Low Energy Compact Electron Guns for Industrial Applications

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Compact electron guns are finding new industrial applications to meet environmental regulations and energy savings demands. Modern treatment of polymers, pulp, and curing coatings and inks require high processing speed, but low curing product thickness (up to 20 µm of water equivalent material), so the electron guns can use lower energy beams (E_{beam} lower than 100 keV), while keeping high current and treating area. They also must be compact in order to be fitted within the processing lines. Up to date low energy electron guns must be compact and modular, and the main design challenges are: beam optics to keep dose uniformity over the whole illuminated area of the product; window heating due to beam energy deposition; and window design to allow modular mounting on the production line. Designs of such devices, as well as specific tailoring to some applications, are proposed and discussed.

I. INTRODUCTION

There are two kinds of electron accelerators currently in industrial use, according to their beam energy range: *i*) High energy, from 1 to 8 MeV, needing huge specific facilities to meet safety standards; and *ii*) Low energy, below 1 MeV (most commonly 500 keV), usually self shielded.

In the past few years there is a growing demand in the printing industry for EB (electron beam) curable coatings and inks on different kinds of substrates, due to more stringent limits on volatile organic compounds (VOC's) and energy saving concerns. The typical substrates are wood, polymer, and paper.

For high productivity it is necessary large illuminated area and high processing speed, corresponding to a high current electron beam uniformly spread over a relatively large irradiation chamber, that must be properly shielded, and, in some cases, have inert atmosphere[1].

Higher energies demand larger volumes to shield the electron gun and consequently the necessary space in the production line to fit it.

Available electron guns have very similar designs: beam generation by multifilament cathode; copper window and titanium foil as the vacuum-atmosphere interface, with beam transparencies up to 75%[ref.2,3]. Their typical energy is 200 keV.

The exception is the modular design by Avnery[4], which introduced a different approach to the beam optics of such systems.

We address the problem of reducing the size of these machines, evaluating up-to-date designs and proposing an improved one.

II. DESIGN STUDIES

Specific parameters of compact electron guns to cure inks and coatings are presented, aiming at the reduction of the machine size.

II.A. Beam Energy

In the graphic industry, as well as for some polymer modifications, only thin layers of material should be irradiated, typically a few tens of µm, so the beam energy can be small, as the calculated[5] range for electrons in water shows on Fig. 1.

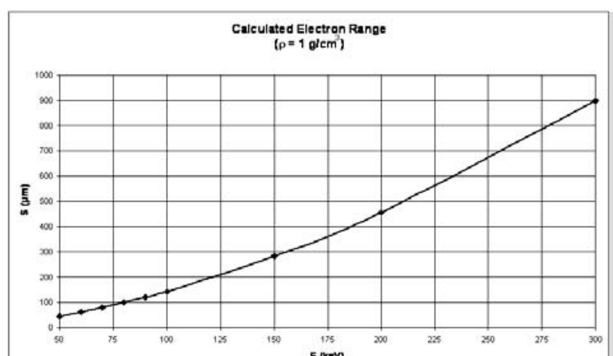

Fig. 1. Range of electrons in water as a function of beam energy[5]

Even though 50 keV would theoretically do for most applications, it would be difficult to have a commercially competitive machine with such energy, due to the materials and assembly procedures to be used. So we have to take higher energies, 80 keV, which will allow a treatment depth of 100 μm.

II.B. Beam Current

Typical processing doses range between 10 and 50 kGy, so we choose 30 kGy for our studies.

Given the beam power, energy and width, it is possible to obtain the processing speed for the necessary dose:

$$s = \frac{P}{wd\rho D}$$

where *P* is the beam power; *w* is the beam spot width; *d* the electron range; ρ is the product density; and *D* is the irradiation dose.

For *P = 100 W*; *w = 7 cm*; *E = 80 keV*, we have a processing speed $s \approx 28$ *m/min* for water treated to a *30 kGy* dose.

Even though very narrow, this low power beam can be used to process narrow band labels, or as a proof of concept for larger machines.

III. SYMETRICAL DESIGN

From the above parameters we simulated with the 2D code TRAK[6] a small cylindrical gun.

As the beam current necessary to obtain *100* W is only *1.25 mA*, and also to take advantage of the symmetry, we have chosen an ordinary TV cathode of *1 cm* overall radius, which is able to deliver up to *3 mA*, and is of the dispenser type, requiring low heating power to deliver this current.

Our design goal was to spread the beam spot for a large area, while keeping the beam uniform.

Figs. 2 and 3 show results obtained for a spot to cathode ratio of approximately *8*.

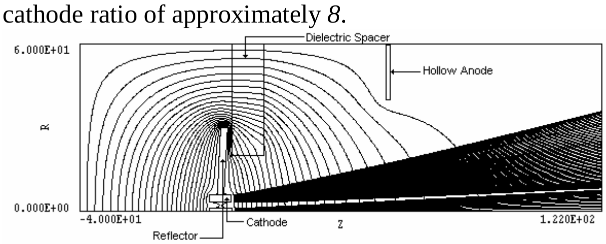

Fig. 2. 2D simulation of a cylindrically symmetrical electron gun with a TV cathode.

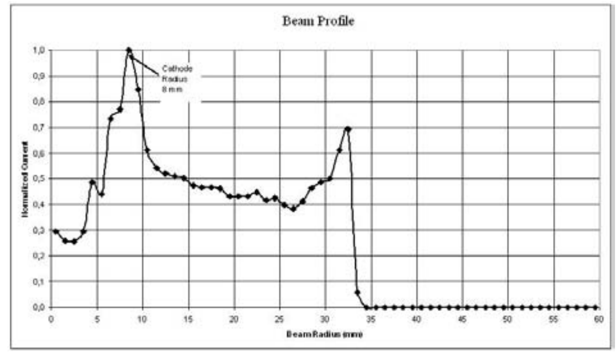

Fig. 3. Dose uniformity along the beam spot.

The dose deposited in the material is proportional to the beam current, and the useful beam will have about half of the necessary current, so we have to reduce the processing speed of this prototype by the same factor to achieve the desired dose.

It is possible to observe the shape of the electron emitting areas on the cathode used: a small cylinder inside another with a void ring between them. This is the reason for such poor beam uniformity. For practical use, this design should have a more uniform cathode shape, as well as an additional electrostatic lens to improve beam uniformity.

IV. CONCLUSIONS

It was shown that small electron guns meet up-to-date needs of graphic industry, and can be built with different components, such as commercially available dispenser cathodes.

This symmetrical design, however, is not the best solution, because the products to be treated are flat and the modular assemblies require a rectangular shape for the irradiation chamber.

Currently the cylindrical prototype is being built, and the next steps will be a 3D simulation and a more realistic design.

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