**Aug. 24, 1965** **M. H. CROWELL** **3,202,864**

ELECTRON BEAM DEVICE HAVING DIVERGENT EMISSION ELECTRON GUN

Filed May 26, 1961 2 Sheets-Sheet 1

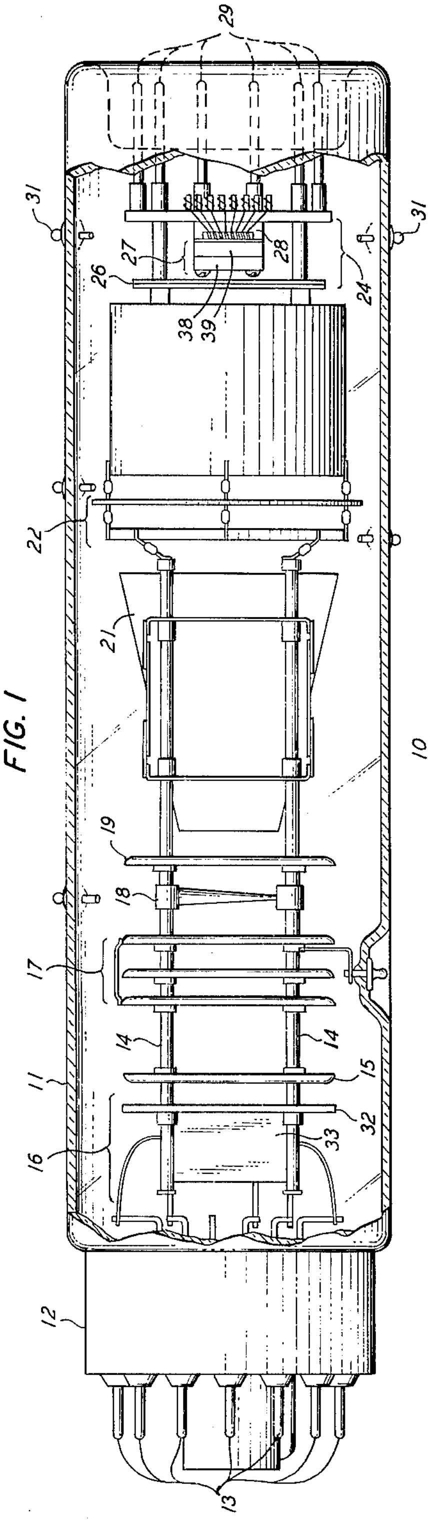

FIG. 1

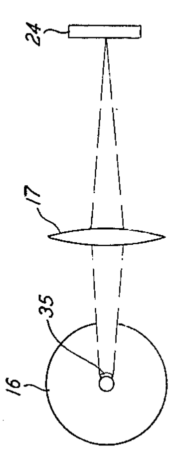

FIG. 3

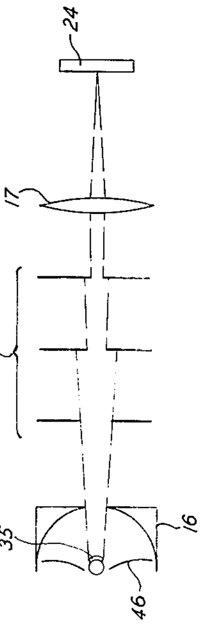

FIG. 4

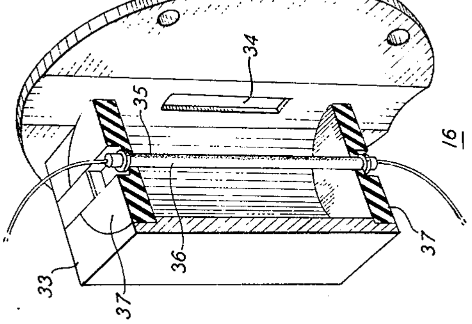

FIG. 2

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FIG. 5

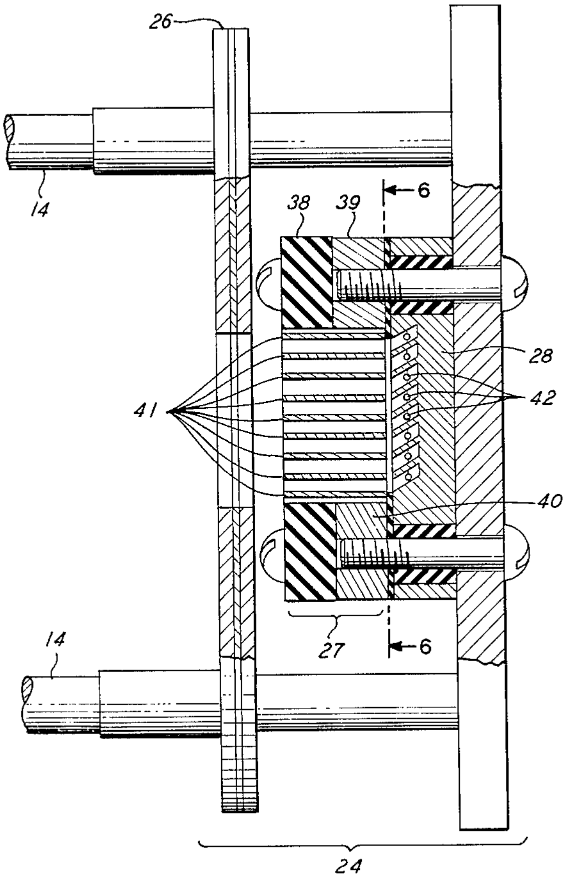
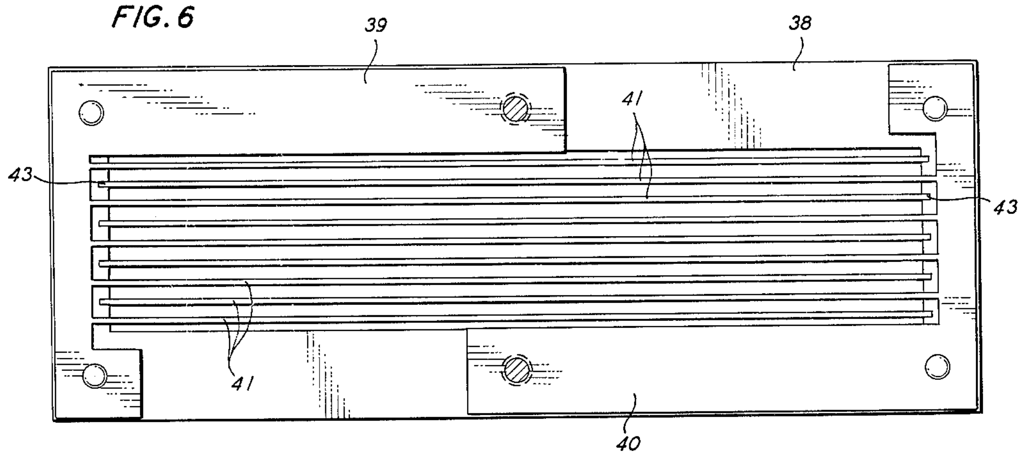


FIG. 6



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# ELECTRON BEAM DEVICE HAVING DIVERGENT EMISSION ELECTRON GUN

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9 Claims. (Cl. 315—21)

This invention relates to electron discharge devices and more particularly to electron beam tubes in which a focused ribbon-shaped beam is pulsed at a high frequency.

While the principle of the invention is applicable to electron beam tubes adapted for a variety of specific uses, it will be described herein with particular reference to an electron beam encoder tube of the type suitable for use in pulse code modulation systems. One successful type of encoder tube is the "flash" coder such as that described in United States Patent 2,713,650 to R. W. Sears. In flash coders a flat or ribbon-shaped electron beam is projected against a target assembly comprising an apertured code plate behind which is positioned a plurality of target electrodes corresponding to the various digits of a binary code. Typically, the code plate apertures are arranged in rows and columns. Each column represents a digit and is aligned with the corresponding target electrode, while each row corresponds to a different combination of digits or "level" of the code. The electron gun is aligned with the target assembly so that the plane of the ribbon beam intersects the code plate along a line parallel to the rows of apertures. When the beam is appropriately deflected the line of intersection coincides with a row and portions of the beam pass through the apertures, thereby selectively energizing the target electrodes in various combinations corresponding to the levels of the code.

As the accuracy with which signal intelligence may be transmitted in PCM systems is dependent on the number of code levels available for quantization, there have been, understandably, continuous efforts to improve the resolution of encoder tubes. However, as the number of digits in the binary code is increased, the mechanical and electrical tolerance in the encoder tube are decreased. Such tolerances are exceedingly stringent in an eight- or nine-digit tube of practical size.

One difficulty heretofore encountered in the design of high resolution encoder tubes arises from the finite thickness of the ribbon beam as it impinges on the code plate. Due to the necessarily small size and close spacing of the apertures in the plate it is essential in order to minimize encoding errors that the beam focus be as thin as possible, so that its intersection with the plate approaches a line. The performance of many electron guns in this respect is, however, severly limited by beam divergence produced by space charge forces. In addition, as the difficulties produced by space charge effects vary directly with the current density of the beam, encoding tubes heretofore known have generally operated with a relatively low beam current density, resulting in a greater number of encoding errors than would otherwise be the case.

The prior art difficulties referred to above are to a great extent due to the nature of the electron trajectories in the electron guns heretofore used in encoder tubes. Thus, for a number of reasons it has been the practice to employ electron guns which produce an axial beam crossover at a small distance from the cathode. The crossover is then imaged onto the target assembly to produce a thin line intersection. It will be recognized, however, that the image has a very definite thickness due to the space charge spreading in the region of the crossover. The beam current, therefore, is limited by the spreading which can be tolerated.

An additional factor which limits the maximum obtainable beam current and minimum obtainable beam thickness at the target is the thermal velocity distribution of the electrons within the beam. The presence of transverse components of the thermal velocities causes a modification or spreading of the beam current profile. As a result, and aside from space charge effects, at a line crossover the beam has a finite thickness and a corresponding finite current density.

In the past it has frequently been the practice to limit the beam profile by placing a slotted aperture plate at the crossover to intercept the "tails" of the distribution. The size of the slit is determined by the desired beam size at the target, taking into account any magnification associated with the focusing system as well as lens aberrations. Difficulty has been encountered, however, in extending this approach to encoder tubes capable of higher resolution due to the extreme narrowness and precision of the slit required. In addition to problems of manufacture and assembly, the slit further limits the obtainable current density of the beam.

The beam current from any electron gun is also a function of the maximum cathode loading which is consistent with a reasonable cathode lifetime. In a gun having a real crossover of electron trajectories where space charge effects are important, the electrons eventually focused on the target tend to be those emitted from a center portion of the cathode. This is so because their trajectories, being near the center of the beam, are less affected by the space charge, while those from peripheral portions of the emissive surface are more subject to spreading and consequent interception by the various beam-forming members employed. As the life of the cathode is shortened by higher loading, it is desirable to adopt other means for increasing the beam current density.

It is an object of this invention to produce a ribbon electron beam capable of being brought to a very thin line focus on a target.

A second object of this invention is to produce a high density ribbon electron beam with a minimum of space charge spreading of electron trajectories within the beam.

It is a third object of the invention to produce a thin ribbon electron beam by means of an electron gun which does not require very precise narrow apertures to limit spreading electron trajectories.

Another object of this invention is to produce a thin high density ribbon electron beam by means of an electron gun having a relatively low cathode loading.

Yet another object of the invention is to improve the performance of ribbon beam encoder tubes by providing an electron gun for forming a thin, high density beam relatively free of space charge spreading effects, without excessive cathode loading, and by providing efficient means for pulsing the beam at high frequencies.

The above-mentioned and other objects of the invention are achieved in a specific illustrative embodiment thereof comprising a ribbon beam encoder tube having an electron gun and objective lens for projecting a ribbon electron beam against a target assembly. The electron gun comprises a convex cylindrical cathode support member having an electron emissive coating on an axially extended surface portion thereof. A hollow cylindrical anode, having a beam-forming slot extending along the axial dimension thereof, is concentrically disposed with respect to the cathode. The anode slot is radially aligned with the emissive surface of the cathode, i.e., the center of the slot is substantially radially aligned with the emissive surface. The target assembly comprises an apertured code plate and a plurality of target electrodes. In addition, a beam pulse modulator, comprising a plurality of conductive strips, is positioned between the code plate and the target electrodes.

It is a feature of the invention that trajectories of the electrons diverge between the cathode and the objective lens, and converge between the objective lens and the code plate where they come to a line focus. As there is no crossover of trajectories before the final focusing of the beam, the electrons in the beam are subject to less space charge spreading than in priorly known devices of this type. However, because the beam is nowhere narrowly constricted, there is no place near the cathode to locate a conventional control electrode for pulsing the beam on and off at the sampling rate.

Accordingly, it is another feature of the invention that the pulse modulator, comprising a grating of conductive strips, is located between the code plate and the target electrodes.

It is a further feature of the invention that alternate strips of the pulse modulator are electrically connected to each other while adjacent strips are electrically insulated from each other. Thus, an electric field may be created between adjacent strips for deflecting the portion of the electron beam which passes between them. The beam current reaching the target electrodes may be pulsed on and off at the sampling frequency by pulsing the potential difference between the strips, thereby deflecting the beam so that it falls alternately on the target electrodes and on the strips.

The above-mentioned and other objects and features of the invention will be fully understood from the following more detailed discussion, taken in conjunction with the accompanying drawing in which:

FIG. 1 is a side view of a specific electron beam tube illustrative of the invention;

FIG. 2 is a perspective view showing in greater detail the electron gun assembly of the embodiment depicted in FIG. 1;

FIG. 3 is a schematic cross-sectional view of an illustrative electron gun of the type utilized in the invention;

FIG. 4 depicts a variation of the arrangement shown in FIG. 3;

FIG. 5 is a detailed side view of the target assembly of the tube shown in FIG. 1; and

FIG. 6 is a sectional view of the target assembly shown in FIG. 5, taken along the line 6—6 and showing in greater detail the ribbon beam pulse modulator.

Corresponding parts are indicated by the same reference numeral throughout the figures of the drawing.

Referring now to the drawing, there is shown in FIG. 1 a ribbon beam encoder tube **10** illustrative of the invention, comprising an envelope **11**, as of glass, evacuated during manufacture through an exhaust tubulation (not shown in the drawing) which is enclosed in a base **12** in the manner known in the art. Pins **13** extend through the base **12** for making electrical contact with various elements of the interior structure of the tube **10**, described hereinafter.

The interior structure of the tube **10** comprises a plurality of support rods **14** which advantageously are of a conductive material provided with an insulating layer or coating, thereby being usable as electrical connectors as well as being structural supports. Mounted on the rods **14** is an electron gun assembly **16** of the type employed in the invention. The gun **16** is adapted to project a ribbon-shaped electron beam towards a target assembly **24** at the opposite end of the envelope **11**. On the target side of gun **16** in beam-passing and beam-forming relation therewith are an accelerating electrode **15** and an electrostatic objective lens **17**. Intermediate the lens **17** and the target assembly **24** are deflection plates **21** for angularly deflecting the plane of the ribbon beam. Dynamic tilt correction rods **18**, as taught in my copending United States patent application M. H. Crowell, Serial No. 99,946, filed March 31, 1961, now Patent No. 3,151,270, are located between the lens **17** and the deflection plates **21**. A beam-passing shield member **19** serves to isolate the tilt-correction field from the deflection field. Also in accordance with the above-mentioned copending application, a diverging lens **22** is positioned on the target side of the deflection plates **21** to increase the sensitivity thereof. The target assembly **24** comprises an apertured code plate **26** and a target block **28**. A deflection modulator **27** is located between the code plate **26** and the target block **28** for pulsing the beam on and off with respect to the latter. Pins **29** extend through the target end of envelope **11** for making electrical contact with the target electrodes **42** which are shown in more detail in FIG. 5. The modulator **27** is connected to appropriate external circuitry by means of pins **31** which extend through the wall of envelope **11**.

The electron gun assembly **16**, shown in more detail in FIG 2, comprises a convex cylindrical cathode support member **36**, an axially extended surface portion of which is coated with an electron emissive layer **35**. Surrounding cathode member **36** and coaxial therewith is cylindrical anode, formed in the illustrative embodiment by an anode disc **32** and an anode block **33**. The cathode member **36** is held in place by insulating discs **37** which are mounted on the anode block **33**. A beam-forming slot **34** in anode disc is radially disposed with respect to the electron emissive surface portion **35** of cathode member **36** and in alignment therewith. In the embodiment shown in FIG 2 the center of the slot **34** is substantially radially aligned with the center of the emissive surface portion **35** while the edges of the slot are substantially radially aligned with the edges of the emissive surface portion.

As can be seen from FIG 3, the cylindrical symmetry of the cathode and anode results in a symmetrical radially directed electric field which is but little distorted by the anode slot **34**. Thus the trajectories of electrons leaving the emissive layer **35** are radial straight lines. The beam may be considered, therefore, to originate at a line source or virtual cathode at the axis of the anode cylinder. The virtual cathode is imaged on the target by an appropriate objective lens **17** without the necessity for an actual crossover of electron trajectories. Thus the severe space charge effects inherent in priorly used guns are avoided. In addition, as all electrons from the emissive surface **35** appear to come from the virtual cathode, a relatively low and uniform cathode loading is sufficient to produce a beam of the required density. Thus the life of the cathode surface **35** is considerably extended. In a variation of the gun **16**, depicted in FIG. 4, the required radial electric field is produced by means of shields **46**, the optimum configuration of which may be determined by techniques known to those skilled in the art.

It will be appreciated that the virtual cathode is not a perfect line even though space charge effects are reduced to a minimum. This is so because of the distribution of thermal velocities of the electrons emitted from surface **35**. In general, it can be shown that the beam size at the target is proportional to the ratio of the cathrode radius to the anode radius, and that it varies inversely with the square of the anode voltage. Thus in some applications where an extremely small beam focus is required it is desirable to include a series of apertured plates **47** between the gun **16** and the objective lens **17**, as shown in FIG. 4. The potential on each of the plates **47** is advantageously adjusted to match the space potential inside the beam. Electrons emitted from the cathode layer **35** with any appreciable transverse thermal velocity will be intercepted by the apertured plates **47**, so that practically all of the electrons focused on the target **27** will appear to come from the line source at the center of the concentric anode and cathode cylinders.

In conventional electron guns emission is usually controlled by means of an apertured control electrode positioned between the anode and the cathode. Electrons are drawn from the region of the cathode by the penetration of the anode field through the aperture of the control electrode. The penetration of the anode field, and hence the intensity of the beam, is varied by varying the voltage on the control electrode. Hence in a coding tube, for example, the control electrode is pulsed at the sampling rate thereby pulsing the beam at the sampling rate. The transconductance of this type of arrangement is strongly dependent on the size of the aperture in the control electrode. Thus, in priorly known electron beam tubes the control electrode has been situated at a real crossover of electron trajectories where it may be made very narrow. Another alternative sometimes adopted heretofore is the use of a larger control aperture covered with a conductive but electron-permeable mesh. However, the finite permeability of the mesh not only reduces the current density of the beam by direct interception of electrons, but the mesh also partially shields the cathode from the anode field. In order to mitigate the latter effect it is necessary to mount the mesh very close to the cathode surface, thus posing serious manufacturing difficulties.

In accordance with the invention the ribbon beam produced by a divergent emission electron gun is pulse modulated by a plurality of deflection plates located near the target on the side thereof facing the electron gun. The beam modulator **27** of the illustrative embodiment **10** is depicted in greater detail in FIGS. 5 and 6. It comprises a set of conductive vanes or plates **41** which are mounted edge-on to the direction of the electron beam and are aligned with the digit columns of the apertured code plate **26** and with the target electrodes **42**. The vanes **41** are positioned between the digit columns so that, in the absence of an applied voltage, the portions of the beam which pass through the code plate **26** pass unintercepted to the target electrodes **42**.

Adjacent vanes **41** of the modulator **27** are electrically insulated from each other, while alternate vanes **41** are electrically connected in parallel with each other. In the illustrative embodiment two sets of vanes **41** are provided, the separate sets being structurally integral with conductive vane holders **39** and **40**. Vane holders **39** and **40** are mounted on an insulating member **38** so that the two sets of vanes **41** are interdigital with each other. Slots in the modulator **38** engage the free ends of the vanes **41** thereby maintaining the desired spacing between them. As adjacent vanes are insulated from each other, a potential difference may be applied between them to deflect the portions of the electron beam which pass through the apertures of the code plate **26**. If the potential is sufficient the beam portions will be intercepted by the vanes, so that the beam may be pulsed on and off with respect to the target electrodes by applying a pulsed voltage of sufficient amplitude to the interdigital sets of vanes **41**. For simplicity, the sampling pulse source and the connections thereto have not been shown.

The advantage gained by means of the invention can be best illustrated by noting that in a particular encoding tube of typical design the anode voltage is about 1,000 volts. In the absence of a control electrode in the region of the cathode, the beam can be pulsed only by pulsing the full anode voltage, an obviously inconvenient expedient. A deflection modulator as described herein, however, having vanes positioned between the digit columns of the code plate, separated from each other by about .025 inch, requires but 62 volts to pulse the beam. Thus, by combining a divergent electron emission gun with a beam deflection modulator located between the gun and the target, a ribbon electron beam is produced which may be brought to a very thin line focus at a target. In addition the beam is conveniently pulsed with respect to the target by means employing relatively low control voltages and requiring no extremely narrow slits or precisely made control electrodes.

While the invention has been described with reference to specific illustrative embodiments, various modifications thereof may occur to workers skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An electron beam device comprising, in combination, a beam target, a divergent emission electron gun for projecting an electron beam toward said target, the electrons of said beam having trajectories which diverge from a virtual source, means between said gun and said target for causing the electron trajectories to converge toward said target, pulse deflection means adjacent said target on the side thereof facing said gun for deflecting said beam away from said target and onto said pulse deflection means in response to signals applied to said pulse deflection means, and means for applying said signals to said pulse deflection means.

2. An electron beam device as claimed in claim **1** wherein said pulse deflection means comprises a plurality of spaced thin conductive strips, adjacent strips being electrically insulated from each other and alternate strips being electrically connected to each other.

3. An electron beam device as claimed in claim **1** wherein said electron gun comprises a convex cathode and a concave anode spaced therefrom and concentric therewith, said anode having a beam-forming aperture radially disposed with respect to said cathode.

4. An electron beam device as claimed in claim **3** wherein said convex cathode comprises an elongated cylinder, said concave anode comprises an elongated hollow cylinder, and said aperture comprises an elongated slot having its long dimension aligned with the axis of said cathode.

5. An electron beam device as claimed in claim **1** wherein said electron gun comprises an elongated cylindrical cathode having an axially extended electron emissive surface portion, the axis of said cathode being normal to the axis of said device, and means including anode means for producing a radially directed cylindrically symmetrical electric field having an axis coincident with the axis of said cathode, said anode means having an elongated slot radially disposed with respect to the emissive surface portion of said cathode, the long dimension of said slot being aligned with the axis of said cathode.

6. In an electron beam pulse coder having beam deflection means, target means and an apertured code plate spaced therefrom, a divergent electron emission gun for producing a ribbon beam, said gun comprising a cylindrical cathode member, an electron emissive coating on an axially extended surface portion thereof, a hollow cylindrical anode member concentrically disposed in relation to said cathode member, said anode member having a beam forming slot radially disposed with respect to the emissive surface of said cathode member; and a pulse deflection modulator positioned between said target means and said code plate, said modulator comprising a grating of conductive strips and means for applying a potential difference between adjacent strips for deflecting the electron beam onto said strips.

7. The combination as claimed in claim **6** wherein each strip of said grating is mounted edge-on to the direction of said ribbon beam, said strips being aligned transversely to the plane of said ribbon beam.

8. The combination as claimed in claim **6** wherein said grating comprises two sets of flat conductive strips, said sets of strips being interdigitally mounted with each strip

edge-on to the direction of said ribbon beam and transverse to the plane thereof.

9. An electron beam device as claimed in claim 1 wherein said electron beam is deflected by, and impinges upon, said pulse deflection means when a signal is produced by said source and wherein said beam impinges upon said target in the absence of a signal produced by said source.

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