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Nablo

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[54] **APPARATUS FOR SIMULTANEOUSLY UNIFORMLY IRRADIATING A REGION USING PLURAL GRID CONTROLLED ELECTRON GUNS**

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Related U.S. Application Data

[63] Continuation of Ser. No. 151,640, June 10, 1971, abandoned.

[52] **U.S. Cl.** **250/492,** 250/398, 250/400

[51] **Int. Cl.** **H01j 37/00,** G01n 23/00

[58] **Field of Search** ..... 219/121 EB, 121 EM; 250/396, 398, 400, 492; 313/74

[56] **References Cited**

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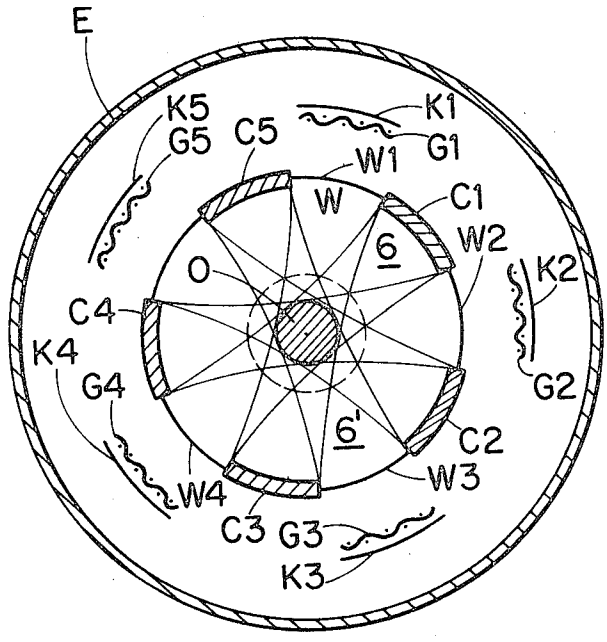
Primary Examiner—William F. Lindquist

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[57] **ABSTRACT**

This disclosure deals with novel techniques and apparatus for the electron-irradiation of objects bilaterally, by directing energetic electron beams substantially simultaneously into such objects from a plurality of widely different directions.

5 Claims, 4 Drawing Figures



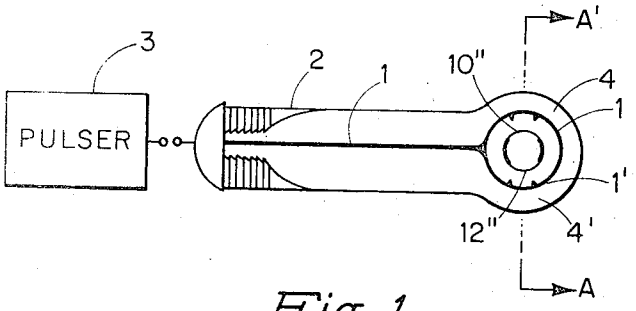


Fig. 1.

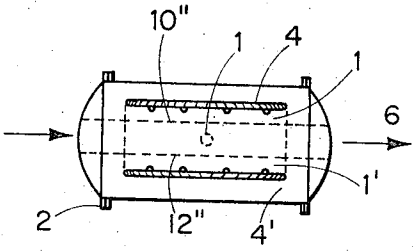


Fig. 1A.

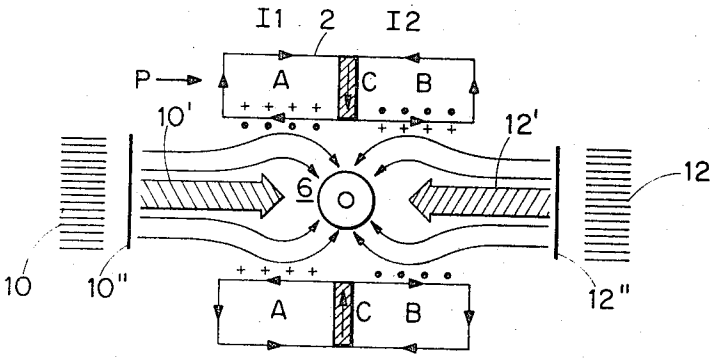


Fig. 2.

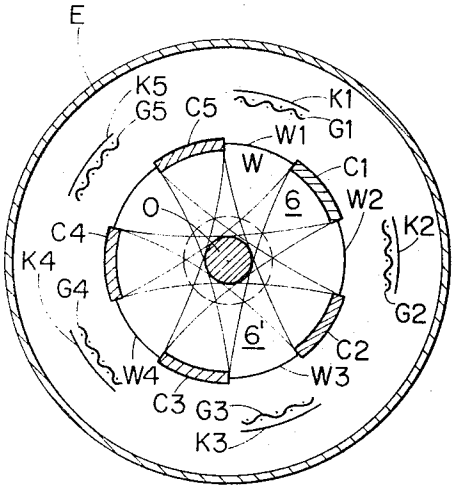


Fig. 3.

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APPARATUS FOR SIMULTANEOUSLY UNIFORMLY IRRADIATING A REGION USING PLURAL GRID CONTROLLED ELECTRON GUNS

This is a continuation of application Ser. No. 151,640, filed June 10, 1971, now abandoned.

The present invention relates to apparatus and processes for the charged-particle irradiation of objects, being more particularly directed to irradiation by energetic electrons for such purposes as surface-treating, curing, sterilization and the like.

It has long been proposed to apply energetic electron beams to industrial applications for the above purposes and others, as described, for example, in U.S. Pat. Nos. 2,456,909 and 2,807,551 to Brasch, and in 3,247,012. Apart from serious limitations in such practical application, there are instances as in the case of objects of substantial cross-section or objects with three-dimensional surfaces-to-be-treated, where the directing of an electron beam upon one portion of the object will not solve the problem of uniformly irradiating all object surfaces or all parts of the interior thereof. While the object may be rotated or re-oriented during irradiation or after successive irradiations, this is time-consuming, complex and costly, and is not adapted for continuous flow or high speed processes.

In other applications of energetic electron beams for bulk or surface processing requiring that the electron flux be distributed uniformly and simultaneously over large two- and three-dimensional surfaces, it has been proposed to utilize electromagnetic or electrostatic scanning of cylindrical beams in one or two dimensions. An example of this is described as an illustration in U.S. Pat. No. 2,931,903. Such techniques, however, always suffer from the disadvantage of non-orthogonal incidence at the workpiece object surface, with resulting variation in the delivered depth-dose distribution across the surface treated, as well as from the high instantaneous dose rates implicit in scanned beams and overlap non-uniformities inherent in the application of such techniques to moving workpieces. In addition, the length, size and complexity of such scanner systems significantly affects the cost, size and reliability of such electron beam machinery.

An object of the present invention, accordingly, is to provide a novel process and apparatus for enabling bilateral, isotropic and cylindrically symmetrical irradiation of objects not subject to the above-described limitations and disadvantages. The invention is applicable to both pulsed and d. c. electron beam apparatus, permitting the uniform distribution of beams over large areas and the shaping of such beams to conform with the contours of complex geometry workpiece objects, such that orthogonal illumination is possible at fixed and controllable dose rates. Such parameters of electron beam machine performance are critical to many areas of industrial application, such as the curing of finishes and molded products, the curing (crosslinking or vulcanization of plastic or elastomeric sheaths on the surface (or inner surface of) conducting cables, conduit, pipe, structural panels or members; sterilization of medical products, raw waste and raw produce; pasteurization of consumable produce and products; and similar applications.

A further object is to provide a novel electron beam irradiating apparatus and process of more general application, as for example, in the excitation of gas filled

cavities of cylindrical or rectangular cross-section for lamp or laser application and the like.

Other and further objects will be described hereinafter and are more particularly delineated in the appended claims. In summary, however, from one of its broad aspects, the invention contemplates the irradiation of objects by energetic charged particles (hereinafter generically referred to as "electrons") by directing beams of the same simultaneously into such objects from a plurality of widely different directions, including bilaterally, isotropically and cylindrically symmetrically (sometimes all generally referred to hereinafter as "substantially coaxially").

The invention will now be described with reference to the accompanying drawing,

FIG. 1 of which is a longitudinal section of an apparatus adapted to practice the bilateral irradiation of the invention;

FIG. 1A is a partial section taken along the line A–A′ of FIG. 1 looking in the direction of the arrows;

FIG. 2 is a similar view of an isotropic irradiator exploring the principles of the invention; and

FIG. 3 is a longitudinal section of a preferred embodiment employing a cylindrical substantially coaxial construction utilizing strip cathode geometries for uniform irradiation of cylindrical workpieces.

The practicality of utilizing multiple cathodes in common or separated shanks and sharing the current from a single (common) pulsed high voltage accelerator or source among a multiplicity of heads or guns has been demonstrated, as described in "The Generation and Diagnosis of Pulsed Relativistic Electron Beams Above 10^{10} Watts," S. V. Nablo and S. E. Graybill IEEE Trans. Nuc. Sci. N5–14, No. 3, P. 702, 1967. The present invention may employ this or other techniques, as later explained. In FIG. 1, a common cathode shank 1, located in an evacuated insulating structure 2 is excited from a single pulser 3 insulated in an appropriate dielectric environment. The shank is then divided and fanned into two or more members or high voltage terminal assemblies 4 and 4′ which support a number of circumferentially opposed gun structures 1′ and 1″ located on separate secondary shanks or on a manifolding or distributor ring configuration. Suitable cathode gun structures 1′ and 1″ are the type described, for example, at U.S. Pat. No. 3,489,944, having electron permeable windows 10″ and 12″. In the limit, this technique will permit full (2π) radial illumination of cylindrical surfaces of objects (not shown) drawn longitudinally through, or otherwise disposed in the region or channel 6 between the gun structures 1′ and 1″, as schematically represented by the arrow. Linear extension of the cathode structures may be effected to reduce the current densities, or to increase the total emitting areas to levels compatible with the dose rate requirements and process speeds demanded by the process. Thus, substantially simultaneous irradiation from widely different directions may be attained.

An additional technique for the near-isotropic illumination of three-dimensional surfaces with two initially unidirectionally opposed beams is depicted in the embodiment of FIG. 2. In this scheme, a magnetic lens structure capable of generating opposed azimuthal magnetic fields is arranged at 2′ so that relatively uniform irradiation of uniform or non-uniformly shaped longitudinally extending objects O can be accomplished. In its simplest form, the lens consists of two to-

roidal coil elements A and B with or without a common central conductor C. These coils carry equal currents I_1 and I_2 in opposed toroids. The azimuthal fields created by the coil geometry are shown in FIG. **2** such that the opposed planar or cylindrical electron beams **10'** and **12'** from opposite sides of the region **6** and object O are guided about the object O to provide uniform illumination of the surface thereof. The opposing beams **10'** and **12'** are directed through corresponding windows **10''** and **12''** from electron gun structures **10** and **12,** as of the type described in our cathode application No. 31,530. Magnetic shims or conventional field shunts (not shown) may be used near the periphery of the beam channel to provide adequate control over beam uniformity from the normally divergent source provided by the opposed electron guns **10** and **12.** Typical operation at 300 kiloelectronvolts of energy requires rather modest fields for beam control and guiding; e.g., particle radii of curvature of 2 inches in a 400 gauss field. Such a head could readily handle three-dimensional surfaces whose major diameters were 30–40 percent that of the lens working volume. In practice, the pieces to be processed would be fed radially through the plane separating the toroid structures. The system of FIG. **2,** moreover, is equally applicable for pulsed beams from **10** and **12,** if necessary for purposes of field strength or beam shaping requirements, with the use of pulsed currents in the toroidal lenses from the pulse generator schematically indicated at P, as, for example, of the type described at U.S. Pat. No. 3,489,944. At lower energies, it is possible to utilize permanent magnets for the generation of the required field topology so that relatively compact shaping heads are permitted.

In accordance with a preferred embodiment of the invention, the apparatus of FIG. **3** is provided that is particularly adapted for many of the industrial applications of energy delivered by energetic electron beams involving the treatment of extended cylindrical workpieces (typically cable, pipe, etc.). As before explained, current-scanned beam technology provides an inadequate approach to such applications due to the high degree of fluence non-uniformity introduced by the illumination of a curved surface with a "planar" beam and the severe surface degradation encountered with the "tangential" irradiation geometries encountered over any cylindrical surface. The technique of FIG. **3,** however, provides a uniform 2π illumination of cylindrical surfaces, such as cable jacketing, utilizing a number of linear or extended cathodes wrapped into a coaxial configuration about the irradiation volume.

The structure of FIG. **3** consists of, for example, a 10 kilowatt, 500 kilovolt system capable of providing a uniform illumination of cylindrical sections up to several inches in diameter on a continuous process. The cathodes K_1 through K_5 are longitudinal emitters (such as those described, for example, in U.S. Pat. Nos. 2,887,599 to Trump) and may deliver current densities of up to several milliamperes per cm^2, generally at a level compatible with window thermal loading limitations of less than 1 ma/cm^2. Each of the five cathodes $K_1 - K_5$ may provide 4 ma of current from corresponding grid-controlled gun structures $G_1 - G_5$ and through respective windows $W_1 - W_5$. The gun segments are so arrayed that opposed cooling channels $C_1 - C_5$ are presented to each window element $W_1 - W_5$ such that absence of a beam absorbing workpiece or object O in the channel or region **6** will not lead to overheating and destruction of the window structure. While the beams **10'** and **12'** of FIG. **2,** or those emitted by cathode guns **1'** and **1''** in FIG. **1** are exactly diametrically oppositely disposed, the pairs of longitudinally extending cathodes of FIG. **3** are substantially oppositely disposed, though not diametrically exactly oppositely disposed, such as $K_1 - K_3$, $K_1 - K_4$, $K_2 - K_5$, etc.; each pair irradiating from widely different directions, and the composite uniformly simultaneously irradiating the region **6** and the object O.

The current art utilizing scanned beams, before described, requires that wire and cabling be convoluted or festooned in the irradiation volume to provide an adequate integrated dose to the bulk or surface to be treated. In addition, because of the unilateral non-uniform nature of the irradiation, rotation of the workpiece is necessary in order to provide some modicum of uniformity over the cylindrical surface. Such complexities in the handling machinery are, of course, avoidable with the use of the coaxial geometry of FIG. **3.** In particular, the head geometry permits a high degree of self-shielding due to its annular configuration, while the closed irradiation channel or region **6** provides significant efficiencies in the recycling of a blanket of inert cooling gas **6'**, which may be needed for the particular radiation induced process of interest and may be used in each of the embodiments of FIGS. **1–3.** The retention of ozone produced at **6** in air by the beams under ambient irradiation may be advantageously applied in the treatment of contaminated material on a continuous or flow basis. If required, moreover, this geometry lends itself admirably to tandem operation if higher process speeds are demanded, or if non-homogeneous cures are required. For example, several wire cable applications can utilize a high energy, medium level bulk cure with a simultaneous or sequential lower energy, higher level surface cure (vulcanization-crosslinking, etc.), particularly where multiple or sequential jacket extrusions are involved. The advantages of this geometry for tubing and conduit are self-evident. Even for very small diameter wire or cord, the use of multiple annular arrays such as shown in FIG. **3,** separated longitudinally along the axis of movement of object O will effectively utilize the uniform cylindrical irradiation provided by the coaxial head, at the same time permitting precise matching of the beam energy with the penetration (workpiece thickness) requirement.

It is of interest to consider the very high throughputs or process rates made possible by the techniques of the invention. Current thermal ovens are severely limited by their low transfer efficiencies (i.e., energy delivered to the film divided by the total energy consumption of the oven), and their very large areas (since the dwell time in the oven is fixed for most curing, and thus high line speed demands long ovens or festooning in a single extended channel). Unilaterally scanned electron beams and their limitations have before been discussed with the most severe problems lying in non-uniformity of the delivery technique (both in area and depth). In the case of the present invention, on the other hand, consider, for example, a 10 kw (20 ma, 500 keV) system working into a 0.050 inch thick jacket of an object O of 1 inch diameter, where the energy utilization is about 60 percent. Material weight is approximately 30 gm/ft, so that for a typical curing (vulcanization) dose

of 5 megarads, process rates of 240 feet/min are possible — well above the capabilities of conventional thermal continuous vulcanizers. Process rates up to several thousand feet per minute are provided by the expedient of linear extension of the curing or irradiating head or by tandem operation of several units of the type shown in FIGS. 1–3.

The system of the invention is particularly well suited for the bulk irradiation of liquids (such as in the sterilization of water) and gases (as in the sterilization of air for aseptic applications or as in radiation chemistry techniques) at efficiencies at least a factor of two above those possible with conventional radiation techniques. The cylindrical or 2π irradiation geometry is particularly effective in the high volume disinfestation of raw material, particularly where surface treatment of thick particles (e.g., cereal grains) or the bulk treatment of fine suspensions (e.g., powders) in high speed pneumatic transfer is essential.

Finally, the present invention is particularly effective for the uniform, simultaneous deposition of energy (excitation or pumping) of cylindrical, gas filled tubes or cavities. Such techniques are particularly effective for electric laser application as well as for high efficiency ultraviolet radiation production. Such practice can utilize either the normal coaxial configuration of FIG. 3 or the inverted geometry, in which the central cylindrical gun is employed to excite the surrounding coaxial gas, liquid or solid filled cavity.

Similar and other applications utilizing this geometry will also occur to those skilled in the art, and all such are considered to fall within the spirit and scope of this invention as described in the following claims.

What is claimed is:

1. Apparatus for simultaneously uniformly irradiating a substantially cylindrical elongated region with energetic electrons directed substantially radially inward toward said region along a plurality of widely different directions, having, in combination, a plurality of grid-controlled electron gun means each provided with means for generating therein energetic electron beams directed substantially radially toward said irradiation region, means for supporting the gun means at a plurality of locations disposed, respectively, along said widely different directions around said irradiation region, a plurality of electron-beam windows one associated with each electron gun means and interposed between the same and the irradiation region for passing the electron beam generated thereby into said region from the corresponding direction, each gun means and the corresponding window being elongated longitudinally of the region to provide a longitudinally extending electron beam at the region, and means for operating the electron gun means substantially simultaneously to irradiate the said region substantially uniformly from the plurality of electron gun means.

2. Apparatus as claimed in claim **1** and in which the electron gun means are disposed at successive locations circumferentially along cylindrical surface and the corresponding windows are disposed at successive locations circumferentially along a further cylindrical surface, said surfaces being substantially coaxial with said irradiation region.

3. Apparatus as claimed in claim **2** and in which said windows are circumferentially spaced sections of a cylindrical structure having non-permeable sections between successive windows, each non-permeable section being aligned diametrically with a window at the opposite side of said irradiation region.

4. Apparatus as claimed in claim **1,** further comprising means providing a gas blanket and cooling channel within said irradiation region.

5. Apparatus as claimed in claim **1,** further comprising means for drawing objects-to-be-irradiated longitudinally through said region past said windows.

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