Jan. 12, 1960 D. A. G. BROAD 2,921,214

LINE FOCUS ELECTRON EMISSION SYSTEMS

Filed April 8, 1957 2 Sheets-Sheet 1

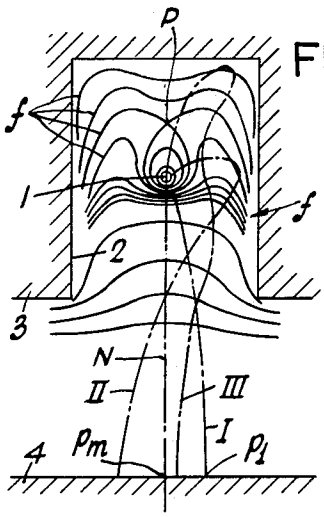


FIG.1.

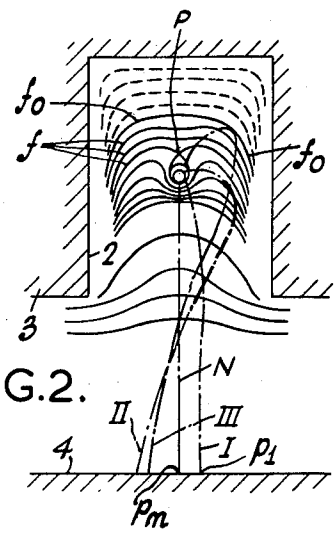


FIG.2.

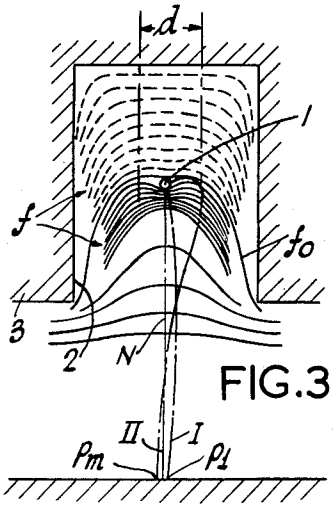


FIG.3.

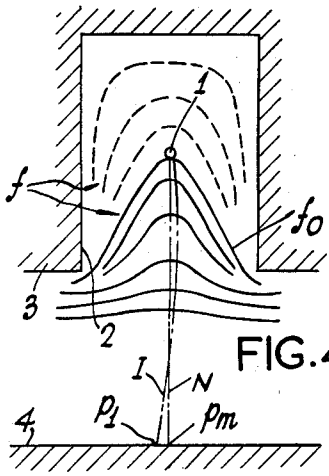


FIG.4.

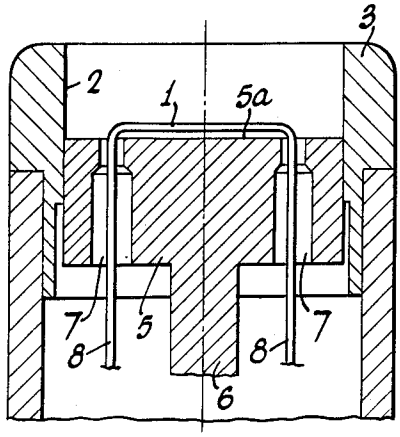


FIG.6.

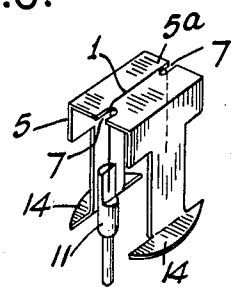


FIG.10.

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LINE FOCUS ELECTRON EMISSION SYSTEMS

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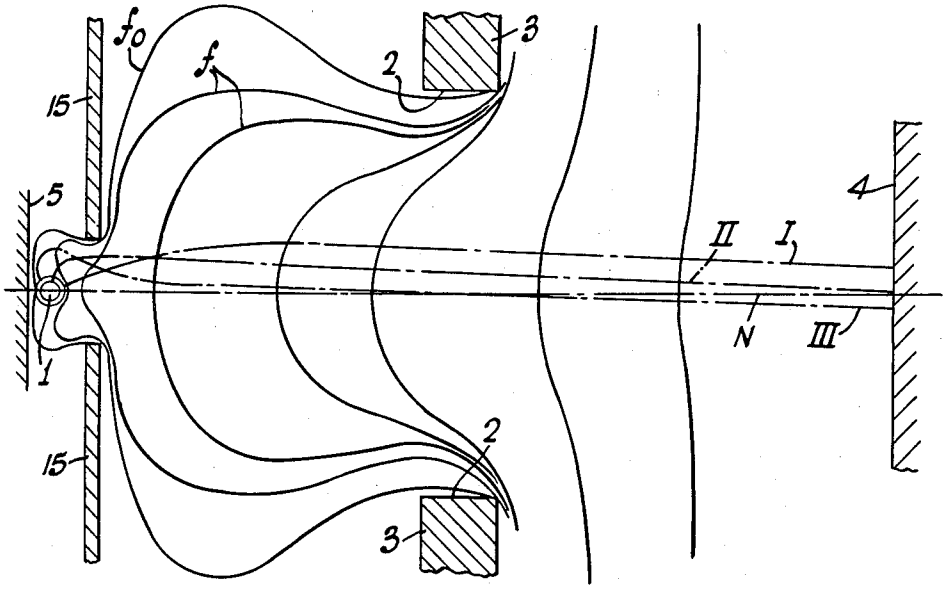


FIG.5.

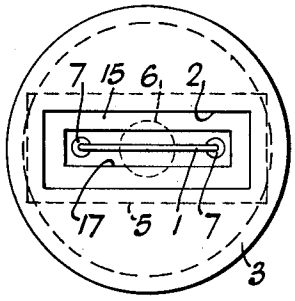
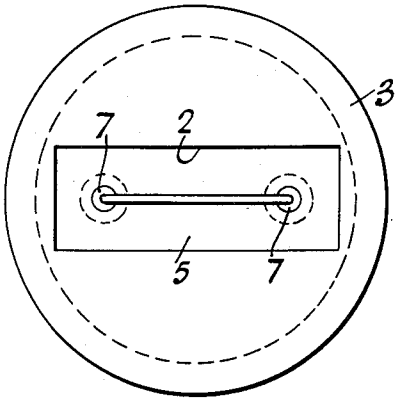


FIG.9.

FIG.7.



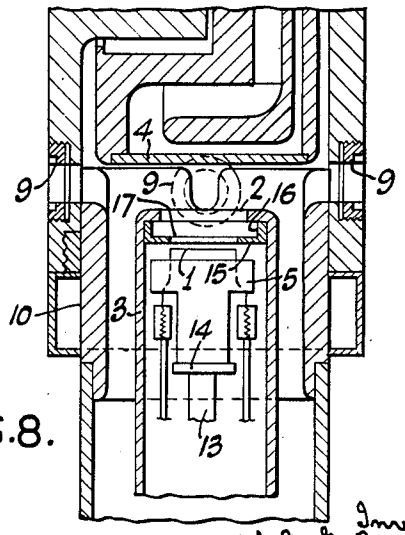


FIG.8.

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LINE FOCUS ELECTRON EMISSION SYSTEMS

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Application April 8, 1957, Serial No. 651,290

Claims priority, application Great Britain April 11, 1956

11 Claims. (Cl. 313—82)

This invention relates to line focus electron emission systems for emitting beams of electrons having a sharply defined directional characteristic, and has for an object to provide an improved construction whereby focusing of the beam can be achieved to a satisfactory degree without the need for applying high bias voltages.

Electron emission systems find application in a number of different types of apparatus, and it will be convenient in the present specification to consider the X-ray tube field, although the invention is not limited to this field. The general arrangement with which the invention is concerned is an electron gun which consists of a filament or an indirectly heated cathode located within a slot formed in a focusing hood. The hood may be at the same potential as the filament, or negatively biased with respect to it, whilst the position of the filament depthwise in the slot can vary.

In many practical cases, such an electron gun operates at temperatures sufficiently high to render the hood red hot. If, in order to achieve the desired degree of focus, high bias voltages have to be applied between the cathode and hood, the insulation between them tends to break down and cause shortcircuiting. It is an object of the invention to overcome this danger without detriment to the beam focusing.

The requirements for crystallographic X-ray tube focal spots vary in scope with the particular technique employed. Where a pinhole or slit system is used for the collimator, which is filled with radiation, a diffuse spot does not affect definition, and only represents an inefficient use of X-rays. Where, however, efficient use is to be made of the X-rays, a camera is employed in which the size of the focal spot itself determines the dimensions of the apparent source. Hence, the size and intensity distribution of the spot must be controlled. This is even more important where the diffraction patterns of single crystals are being investigated, since the shapes of the spots from small, sharply reflecting crystals are largely determined by the nature of the focal spot. A sharp focus is essential for high angular resolution.

In the drawings:

Figs. 1–4 are plots of equipotential surfaces and representative electron trajectories for an emissive cathode located in a slot in a conventional hood, and showing the changes which occur as the negative potential of the hood relative to the cathode is increased from zero (Fig. 1) to a high value (Fig. 4);

Fig. 5 is a schematic diagram of one arrangement of electron gun according to the present invention showing plots of the resultant equipotential surfaces and electron trajectories;

Fig. 6 is a longitudinal section through the hood and filament assembly of a single-slot form of electron gun according to the present invention;

Figure 7 is a plan view of Figure 6;

Figure 8 is a section similar to Figure 6 of a double-slot electron gun in a rotating anode X-ray tube;

Figure 9 is a plan of the electron gun of Figure 8, and

Figure 10 is a perspective view of a modified construction of cathode and reflector electrode.

Figures 1–4 of the accompanying drawings show, for a conventional arrangement of focusing electron emission system, the general patterns of equipotential surfaces in the vicinity of a straight line filament **1** located in a slot **2** formed in a focusing hood **3**. The slot faces towards a target or anode **4**. The figures represent experimental plots *f* of the equipotentials obtained by visual observations made on a model arranged to simulate the electric field conditions in the system. Figure 1 shows the equipotential surface pattern for zero bias on the slot **2**, whilst the remaining three figures show the effects of increasing the negative bias.

In Figure 1, the full lines *f* lying across the slot **2** show that the field behind the filament **1** is low and non-uniform, and has a saddle point P. The chain lines I, II, III show typical configurations of three main types of electron trajectory. The path marked I is that generally followed by electrons emitted forwards at angles not exceeding about 60° with a mean axis N drawn perpendicular to the filament **1**, and normal to the anode **4**. The distance between the point p_1 where the typical trajectory I strikes the target or anode **4**, and the point p_m where the mean axis N meets the target, varies rapidly with changes in slot width.

The path marked II indicates a typical trajectory for electrons emitted from the filament **1** at angles between 60° and 135° to the mean axis N. The penumbra usually associated with the spot on the target is due to electrons moving in these two trajectories. The width of the penumbra does not vary to any large extent with changes in slot width, and cannot therefore be reduced to within the limits acceptable for the above-mentioned sharp focus requirements by simple mechanical design.

The third typical trajectory III applies to rearwardly emitted electrons and is the most complex. It is also fairly sensitive to slot width.

Figures 2, 3 and 4 show the effects, in the conventional arrangement, on the equipotentials and electron trajectories of increasing the negative bias on the slot **2**. As bias is increased, the zero equipotential f_0 approaches ever nearer to the filament **1** until, in Figure 4, it lies mainly in front of it. This latter condition produces a narrow focus largely independent of the shape and position of the hood **3**. The advance of the zero equipotential surface towards the filament **1** has the effect of progressively restricting the rearward loops of the trajectories II and III until, in Figure 3, the trajectory III disappears and in Figure 4 both are suppressed entirely. It will also be noted that in Figure 3 the saddle point P of Figures 1 and 2 disappears, whilst for an appreciable part *d* of the zero equipotential f_0, approximately symmetrical about the filament **1**, the contour is substantially flat. The portion *d* constitutes, for practical purposes, the effective length of this equipotential.

In the conditions of relatively large negative bias—say about −1 to −3 kv.—represented in Figure 4, a sharp focus is obtainable. On the other hand, only a very small portion of the surface area of the filament **1**, of the order of one twentieth, is available for emission, so that, for the same beam current, the specific emission increases, leading to high filament temperatures and a high tungsten evaporation rate. Filament life is thus shortened, leading to increased operating costs and reduced reliability, whilst the need for heavier insulation at the high bias voltages imposes undesirable design

limitations. A high bias voltage generator must also be provided.

The present invention aims at enabling the sharpness of focus corresponding to the conditions of Figure 4 to be approached or obtained without the above disadvantages, and this is achieved, broadly, by inserting into the slot 2, close behind the filament 1, a single back plate or reflector electrode at zero or slightly negative potential simulating the contour of at least the effective portion of the zero equipotential f_0. The electric field pattern in the slot 2 is thus made to resemble more nearly that of Figure 3, but without requiring a high negative bias. In fact, the maximum operating bias is preferably not greater than 1% of the anode voltage.

The conditions shown in Figure 4 can be approximately simulated in a zero bias gun, by placing in front of the filament 1 a second zero potential electrode or diaphragm having a slit extending parallel to and symmetrical with respect to the filament. Figure 5 illustrates schematically such an arrangement and the resultant field configuration and typical electron trajectories. The first zero potential electrode or "reflector" is indicated at 5. It is flat, or substantially flat—corresponding to the portion d of the zero equipotential f_0 in Figure 3—and is spaced closely behind the filament or cathode 1. The second zero potential electrode is indicated at 15 with a slit formed in it at 17, whilst the equivalent of the slot 2 of Figures 1—4 is also referenced 2, although its side walls do not extend in the same plane for the full depth of the slot i.e. as far as the "reflector" electrode 5. The slot 2 is formed in the front wall of the focusing hood 3 as before. As in Figures 1–4, the equipotential surfaces f are indicated by the full lines and the typical electron trajectories by chain lines I, II, and III.

The cathode back plate or reflector 5 and the additional aperture 17 shape the electric field from the anode 4 in such a manner as to produce a slender, slightly divergent beam of electrons from the filament 1. This electron beam is brought to a focus on the anode by the lens action of the large aperture 2 in the hood 3 and forms a narrow focal line—for example, 1 mm. wide. At beam currents of 100 ma. (peak) a slight space charge effect causes a reduction of the spherical aberration of the first part of the system and improves the uniformity of the focus. The specific emission from the cathode filament 1 is reasonably uniform over the side facing the anode 4. The rear half of the filament operates in a weaker field and contributes approximately 25% of the total beam current. Thus it may be seen that the specific emission from the filament is considerably less than that prevailing in the heavily biased electron guns.

Practical embodiments of the invention will now be particularly described, by way of illustration only, with reference to Figures 6–10 of the accompanying drawings.

Referring first to Figures 6 and 7 of the drawings, a straight wire filament 1 is located in a rectangular slot 2 in a hood structure 3. The base of the slot is formed by a plug 5 carried on a stem 6 for axial adjustment within the slot, the plug being drilled at 7 for the passage, with insulating clearance, of the filament supporting legs 8 which are integral with the filament 1. The legs are anchored — preferably adjustably — at their ends (not shown) on the stem 6. The front surface 5a of the plug 5 constitutes a "reflector" electrode which simulates very nearly the effective portion d of the zero equipotential f_0 of Figure 3, especially if it is accepted that, for practical purposes in a relatively narrow slot, the contour of this equipotential is substantially rectangular. The filament 1 is spaced in front of the surface 5a by a distance, measured to the axis of the filament, approximately equal to twice the filament diameter. In one specific construction of electron gun according to Figures 6 and 7 the following dimensions were used to obtain a line focus 0.5 mm. wide:

Filament diameter	0.3 mm.
Filament length	9 mm.
Filament spacing from surface 5a	0.65 mm.
Emission current	200 ma. (peak).
Anode voltage	35 kv. (peak).
Slot width	4 mm.
Slot length	14 mm.
Slot depth set to	4.5 mm.
Slot depth (range of adjustment)	3–7 mm.
Bias on hood	½% H.T. volts.

Using the above dimensions, and the very low bias voltage indicated, elimination of penumbra was achieved in the spot focused on a rotating anode.

Figures 8 and 9 illustrate a double-slot zero bias electron gun in a rotating anode X-ray tube, a portion of the anode drum being shown at 4. Windows are shown at 9, and a water-cooled copper sleeve 10 surrounds the electron gun. A suitable construction of X-ray tube is shown in the co-pending patent application Serial No. 640,707. A cylindrical focusing hood 3 encloses a cathode filament 1 and a back or reflector electrode 5 flanged at 14 carried on a pair of supporting pillars 13 (only one is seen in Figure 8) which serve both as conductors to maintain the electrode at zero potential and as mechanical adjusters to locate it rigidly with respect to a slot 2 formed in a flat disc 3a constituting the front end wall of the focusing hood 3. The axis of the slot 2 is parallel to the axis of rotation (not shown) of the anode 4. The electrode 5 is preferably of a relatively thick refractory material such as heavy gauge molybdenum sheet, to avoid warping under heat.

In front of the filament 1 is an additional or field control electrode 15 in the form of a circular conducting plate or diaphragm supported from the hood 3 by a circumferential flange 16 spot welded to the hood 3. The plate 15 has a slit 17 cut in it so as to extend parallel to, and symmetrically with respect to, the filament 1. The plate 15 is located accurately, both as regards its spacing from the filament 1 and its plane.

In a specific construction of electron gun in accordance with Figures 8 and 9 the "reflector" electrode 5 was of molybdenum sheet, 0.20" thick, and the plate 15 of a nickel alloy known commercially under the trademark "Inconel," having a thickness of 0.018". The following dimensions were used:

Hood to anode spacing	mm.	8
Width of slot 2 in hood	mm.	8
Front of hood to front of plate 15	mm.	7
Front of plate 15 to filament axis	mm.	1
Front of plate 15 to electrode 5	mm.	1.5
Width of slit 17	inch	0.088
Length of slit 17	do	7/16

The above construction, using no bias on the hood 3, gave a very sharply defined focus on the anode 4 having a width of 1 mm., with no great variation in intensity across its width. By varying the width of the slit 17, variations of width of focus can be obtained within limits.

Figure 10 shows an alternative construction of reflector plate electrode and filament. In this arrangement, the filament 1 is spot welded to terminal pillars 11 (only one shown in the figure) by which its spacing from the reflector electrode can be adjusted, and passes through slots 7 cut in each end of a flat reflector surface 5a. The electrode 5 is of generally inverted U-shape.

From the foregoing, it will be seen that the slot 2 within which the filament 1 is located need not have flat continuous walls, nor need the zero potential "reflector" electrode 5 physically touch the opposite walls of the slot 2. Moreover, for practical purposes, this reflector electrode is only required to simultate the effective por-

tion of the zero equipotential surface f_0 in the immediate vicinity of the filament 1, so that—as is evident at *d* in Figure 3—a flat surface 5*a* is in most cases adequate for sharp focusing. The axially spaced slot 2, slit 17, and electrode 5 of Figure 8 serve to define the contour of the near-zero equipotential surfaces in the general manner illustrated in Figure 5.

The provision of a reflector electrode according to the present invention which simulates, in contour and position the contour and position of at least the effective portion *d* of the zero equipotential f_0 in Figure 3 thus enables an electron beam to be focused on an anode with a sharpness equivalent to that hitherto obtainable only by the use of high hood bias voltages but without the necessity for a high bias voltage generator or the limitations on mechanical design imposed by high voltage insulation. Closer mechanical tolerances are thus made possible.

I claim:

1. A sharp focusing electron gun assembly comprising a hood adapted to be located near an anode; a slot in the said hood; a linear cathode located in said slot parallel to the plane of the mouth thereof; a reflector electrode mounted immediately behind but not touching said cathode and simulating, in position and shape, the position and contour of the zero electric equipotential surface generated in the slot if a high negative bias were applied, in the absence of said reflector electrode, to the hood relative to the cathode; and means for maintaining said electrode and said hood at potentials relative to the cathode lying within the range from zero to a negative maximum which is small compared with the working anode potential.

2. An electron gun assembly according to claim 1 wherein the maximum value of the negative bias on the reflector electrode is of the order of 1% of the anode voltage.

3. A sharp focusing electron gun assembly comprising a hood adapted to be located near an anode; a slot in said hood; a straight cathode located in said slot parallel to the plane of the mouth thereof; a reflector electrode mounted close behind said cathode and simulating, in position and shape, the position and contour of the effective electron reflecting portion of the zero electric equipotential surface which would exist in the slot if, in the absence of said reflector electrode, the hood were highly negatively biased with respect to the cathode; and means for maintaining the potentials of the said hood and reflector electrode at a value relative to the cathode in the range from zero to a negative maximum which is small compared with the working anode voltage.

4. An electron gun assembly according to claim 3 wherein the effective slot width is sufficiently small to cause the contour of the zero equipotential surface to be approximately rectangular.

5. An electron gun assembly according to claim 3 wherein the distance of the reflector electrode behind the mouth of the slot is adjustable at will.

6. A sharp focusing electron gun assembly comprising a hood adapted to be located adjacent an anode; a slot in the end wall of said hood facing said anode; a straight cathode located behind and parallel to the plane of the mouth of said slot; a reflector electrode mounted close behind said cathode and simulating, in position and shape, the position and contour of the effective electron-reflecting portion of the zero electric equipotential surface established in said slot, in the absence of said reflecting electrode, by a high negative potential on the hood relative to the cathode; an electric field control electrode interposed between the cathode and said slot and having a relatively narrow slit extending parallel to said cathode and symmetrical with respect to said cathode and said slot; and means for maintaining the hood and both said electrodes at a potential relative to the cathode in the range from zero to a negative maximum which is small compared with the working anode voltage.

7. An electron gun assembly according to claim 6 wherein the hood is constituted by a straight hollow member having an end closure wall adapted to be located opposite the anode and having the slot formed therein, and said field control electrode is fixed in said hood behind said end wall.

8. A sharp focusing electron gun assembly comprising a straight hollow hood having a plane end wall adapted to be located adjacent an anode; a slot in said end wall; a straight cathode mounted behind and parallel to said slot and disposed symmetrically thereto; a reflector electrode located behind and close to said cathode and shaped to simulate the contour of the zero electric equipotential which, in the absence of said electrode, would be established within said hood behind the cathode by a high negative bias on said hood relative to said cathode; means for adjusting the relative positions of the said reflector electrode and the cathode; and means for maintaining both said hood and said reflector electrode at potentials relative to the cathode in the range from zero to a negative maximum which is small compared with the working anode voltage.

9. An electron gun according to claim 8 wherein the reflector electrode is adjustable for position relative to the slotted end wall of the hood.

10. A sharp focusing electron gun cathode system comprising a substantially linear cathode located behind, and parallel to the plane of, the mouth of a slot in a focusing hood adapted to be mounted adjacent an anode and to be maintained at a negative potential with respect thereto, a reflector electrode mounted close behind the cathode and simulating, in contour and position, the contour and position of the zero equipotential surface which, in the absence of the reflector electrode, would exist within the slot immediately behind the cathode when the focusing hood is sufficiently highly biased negatively with respect to the cathode, and means for maintaining the reflector electrode at a potential relative to the cathode lying within a range from zero to a negative maximum which is small compared with the operating anode voltage.

11. An electron emission system according to claim 10 wherein an additional field control plate electrode is located immediately in front of the cathode and is formed with a narrow slit extending parallel to and symmetrical with the cathode, and means is provided for maintaining zero bias potential contours within the slot to approximate to those of the field which would be established, in the absence of the reflector and field control electrodes, by a high value of bias potential on the focusing hood.

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