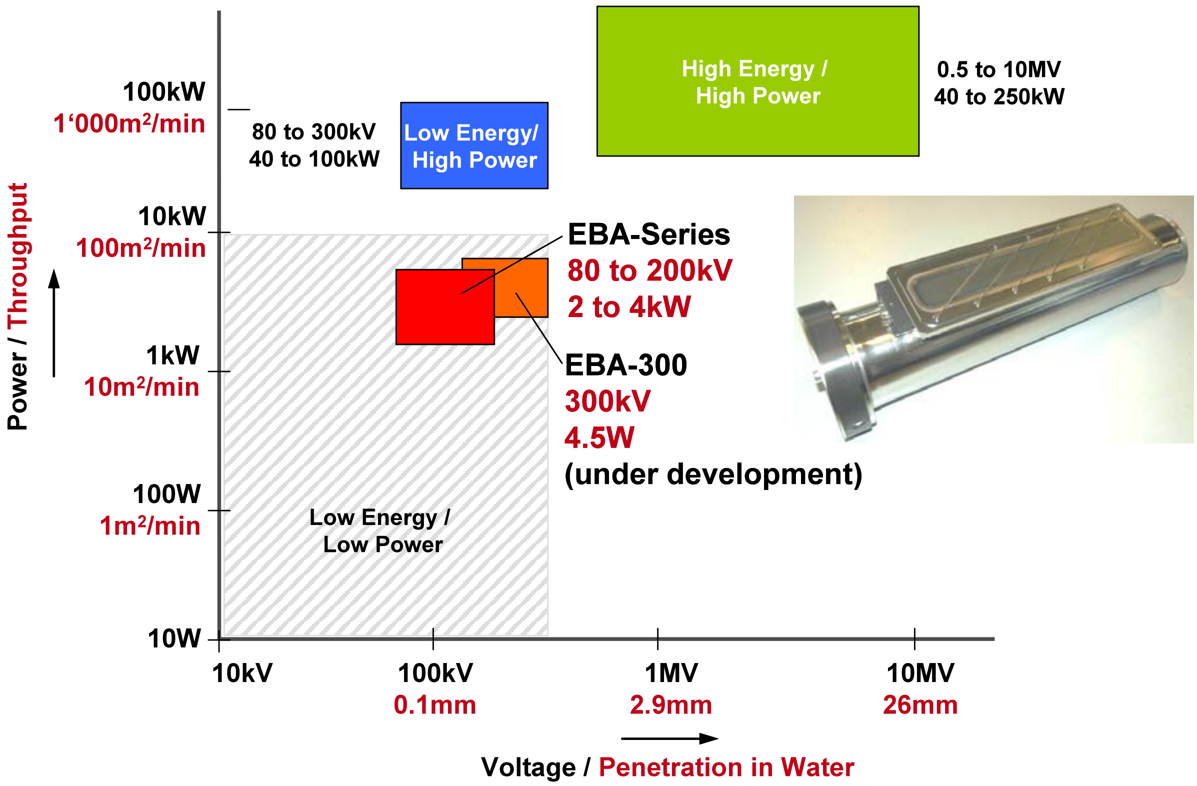
A new generation of highly compact e-beam emitters with an accelerating voltage of 80kV to 200kV and treatment widths of up to 600mm is described. The new e-beam equipment features a sealed accelerator tube making vacuum pumping unnecessary. First applications are in the areas of surface sterilisation, narrow web curing and laboratory test systems.

The paper describes the new generation e-beam emitter. In addition a narrow web curing system, a food packing sterilisation technology and an e-beam laboratory unit are presented, which incorporate the new generation e-beam emitter. The laboratory test system allows the treatment of A4-sized samples with a height of up to 50mm. The operation of the lab unit is simplified by a powerful user interface.

Introduction

The graph below puts into perspective the performance and the potential applications of the new generation of e-beam emitters. The x-axis shows the voltage, which relates to penetration, and the y-axis shows the power, which relates to throughput. In the current version, the e-beam emitter is rated at a voltage range of 80 to 200kV and a power of 4kW, which corresponds to a maximum penetration of approximately 0.25mm (in water) and a maximum web speed of about 100m/min (throughput approximately 40m^2 per minute given a web width of 400mm). The potential of the technology is significantly higher in that it allows voltages of up to 300kV and a power of at least 10kW.

When compared with the traditional e-beam systems available since the 1970s, which account for at least 90 per cent of the installed base, there is no overlap. Clearly, the compact new generation e-beam emitter aims at different applications.



Key Requirements E-Beam Emitter

Before looking at the design, the test results and the applications of the e-beam emitter, we list and explain the key requirements drawn up at the beginning of the development project.

- **Web width:** The specification required a web width of at least 550mm, which implies a window length of up to 600mm. This is in sharp contrast to the traditional systems which feature web widths of at least 1m. However, it caters for in-line sterilisation applications and narrow width, web-curing applications.
- **Maximum voltage:** While a maximum voltage of 120kV would be sufficient for curing of inks and varnishes, sterilisation applications often need voltages of up to 180kV and even more, be it to bridge an air gap or be it to achieve some penetration in the material to be treated.
- **Good high voltage stability low arcing rate:** This means that any interruptions to the sterilisation or the curing process should be very infrequent. As we will see, it is only an issue at high voltages.
- **Performance:** A web speed of up to up to 100m/min at 90kV to 120kV at a dose of 25kGy has been specified, which is mainly driven by the sterilisation applications initially considered. Some narrow web curing applications will require significantly higher speeds.
- **Lifetime:** Behind a requirement of 5’000 to 6’000 hours is the rationale that the emitter should last for a full year, assuming two-shift operation. But it is also critical for the economic viability of the applications considered.
- **Online beam monitor**: It allows for the monitoring of various sections on the electron window: This was a requirement driven by sterilisation applications outside the medical industry. Classical dosimetry, using, for example, dose films, is a time-consuming process that one wants to avoid in some industries. In addition, the beam monitor allows for continuous monitoring, not only at defined points in time.

Overview of Design of E-Beam Emitter

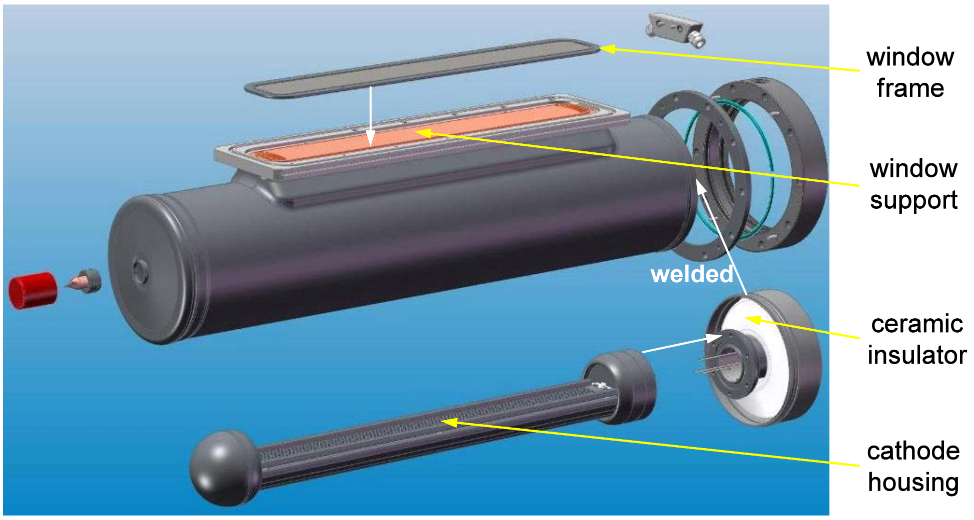
Unlike the traditional large e-beam systems, the e-beam emitter is compact, in part because it does not need to be continuously pumped to maintain vacuum. Rather, it is hermetically sealed and maintains vacuum for years. Apart from using high quality materials, this is achieved by extensive cleaning of parts during production, which accounts for roughly one third of the total processing costs. The design and production technology is shared with that of metal-ceramic X-ray tubes. Furthermore, the EBA series of e-beam emitters is based on the proven high voltage design of a bipolar 450kV industrial X-ray tube.

The design of the e-beam emitter is scalable, allowing window lengths of 100mm to 600mm, currently available are lengths of 270mm and 400mm. A version with a 460mm window is under development. Given that the emitter is based on a bipolar 450kV X-ray tube, it is (in its unipolar version) a 225kV design. Currently available voltages are 80kV to 180kV and 80kV to 200kV. The maximum power is 4kW. At voltages below 110kV, the power will have to be reduced in order to avoid too high a maximum temperature on the window. At voltages above 120kV to 140kV the power is constrained by the power supply since at such high voltages the dissipated power in the window foil is relatively low.

The “wire”-like parts extending over the window are the online beam monitors, which pick up some of the electrons, whereby the emission of each of five sections (400mm version) on the window can be monitored.

Refurbishing of Used Emitters

The picture below shows the sub-assemblies of the e-beam emitter and the way they are assembled.



When an emitter eventually fails, the user will replace it with a spare and send the used one back to the supplier. At the supplier, the window frame is milled out and the tube is cut open. All parts are cleaned and possibly replaced (e.g. the filament wire). The tube is then welded together again and a new window frame (with the critical titanium foil) is welded in.

The benefits of this approach are that the user will not have to carry out the fairly critical tasks of replacing the filament and the titanium foil. Also, the time to replace an emitter is comparatively short (typically less than one hour).

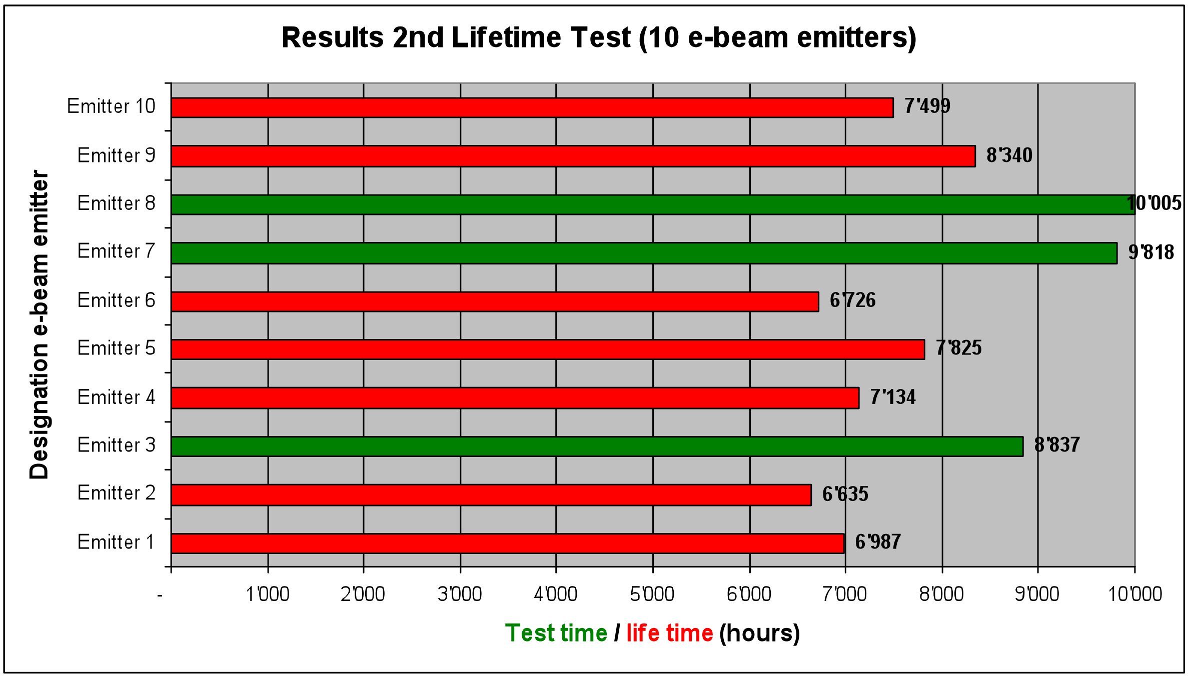
Lifetime and High Voltage Stability Test

Together with customers, we carried out extensive testing, most importantly a lifetime test. In order to arrive at some statistically significant data, yet avoiding excessive cost, the test was carried out with ten e-beam emitters. It was started in April 2010 and was completed in mid-October 2011. The voltage was deliberately set at 80kV. At that low level the dissipated power in the window foil and the temperature are highest. The power was set at 2.3kW, which is equivalent to a speed of 76m/min at 25kGy. The figure on the right shows the massive cabinet that was purpose-built for the test.

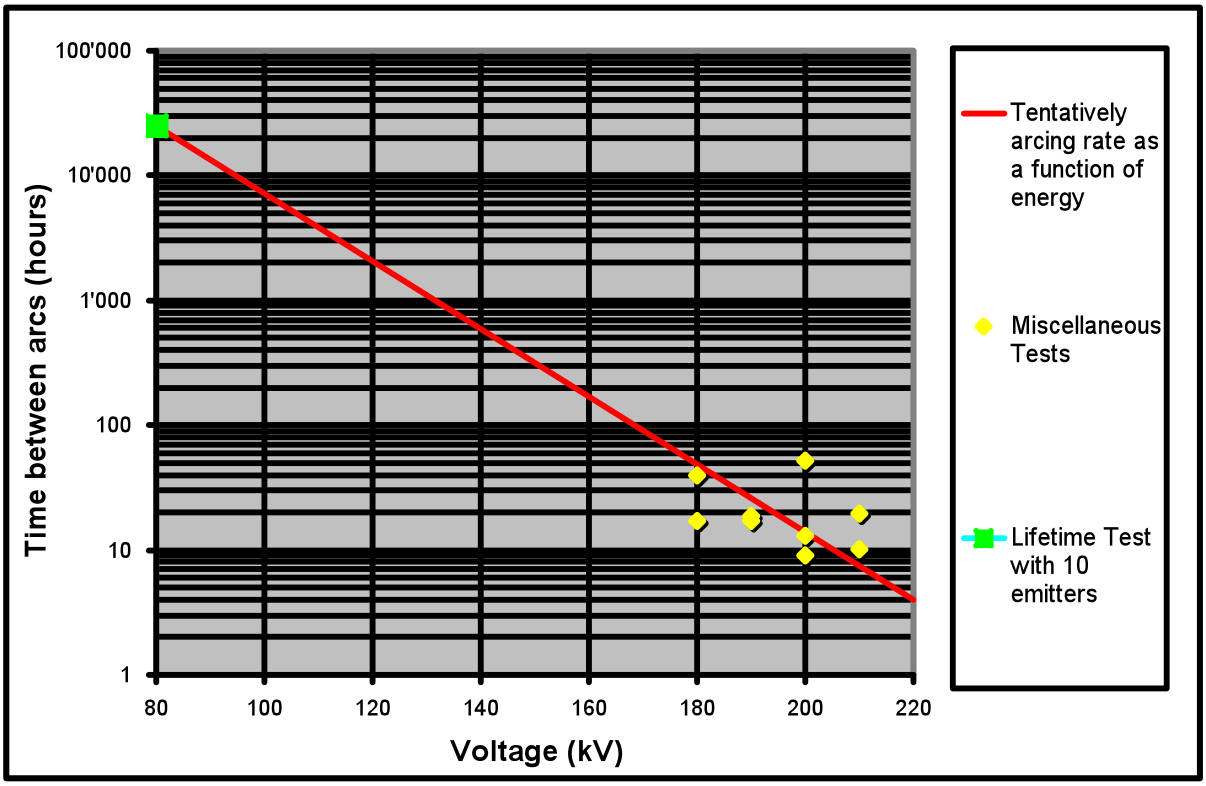
Results Lifetime and High Voltage Stability Tests

At the end of the test, the ten emitters reached an average lifetime of 7’981 hours. 7 out of 10 emitters had failed (red), while 3 were still running (green). As the graph below shows, the minimum lifetime achieved was 6’635 hours, which exceeds the requirement defined at the beginning of the project.

Since it was felt that not only the run-time played a role, the emitters were cycled. The average total number of on/off cycles was 3’608 per emitter, which represents an average run-time of about two hours which was regarded as typical for many applications.



The lifetime test also permitted determining the number of arcs (short interruptions) at 80kV. As it transpired, arcs (short interruptions) were less frequent than expected. During the test only three arcs occurred, which corresponds to an average rate of arcs of one every 26’000 hours. Additional tests with ten emitters at the voltages 180kV, 190kV, 200kV and 210kV provided data at the high end of the voltage range. Based on this data an inference may be made of the relationship of the arcing rate as a function of voltage. However, since no tests have yet been carried out at an intermediate voltage such as at140kV, that would be speculative. In conclusion, the arcing rate is negligible at voltages below 100kV and at 180kV it is in the order of one arc every 10 to 50 hours.



Current and Potential Applications

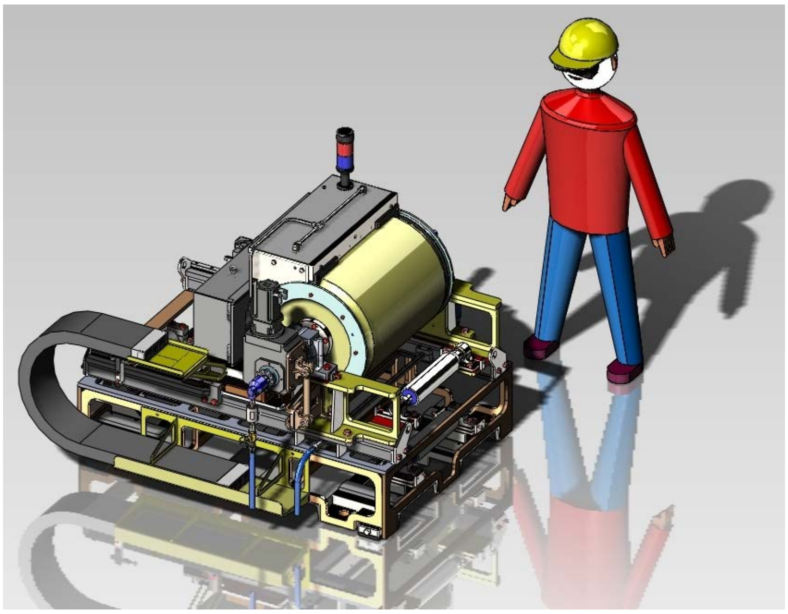
Although the design of the e-beam emitter was driven by sterilisation applications, the aim was to design it in such a way that other applications, for example curing of inks and varnishes, would also be possible. However, the aim was not to replace the traditional systems, rather to cater for applications that, at present, are outside the mainstream, including narrow width webs, new printing techniques, such as inkjet printing, or printing of short production runs.

Apart from the maximum web width of about 550mm, the required speed may limit applications. This can be addressed in two ways, either by using two e-beam emitters, arranged one behind the other, or by relying on future developments, which will allow speeds of up to 150m/min. In this way, maximum speeds of 150m/min to 300m/min would be possible.

An obvious other application for the e-beam emitter, thanks to its compactness, is its use in test systems, which both R&D and Quality Assurance need.

To conclude, we will describe three applications.

Narrow Web Curing System

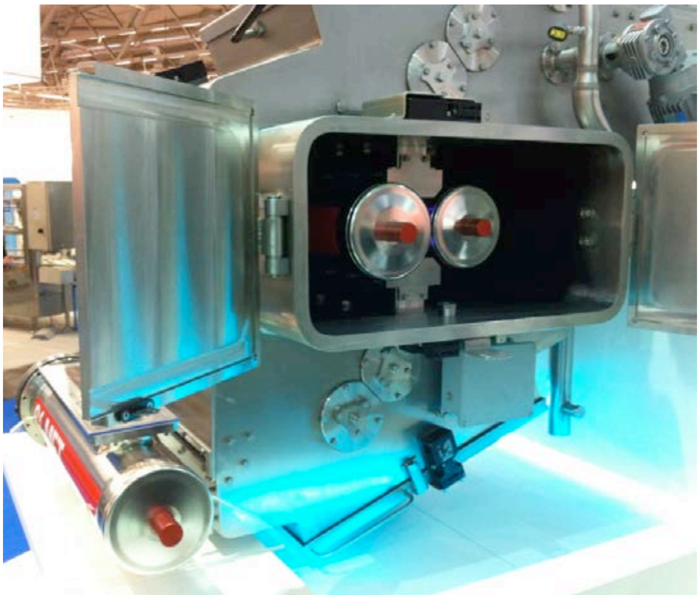


PCT Engineered Systems, Davenport, Iowa, is currently building a narrow web system that is based on its proven integrated shield roll design and the EBA-180/400 sealed emitter.

Key features include a maximum web width of 360 mm, a maximum voltage of 180kV and a speed of 90 metres per minute at 25kGy.

This system is suitable for use on pilot or development lines and narrow web printing presses, especially those used to produce shrink sleeve labels.

Sterilisation of Packaging Material



Tetra Pak, a major company providing liquid food packaging solutions, presented at the trade fair Anuga 2012 an innovative sterilisation technology incorporating the EBA-90/400 sealed emitter.

An electron beam is used to sterilise packaging material used for liquid food. It is a dry, non-contact technology substituting hydrogen peroxide, which has been in use for 40 years.

Benefits include a reduction in the energy consumption of 30 per cent, reduced operational costs and the potential for higher throughput.

Laboratory Test Unit

In 2007 we already developed a Laboratory Test Unit in close collaboration with a partner. It met some customer-specific requirements, which prevented it from being a general offering. Since then we increasingly perceived the need for a test system both for our own use, to carry out tests with customers and as a market offering.

Consequently, we carried out extensive interviews with both experts and users, with the aim of defining a standard unit that would cater for the bulk of e-beam test needs. The interviews with experts and users resulted in the following key requirements:

- Need to cater for both sterilisation and curing/cross-linking applications. As regards research into sterilisation, samples may be comparatively large and thick (up to 50mm)
- Maximum voltage needs to be 180kV or higher. This requirement is driven by sterilisation and cross-linking applications
- Unit must be reliable, compact and easy to use and maintain

- User interface should be intuitive: users should be able to use it with only minimal training. It should give the user extensive feedback on settings and its status.
- Selectable oxygen concentration, such that the sensitivity of some product / process can be determined

The main features of the standard Laboratory Test Unit include:

- Use of sealed 270mm e-beam emitter
  - No vacuum pump needed, simple replacement of emitter
  - No need to replace window or cathode
- Compact, footprint 930mm by 1330mm
- Samples to be irradiated up to the size of A4 (210mm * 297mm) and up to 50mm high
- Maximum voltage: 180kV, optionally 210kV
- Inerting with nitrogen: oxygen concentration <100ppm
- Intuitive user interface providing broad functionality (e.g. setting of dose or current), as well as feedback to user (e.g. displays absolute and depth dose, shows status of system)