Nov. 9, 1965 R. B. GETHMANN 3,217,200

INTERNAL MAGNETIC LENS FOR ELECTRON BEAMS

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FIG. 1

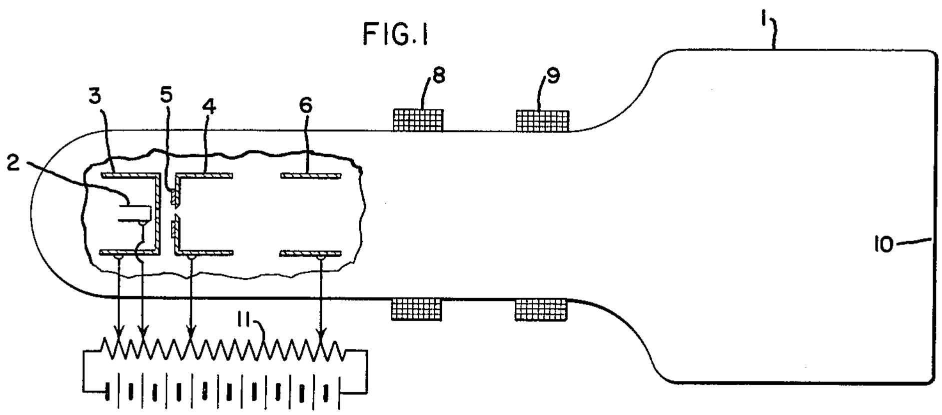

FIG. 2

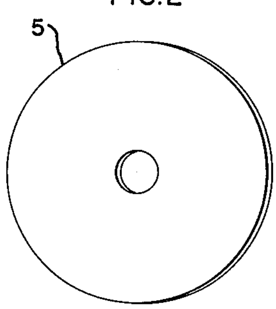

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FIG. 3

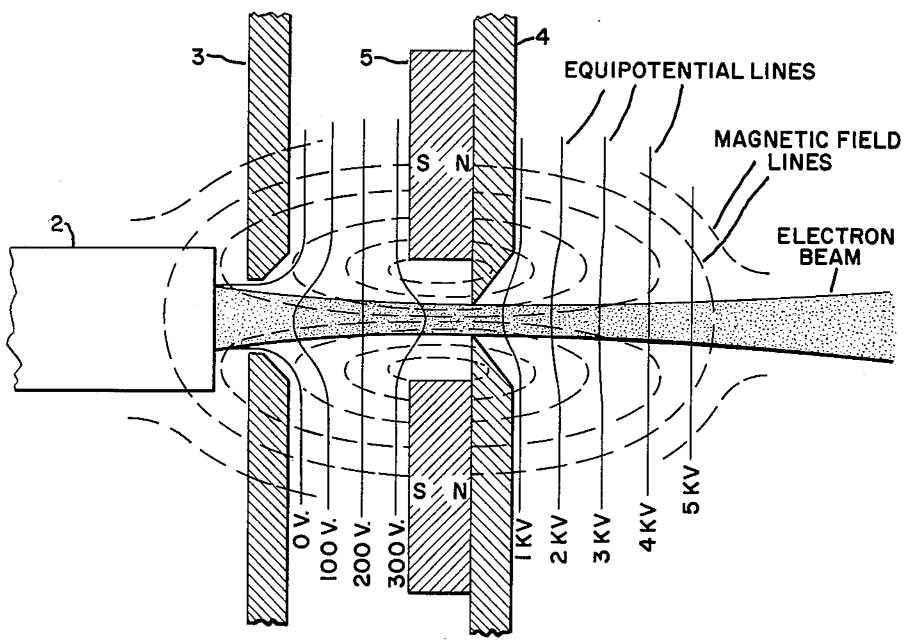
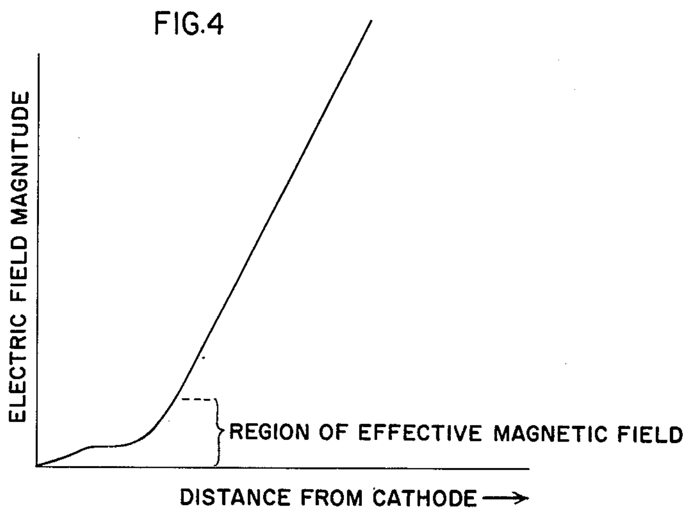


FIG. 4



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INTERNAL MAGNETIC LENS FOR ELECTRON BEAMS

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The present invention relates to electron tubes of the type wherein a beam is focused onto a surface, such as cathode ray tubes and the like, and more particularly to a novel internal magnetic lens positioned near the cathode of such tubes which provides a high electron density, restricted dimensioned effective beam source that can be readily focused by subsequent focusing mechanism onto the tube target so as to provide an impinging beam of reduced spot size and increased current.

In cathode ray type tubes it is a disadvantageous characteristic of the cathode structures that as their emission increases the area of emission on the cathode must also increase. This increases the cross sectional area and the length of the crossover region which is imaged as the beam spot on the screen or target, the crossover region normally occurring immediately forward of the cathode where the emitted electrons converge and effectively form the apex of the beam. Because of this cathode characteristic, plus limitations in existing beam focusing mechanisms, extremely small spot beams of adequate current are not readily obtained. Workers in the field of electron optics have been striving for many years to obtain a reduction in beam spot size at adequate beam currents. Such a beam spot is of course highly desirable for providing improved resolution and bandwidth of the image appearing on the target of the tube. A number of different techniques have been attempted seeking this goal. One technique is to provide a demagnifying focusing lens, either of the magnetic or electrostatic type, which demagnifies the beam and produces a beam spot size on the target smaller than the effective beam source at the cathode. For adequate demagnification, the demagnifying lens must have a short focal length and be placed in close proximity to the target. Since the deflecting mechanism must normally be confined within the limited available space between the demagnifying lens and the target, its structure is limited and only a restricted beam deflection angle is obtainable.

Another technique that has been attempted is to reduce the dimensions of the crossover region by the employment of a limiting apertured electrode placed in the vicinity of the cathode. It is the purpose of the limiting apertured electrode to admit only a portion of the electrons emitted from the cathode through a restricted opening and thereby concentrate the emitted beam into a reduced cross sectional area, thus providing a reduction in size of the beam spot that is imaged onto the target. It has been found, however, that limiting apertured electrodes are not effective for both reducing the beam spot and maintaining adequate beam current. Since a large portion of the emitted electrons strikes the metal which surrounds the aperture, a cloud of secondary electrons is formed which acts to restrict current flow through said aperture. As the cathode emission is increased, the beam current at the target remains the same or even decreases due to an increased cloud formation and restriction of electron flow through the aperture.

Accordingly, it is an object of the present invention to provide an electron lens of novel construction for use in electron tubes which obtains a beam of reduced spot size and increased current.

Another object of the present invention is to provide an electron tube of novel construction which obtains an extremely small spot size, high current beam that can be readily deflected through a wide angle.

A further object of the present invention is to provide in an electron tube a novel electron lens of minimum complexity for obtaining an extremely small spot size, high current beam.

A still further object of the invention is to provide a novel electron lens positioned in the vicinity of the cathode of an electron tube which reduces the dimensions of the beam crossover region while maintaining high current density, thereby providing at the target a reduced spot size, high current beam.

These and other objects of the invention are accomplished in an electron tube of the type in which a beam is focused onto a target or screen, and in which an electron accelerating electric field configuration is established by the grid and accelerating electrodes that cause the electrons emitted from the cathode to converge in a crossover region in the vicinity of the cathode, thereby forming the beam, the crossover region being subsequently imaged by a focusing lens system onto the target of the tube. In accordance with the invention, a thin disk permanent magnet having a small aperture therein is positioned in the vicinity of the cathode for reducing the cross sectional and longitudinal dimensions of the crossover region to thereby provide a small spot size, high current beam at the target. The thin disk permanent magnet is constructed of a high energy magnetic material, such as cobalt platinum, for providing a strong magnetic field through the aperture, said magnetic field being toroidally shaped and of restricted dimension along the longitudinal axis of the tube. The magnetic disk lens is positioned sufficiently close to the cathode so as to confine its magnetic field within the region of initial electron acceleration, and so that the magnetic field between the cathode and the disk has a relatively strong radial component. The described magnetic field tends to direct the electrons emitted from the cathode in a spiral path following the magnetic field lines through a confined area in the disk aperture, thereby reducing the cross sectional and longitudinal dimensions of crossover. Accordingly, the generation of secondary electrons is also substantially reduced, thereby limiting the formation of a beam restricting electron cloud around the aperture. The magnetic field beyond the disk is relatively weak with respect to the electric field and has little effect on the high velocity electrons, resulting in the formation of a slightly divergent, conically shaped beam which can be readily focused by a subsequent focusing lens to provide an extremely small spot size, high current beam.

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention, it is believed that the invention will be better understood from the following description taken in connection with the accompanying drawings in which:

FIGURE 1 is a schematic diagram of a cathode ray tube embodying a thin disk permanent magnet in accordance with the invention;

FIGURE 2 is an expanded perspective view of the thin disk permanent magnet of FIGURE 1;

FIGURE 3 is a schematic diagram of a portion of the gun structure of the tube in FIGURE 1, illustrating the electric equipotential lines and magnetic field lines effective in this region; and

FIGURE 4 is a graph in which the electric field strength along the longitudinal axis of the tube is plotted versus distance from the cathode along said axis.

Referring now to FIGURE 1, there is illustrated a cathode ray tube **1** comprising an electron beam emitting cathode **2**, a grid electrode **3** adjacent to said cathode, a first accelerating electrode **4**, a thin disk permanent magnet 5 supported by the electrode 4, a second accelerating electrode 6, a focusing coil 8, a deflection coil 9 and a target in the form of a phosphor screen 10. The cathode 2 may be a heated oxide coated electrode having an emissive area of approximately 20 mils in diameter. The grid 3 and first accelerating electrode 4 may be non-magnetic metal cylindrical cups, having small apertures therein, that of electrode 4 being a limiting aperture. The second accelerating electrode 6 may be a non-magnetic metal cylinder. Voltages are applied to the various electrodes of the tube 1 from a variable voltage source, shown as a tapped potentiometer 11. Voltages on the order of +300 volts and +20,000 volts are applied to the accelerating electrodes 4 and 6, respectively, to provide an electric field for accelerating the electrons emitted from the cathode in a direction towards the screen 10. A bias voltage on the order of −90 volts is applied to the grid 3 and the cathode is maintained at ground potential. The electric field configuration provided is such as to cause the electrons to converge in a crossover region near the cathode 2. The crossover region is imaged by the focusing lens 8 on to the screen 10.

The thin disk permanent magnet 5, shown in perspective view in FIGURE 2, provides a magnetic field in the vicinity of the cathode 2 which constricts the crossover region. In the prior art, absent the permanent magnet 5, it has been found that for sufficient current levels, only a limited minimum cross sectional and longitudinal dimension of the crossover region can be obtained. This may be explained by the fact that electrons emitted from the outside portions of the cathode are directed by the electric field so as to converge at crossover points closer to the cathode than do electrons emitted from the inside portions, the crossover points thereby being distributed in a direction along the longitudinal axis of the tube, forming the crossover region. Since the crossover points are longitudinally distributed, the region of crossover may be appreciated to have a fine cross sectional area of limited minimum dimension. The longitudinal distribution of the crossover points is a manifestation of spherical aberration of the beam. As the beam current is increased by increasing the emission of the cathode, the area of emission enlarges which may be seen to increase both the cross sectional and longitudinal crossover dimensions. The magnetic field provided by the disk magnet 5 acts to draw the electrons together into a constricted crossover region, thereby providing an improved crossover configuration of reduced cross sectional area and length, and one exhibiting substantially less spherical aberration. The dimensions of the constricted crossover region are such as to cause a major portion of the electrons emitted from the cathode to be projected through the limiting aperture of accelerating electrode 4, with very little secondary electron formation occurring. Accordingly, the impinging beam on the screen 10 is of reduced spot size and increased current.

The thin disk permanent magnet 5 is constructed of a high energy, high coercive force magnetic material of high temperature stability. A suitable material is a cobalt platinum alloy having a weight-percent composition of 40–50% cobalt and 50–60% platinum, heat treated at approximately 850° C., such as disclosed in Patent No. 2,622,050 entitled "Process for Heat-Treating Cobalt-Platinum Magnets" issued December 16, 1952, to D. L. Martin and A. H. Geisler. The thin disk magnet 5 provides a relatively strong toroidal magnetic field which is of restricted length along the longitudinal axis of the tube. The diameter and thickness dimensions of the disk magnet are limited so as to provide the required magnetic field of restricted axial dimension. The aperture of the disk 5 should be as small as possible and yet support a sufficiently strong magnetic field of uniform character. The disk is positioned with respect to the cathode 2 and the accelerating electric field so that the restricted magnetic field essentially lies within the region of initial accelera-

tion of the electrons, as indicated in the graph of FIGURE 4, and so that the magnetic field has a substantial radial component at the surface of the cathode and in the region between the cathode and the disk. With the magnetic field of restricted axial dimension and effective as indicated, it has a minimal undesirable magnifying action on the beam that is formed. A cross sectional view of the magnetic field configuration provided by the disk 5 is shown in FIGURE 3, which will be considered in more detail presently.

By providing a magnetic field as described, the radial component of the rearwardly extending magnetic field provides forces acting on relatively low velocity emitted electrons which cause said electrons to follow a spiral path centered on the field lines and thus be directed through the central portion of the aperature of the disk 5. The stronger the magnetic field, the tighter the spiral path. Thus, the magnetic field must be sufficiently strong so as to confine the spiral paths close to the field lines, providing constriction of the crossover region. Accordingly, there results a restricted dimensioned crossover region, restricted both in longitudinal and transverse dimensions. Further, the electrons leaving the disk aperture, which have been appreciably accelerated, will not be very much effected by any divergent action of the magnetic field in this region. The beam formed by the composite lens of the magnetic and electric fields assumes a gradual conical shape which can be readily imaged by the focusing system 8 onto the screen 10 of the tube 1 as an extremely small spot, and which substantially avoids spherical aberration effects.

In one specific embodiment the diameter of the disk 5 is ¼ inch thick, the thickness of the disk 5 is 20 mils, the diameter of the aperture of the disk 5 is 40 mils, and the spacing between the disk 5 and the cathode 2 is 40 mils. The magnetomotive force generated by the permanent magnet disk provides a flux density on the order of 400 gauss. It has been found that the aperture of disk 5 cannot be made appreciably smaller than 40 mils without introducing undesirable non-uniformities of the magnetic field within the aperture. However, the significant portion of the magnetic field for constricting the crossover region is that which passes within the central portion of the aperture of disk 5, through an area less than that of the limiting aperture of the first accelerating electrode 4, i.e., a 4 mil diameter in this case. Thus, the aperture of the disk 5 must be merely sufficiently small to support a relatively strong and uniform localized field therethrough. The primary function of the limiting aperture of the accelerating electrode 4 is to establish precisely the periphery of the crossover cross sectional area, hence block any random or scattered electrons at the fringe of the crossover. However, such limiting aperture is not required for obtaining a constricted crossover region and need not be employed in many applications.

Examining the diagram of FIGURE 3, it is seen that the grid electrode 3 and the accelerating electrodes, only accelerating electrode 4 being shown, have established an electric field configuration which accelerates the electrons emitted from the cathode 2 towards the screen, not shown, causing the electrons to converge at a crossover region near the cathode, the crossover region actually occurring within the coaxial disposed aperture of the thin disk permanent magnet 5 and the accelerating electrode 4. The magnet 5 provides a magnetic field configuration the field lines of which cut across the equipotential lines of the electric field. Thus, as the electrons are emitted from the cathode the electric field configuration draws them into the region of convergence. The magnetic field, having a substantial radial component at and immediately beyond the cathode surface, provides forces which direct the electrons into a spiral path following the magnetic field lines through the central portion of the aperture of the disk magnet 5 and through the aperture of accelerating electrode 4. It is seen that the electric field gradient is small in the region between the cathode 2 and disk 5, so that the electron velocity is relatively low and the effect of the magnetic field on these electrons is appreciable. Forward of the disk 5 the electric field gradient is large, and the effect of the magnetic field on the relatively high velocity electrons in this region is slight so that a gradually divergent conical beam is formed.

It may be appreciated that the described invention embodies principles for reducing beam spot size and increasing beam current, with wide angle beam deflection, which are widely applicable to numerous electron tubes, including various display and storage tubes. As such the invention is particularly useful for extremely high resolution and high storage capacity applications.

Although the invention has been described with respect to a specific configuration for purposes of illustration and complete disclosure, it is not to be so limited and numerous modifications may be made by those skilled in the art. For example, the thin disk permanent magnet need not be at the same potential and contiguous with the first accelerating electrode, as illustrated, but may be fixed separate from and at a different position with respect to the accelerating electrodes. Accordingly, the appended claims are intended to include all modifications that fall within the true scope and spirit of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electron tube of the cathode ray type in which a beam is focused onto a surface comprising:

(a) a source of electrons,
(b) a target displaced therefrom for receiving the electrons emitted from said source,
(c) means for providing an electron accelerating electric field for accelerating the emitted electrons away from said source in a direction towards said target, said electric field having an initial accelerating portion in the vicinity of the said source of a configuration such as to cause the accelerated electrons to converge in a crossover region,
(d) a thin disk permanent magnet having a small aperture therein positioned within said tube in the vicinity of said source at said crossover region, said disk magnet being constructed to have a radius that is no greater than on the order of three times the axial spacing between said magnet and said source for generating a toroidal magnetic field of restricted axial dimension effective in the initial accelerating portion of said electric field, said magnetic field having a substantial radial component at the emissive surface of said source for directing said accelerated electrons through said aperture to provide a constricted crossover region, and
(e) electron focusing means positioned between said disk and said target for imaging said constricted crossover region on to said target.

2. An electron tube as in claim 1 wherein said means for providing an electron accelerating electric field includes an accelerating electrode having a limiting aperture therein.

3. An electron tube as in claim 1 wherein said thin disk permanent magnet is composed of a high energy cobalt platinum alloy.

4. An electron tube of the cathode ray type in which a beam is focused onto a surface comprising:

(a) a source of electrons,
(b) a target displaced therefrom for receiving the electrons emitted from said source,
(c) means for providing an electron accelerating electric field for accelerating the emitted electrons away from said source in a direction towards said target, said electric field having an initial accelerating portion in the vicinity of the said source of a configuration such as to cause the accelerated electrons to converge in a crossover region,
(d) a thin disk permanent magnet having a small aperture therein positioned within said tube in the vicinity of said source at said crossover region, said disk magnet being approximately ¼ inch in diameter and 20 mils thick and axially spaced about 40 mils from said source for generating a toroidal magnetic field of restricted axial dimension effective in the initial accelerating portion of said electric field, said magnetic field having a substantial radial component at the emissive surface of said source for directing said accelerated electrons through said aperture to provide a constricted crossover region, and
(e) electron focusing means positioned between said disk and said target for imaging said constricted crossover region on to said target.

5. An electron tube of the cathode ray type in which a beam is focused onto a surface comprising:

(a) a source of electrons,
(b) a target displaced therefrom for receiving the electrons emitted from said source,
(c) an apertured grid electrode positioned adjacent to said source for modulating the flow of electrons from said source,
(d) an accelerating electrode having a limiting aperture therein positioned in the vicinity of said grid electrode between said grid electrode and said target,
(e) means including said accelerating electrode for providing an electron accelerating electric field for accelerating the emitted electrons away from said source in a direction towards said target, said electric field having an initial accelerating portion in the vicinity of the said source of a configuration such as to cause the accelerated electrons to converge in a crossover region,
(f) a thin disk permanent magnet having a small aperture therein mounted adjacent to said accelerating electrode at said crossover region, said disk magnet being constructed to have a radius that is no greater than on the order of three times the axial spacing between said magnet and said source for generating a toroidal magnetic field of restricted axial dimension effective in the initial accelerating portion of said electric field, said magnetic field having a substantial radial component in the region between the emissive surface of said source and said disk for directing said accelerated electrons through said limiting aperture to provide a constricted crossover region, and
(g) electron focusing means positioned between said disk and said target for imaging said constricted crossover region on to said target.

6. An electron tube of the cathode ray type in which a beam is focused onto a surface comprising:

(a) a source of electrons,
(b) a target displaced therefrom for receiving the electrons emitted from said source,
(c) an apertured grid electrode positioned adjacent to said source for modulating the flow of electrons from said source,
(d) an accelerating electrode having a limiting aperture therein positioned in the vicinity of said grid electrode between said grid electrode and said target, said limiting aperture having a diameter of approximately 4 mils,
(e) means including said accelerating electrode for providing an electron accelerating electric field for accelerating the emitted electrons away from said source in a direction towards said target, said electric field having an initial accelerating portion in the vicinity of the said source of a configuration such as to cause the accelerated electrons to converge in a crossover region,
(f) a thin disk permanent magnet having an aperture therein of approximately 40 mils in diameter mounted adjacent to said accelerating electrode at said crossover region, said disk magnet being approximately ¼ inch in diameter and 20 mils thick and axially spaced about 40 mils from said source for

generating a toroidal magnetic field of restricted axial dimension effective in the initial accelerating portion of said electric field, said magnetic field having a substantial radial component in the region between the emissive surface of said source and said disk for directing said accelerated electrons through said limiting aperture to provide a constricted crossover region, and

(g) electron focusing means positioned between said disk and said target for imaging said constricted crossover region on to said target.

7. An electron tube as in claim **6** wherein said thin disk permanent magnet is composed of a high energy cobalt platinum alloy.

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