June 30, 1942. J. H. O. HARRIES 2,288,239

ELECTRON LENS AND DEFLECTING SYSTEM

Filed Nov. 2, 1939 4 Sheets-Sheet 1

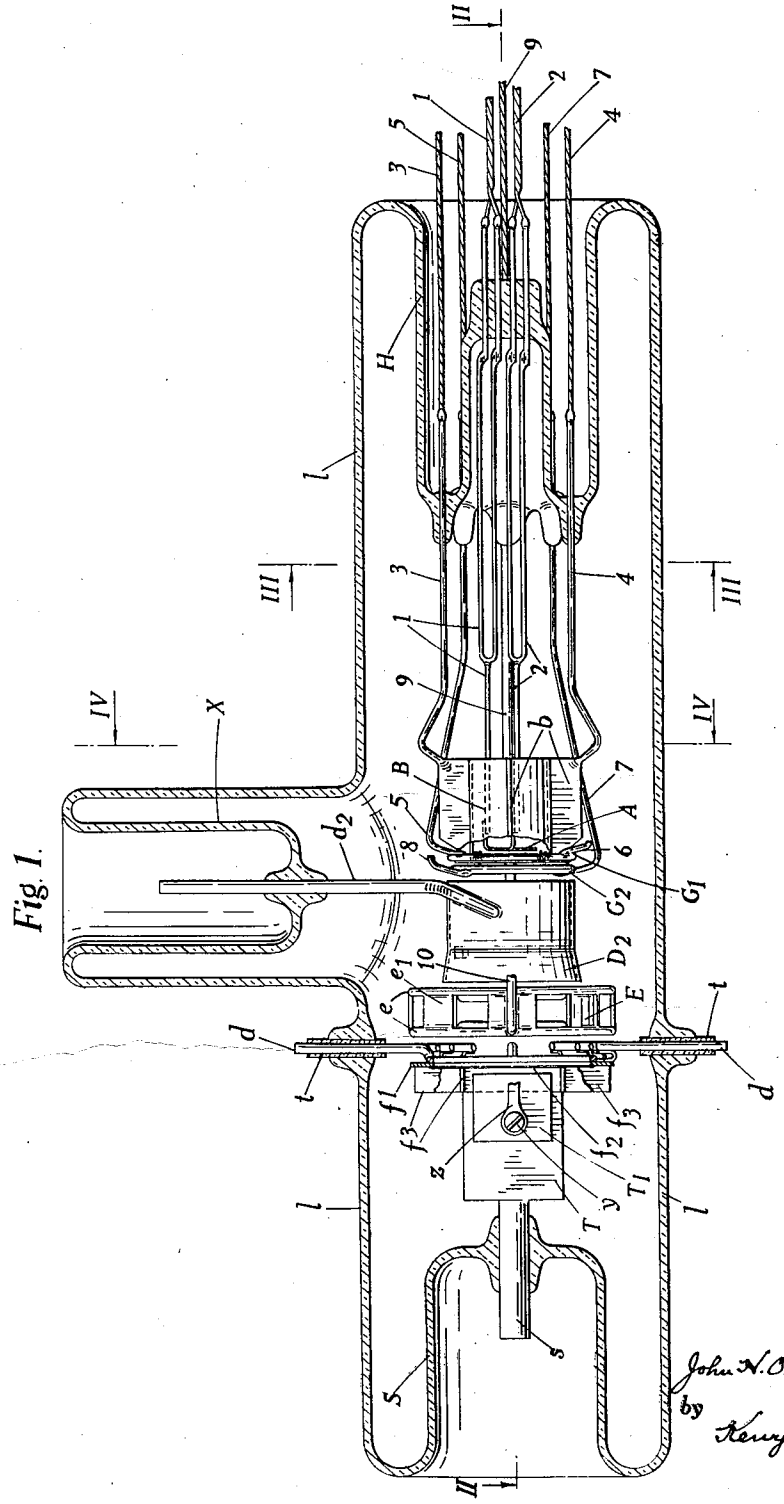

Fig. 1.

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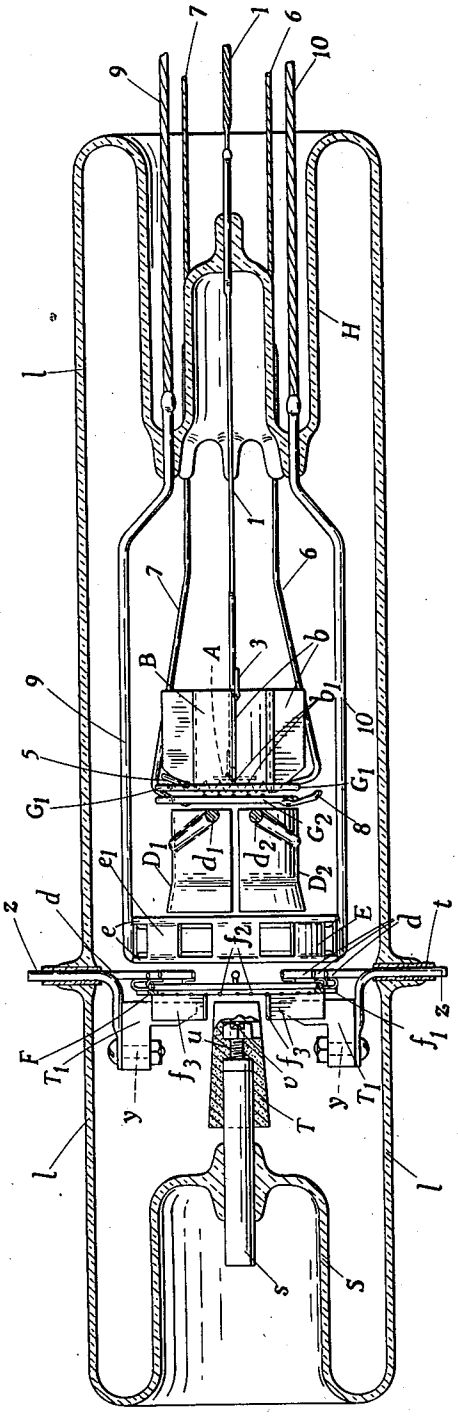

Fig. 2.

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ELECTRON LENS AND DEFLECTING SYSTEM

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Fig. 4.

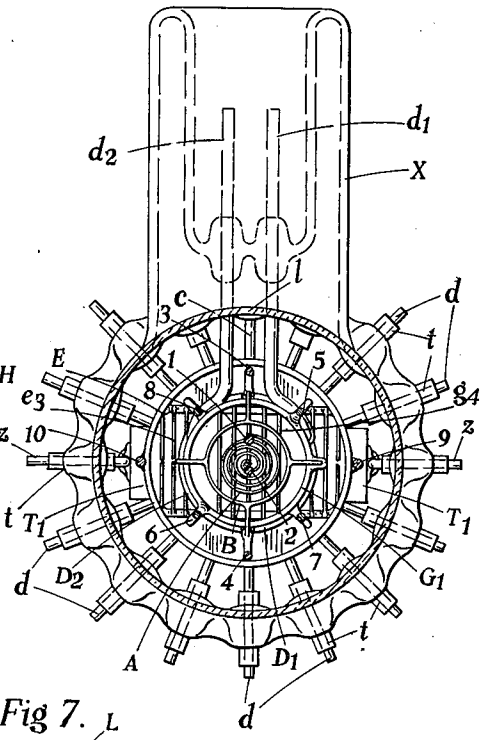


Fig. 3.

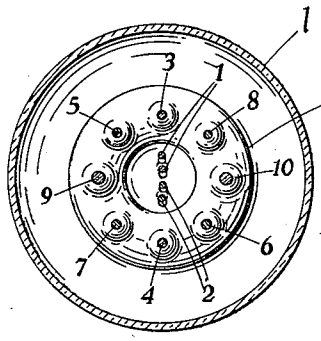
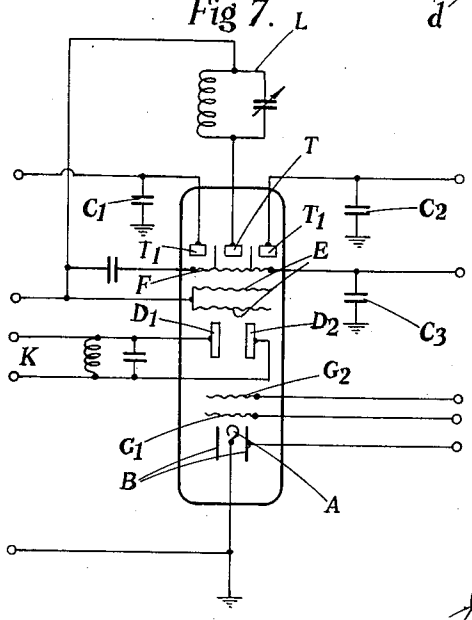


Fig 7.



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ELECTRON LENS AND DEFLECTING SYSTEM

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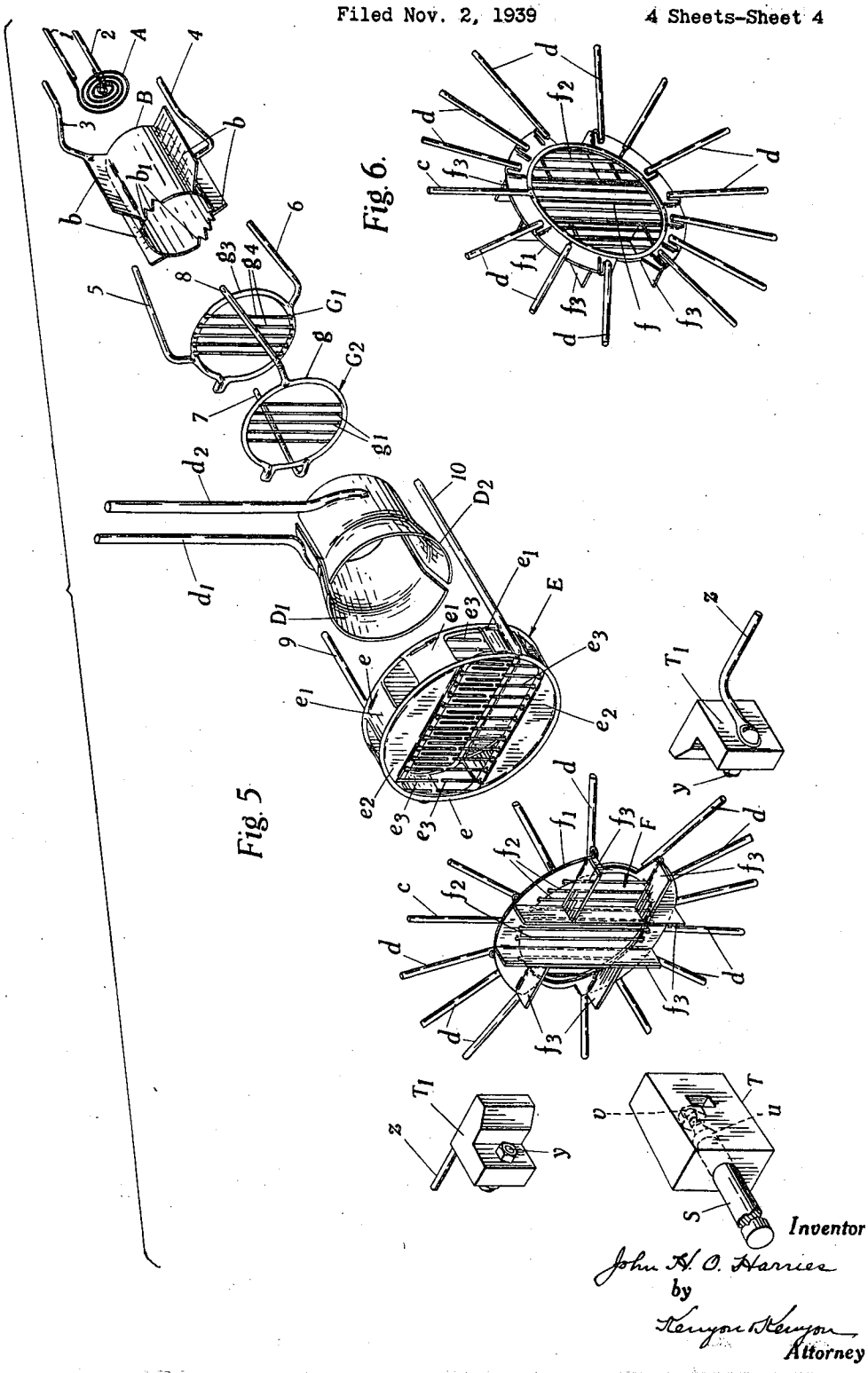

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UNITED STATES PATENT OFFICE

2,288,239

ELECTRON LENS AND DEFLECTING SYSTEM

John Henry Owen Harries, London, England

Application November 2, 1939, Serial No. 302,470
In Great Britain November 9, 1938

15 Claims. (Cl. 250—27)

This invention relates to systems for the production and control of electron streams, and particularly to lens systems and deflection systems for electron discharge tubes.

Electron discharge tubes are known in which a beam or jet of electrons is deflected over a series of contacts or the like. Such tubes may be used as relays or frequency multipliers. The beam may be deflected by input currents or voltages applied, for instance, to electrostatic deflecting plates or magnetic deflecting coils and the output current produced in circuits connected to the contacts upon which the beam impinges. Pulsating currents or amplified currents may be produced in these circuits in accordance with the movement of the beam, which is in turn proportional to the variation of the deflecting voltages or currents applied to the deflecting plates or deflection coils. Electron discharge tubes of this kind are sometimes known as "deflection valves." One particularly important application of the present invention is the production of a beam of electrons for use in a deflection valve.

There is no great difficulty in making certain types of deflection or like valves operate provided that the current in the beam is very small, and the voltage producing it is very high; but such valves will not carry appreciable power, and many will not operate efficiently with any practical value of load impedance. Many valves depending for their operation upon the movement of a beam of electrons carrying a large current, will not operate at all with such a ratio between the current in, and the voltage producing, the electrons. For efficient operation, it is necessary to use a very much higher current to voltage ratio. An example of a suitable value of such a current to voltage ratio in the beam, for efficient operation is 300 or 400 milliamperes at 2000 volts. Lower or higher powers than this may be used, but a ratio between current and voltage as high as the order of the above ratio must be maintained if efficient operation is desired.

Beams of electrons in which the ratio of current to voltage is of the above order but which are not focussed as may be effected by the present invention, may be produced by the methods described in my British Patent specification No. 380,429.

Methods are well known according to which jets of electrons of the above-mentioned unsuitable low current to voltage ratio may readily be produced and maintained. For instance, the well known methods employed in cathode ray oscillographs and the like may be used. In this type of apparatus, the beam of electrons is frequently focussed by the converging field which exists between two co-axial cylinders of different diameters which are maintained at different voltages; but it has now been found that all such known methods which have been tried fail if an endeavour is made to cause them to operate with current to voltage ratios of, for instance, the order specified above as desirable for efficient operation of deflection valves and the like. This is principally because, with the desired comparatively high ratio between current and voltage, space charge effects in the beam destroy the converging effect of these known electron lens systems.

A further very serious difficulty found in producing beams of electrons of the above-mentioned desirable orders of current to voltage ratio by known electron lens systems, is that these systems frequently operate largely by means of immersing in the flow of electrons from the cathode such large areas of positively charged metal that a very large portion of the electron stream is intercepted by such metal. This is not serious in the case of very low current jets used in cathode-ray oscillographs, and it is not unusual in such devices for the current intercepted by the electron lens system or "electron gun" to be many times greater than the current which forms the actual jet of electrons. Not only are such arrangements very wasteful of power and therefore impracticable for use in deflection valves and the like, but, particularly in the case of such valves which are intended to handle appreciable powers, it is found that the known electron lenses are destroyed or severely damaged, due to the heating effect of this waste current, and are therefore useless. For instance, if, as in the above example, a beam of electrons of 300 or 400 mA. at 2000 volts is to be produced for a deflection valve, then, should the electron lens system used intercept even 50% of this power (and most known systems intercept several times this proportion), such will be destroyed due to the fact that its construction will not allow it safely to dissipate such a large amount of energy—namely in the above example, 300 or 400 watts.

Another difficulty in the production of a beam of electrons with the desired ratio of current to voltage is that the working area of the cathode is naturally limited to some value which is not too great compared with the desired area of the beam. Unless, therefore, the positive electrode

first in the path of the beam after the cathode is very close to the cathode, sufficient current will not be drawn from it into the beam at the desired ratio of current to voltage. If, however, a suitable electrode is placed very close to the cathode, it will be found to intercept an amount of current which is much greater in proportion to the total current than the ratio of the projected working area of the electrode to the area of the stream of electrons. This is probably due to the fact that in the neighbourhood of the cathode all the electrons are not travelling in straight lines parallel to the axis of the beam. It is found that the interception of current is usually not less than about 10 to 20 per cent of the total current, and that this, besides wasting some of the available power, prevents the larger values of jet power from being obtained at all, because the proportion wasted is found to overheat and destroy the electrode which intercepts the current.

One object of the present invention is to produce a beam of electrons capable of operating with current to voltage ratios of the above-mentioned desirable order, as well as with other ratios.

It has been usual to produce a beam of electrons which is to be deflected by means of an electron converging system or electron lens. Deflecting forces have been applied in a transverse direction with respect to the path of the stream by means of magnetic deflecting coils or electrostatic plates at a part of the beam further from the cathode than the lens. Deflection valves are frequently required to operate at extremely high frequencies at which frequencies the production of a concentrated magnetic field is extremely difficult. The deflecting field in this case, therefore, has to be electrostatic. This is usually the most convenient method at other frequencies also; but it has now been found, however, that, in practice, a further difficulty arises. A reasonable current at the desired current to voltage ratio may be obtained from a cathode only if the working area of the cathode is not too small. A beam of electrons of the desired high current to voltage ratio has a cross-section which is not much less than that of the working area of the cathode employed. An electrostatic deflecting field has hitherto usually been obtained by means of two deflecting plates placed one on each side of the beam. Due to the fact that, for the above reasons, the beam of electrons cannot be much smaller in width than the width of the cathode, and because, moreover, room has to be provided in which the beam may move under the influence of the deflecting field (without being intercepted by the deflecting electrodes), the deflecting electrodes have to be widely spaced compared to their length. In practice, it is found that this spacing has to be so great that the sensitivity of the beam to deflection is small due to this reason alone. Such deflecting plates are given some mean potential with respect to which they are varied to produce deflection of the beam. It is found that, if such deflection plates are operated at a low mean potential compared to that of the nearby electrodes, a negative potential gradient will be produced between the plates; and the deflectable property of the beam of electrons will tend to be destroyed. If, however, they are at a higher potential, the space charge in the beam will itself cause a dip in potential between the deflection plates; and it is found that the result is a kind of imperfect lens action causing a very pronounced distortion in the cross-sectional shape of the beam when undeflected, and, to an even greater and more undesirable extent, when the deflection forces are applied. If, alternately, the deflection plates are spaced sufficiently closely to obtain adequate sensitivity, they will intercept an undesirably large portion of the current in the stream. If they are wider apart they will require a very high deflecting voltage in order to operate. In any case, the deflecting forces if applied in accordance with these known methods will not so much deflect the beam of a high current to voltage ratio as a whole as distort it seriously, and so prevent the desired characterization of the deflection valve from being obtained.

A further difficulty presented by the known method, (when it is endeavoured to apply it to the production of electron beams of high current to voltage ratios) is that, because the deflection is performed after the emission from the cathode has been formed into a beam (largely by passing through a high potential field), the deflection is of necessity performed upon electrons travelling at a high velocity. High velocity electrons are comparatively insensitive to deflection forces. It is found that endeavours to decelerate the electrons previous to deflection involves a very difficult problem, since such deceleration almost invariably causes the beam to lose its deflectable property by accentuating space charge effects in the beam.

It will be appreciated, in view of the above information, that a beam of electrons of the desired high current to voltage ratio cannot be either produced or deflected adequately by means of known technique.

Thus a further object of the present invention is to produce a beam of electrons of current to voltage ratios of the above-mentioned high and desirable order, as well as of other ratios, and to provide means whereby such beams may be readily deflectable. A further object is to provide that a substantial portion of the space current is concentrated into such a beam, and only a small portion wasted to the electrodes in the stream.

Still another object of the invention is the deflection of such a beam of electrons with a small expenditure of power as compared to the power in the deflected beam.

Thus, according to the present invention, an electron lens system for use in an electron discharge tube includes a cathode mounted close to a positive accelerating electrode, an electrode permeable to electrons and placed in the stream of electrons, and a further electrode so placed and of such configuration as to surround the path of the electron stream without intercepting it, and mounted between the cathode and the permeable electrode. The permeable electrode is maintained at a positive potential so as to provide a substantial positive field in a direction substantially parallel to the axis of the beam and directed along the path of the beam in the direction of the cathode, while the potential upon the electrode which is arranged partially to surround the beam is lower than that upon the permeable electrode. In order to produce a converging field acting upon the electrons drawn from the cathode by the positive potential applied to the positive accelerating electrode, a shield electrode may be provided so located and of such a configuration that it partially encloses the cathode, leaving an aperture between the cathode and the positive accelerating electrode.

The electrode partially enclosing the cathode

is conveniently maintained at earth or negative potential while the electrode which surrounds the beam may be a cylinder of appreciable length relatively to its diameter mounted so that it is coaxial with the path of the electron stream. In order to reduce the interception of current by the positive accelerating electrode, which, in practice assumes the form of a grid, a further electrode at a low potential, preferably zero or negative, is located between the positive accelerating electrode and the cathode and is, as regards its working area, of similar configuration to the positive accelerating electrode and is aligned with respect to it so as to shield it from the electrons coming from the cathode.

Then, the electrode which surrounds the beam can be sub-divided in the direction of the path of the beam so that deflecting forces may be applied to its sub-divisions, and thus the sub-divided electrode then serves as the deflecting means in the system. The deflecting voltages may be applied to the sub-divisions in push-pull.

It has already been pointed out above that a problem exists of producing a beam of electrons which remains focussed both when deflected and undeflected although the current in the beam is very large. It is found experimentally that this difficulty is only overcome by a beam-forming and deflecting system in accordance with the present invention. It is necessary from the basic principles of beam focussing that the electrostatic field through which the beam of electrons passes should have a shape which is axially-symmetric when the beam is undeflected, and of such a shape as to maintain the beam focus when the shape of the electrostatic field is deliberately distorted in order to deflect the beam.

It has been found that this double purpose is attained by the electrode system described herein, and that, for instance, the electrode surrounding the beam should be approximately at least in the form of a cylinder of appreciable length relative to its diameter, or the beam will not remain focussed both when deflected and undeflected, and when operating with a high as well as with a low current density. This is because if this electrode itself is not at least approximately axially symmetric, or if it is combined with, for instance, a permeable electrode which is not also at least approximately axially symmetric, the electrostatic field shapes resulting will not guide the electrons in such a way as to maintain a focussed beam.

It is found that a converging field is then produced between the permeable electrode and the electrode surrounding the stream which concentrates the partially converging stream of electrons from the cathode. It is also found that this desirable effect is obtained even although the current density in the beam is very high, compared with the voltage on the electrodes of the lens, and this is believed to be a feature unique to this kind of electron lens.

In order to prevent the beam configuration of the electron stream from being lost when it leaves the system described above, it may be preserved by maintaining a sufficiently positive potential gradient in the part of the beam which follows the lens system by means of a suitable anode system which may conveniently consist of the output electrodes of a deflection valve.

In order that the invention may be clearly understood and readily carried into effect, one form of electron-discharge tube in which a system according to the present invention is incorporated, together with a circuit with which this tube may be used, will now be fully described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a vertical section of the deflection valve taken through the axis of the electrodes;

Figure 2 is a horizontal section on the line II—II in Figure 1;

Figure 3 is a vertical cross-section on the line III—III in Figure 1, showing the connections to the right hand seal;

Figure 4 is a vertical cross-section on the line IV—IV in Figure 1;

Figure 5 is a so-called exploded view in perspective showing each of the electrodes in detail, but spaced apart;

Figure 6 is a perspective view of the anti-cross-field grid electrode, seen in the opposite direction to Figure 5; while

Figure 7 is a circuit diagram showing a method of connection of the valve for operation at medium frequencies.

In Figures 1 to 6, the cathode A is a flat spiral wound from a length of 150 mms. of tungsten wire of 0.5 mm. diameter, wound to a spiral of 12 mms. diameter. As seen in Figure 1, it is placed 1 mm. within the left hand end of the filament shield or hood B, which is maintained at a negative voltage with respect to the cathode of 100 volts. The electrode B is a sheet metal cylinder with four radial ribs b, and having its left hand edge formed with a number of V notches b_1.

The electrode G_2 is a positive accelerating grid maintained in the particular example at a positive voltage of 1250 volts and, as seen in Figure 1, there is an aperture or gap between it and the shield B, so that a converging field can act on the electrons drawn from the cathode A by this positive grid G_2. This grid has a nickel frame g of wire of 1.5 mm. diameter spanned by five tungsten grid wires g_1 of 0.4 mm. diameter and spaced 3 mms. apart.

The electrode G_1 is a negative grid maintained at an adjustable voltage of about 9 volts with respect to the cathode. It is in all respects similar in construction to the grid G_2, having a nickel frame g_3 and grid wires g_4 which are aligned with the wires g_1 of the grid G_2. In this way, the grid G_1 effectively shields the wires of the grid G_2 from the electrons coming from the cathode A and, as a result the positive electrode G_2 can be readily made to intercept only a small percentage of the total beam current. The grid wires g_4 are disposed in the notches b_1 of the shield B in the manner, and for the reasons, set forth in British Patent No. 521,246 dated November 9, 1938, that is to preserve the field of the filament shield B and to reduce the distance of the filament A to the grids G_1 and G_2 so as to keep up the current to voltage ratio. The wires of the electrodes G_1, G_2 do not lie in the mid-planes of the frames g, g_3 but are secured in planes respectively at the right hand edge of the frame g and at the left hand edge of the frame g_3 so that the wires of the two grids lie in planes 1.25 mm. apart. The cathode A is of smaller diameter than the frame g so that it can be mounted with its flat face at a distance of 1.25 mm. from the wires g_4.

The next electrode is the sub-divided electrode consisting of a cylinder divided into two parts D_1, D_2 and in this example maintained at the mean initial potential of 280 volts. These parts are formed of sheet nickel of 0.25 mm. thickness. The cylinder has a diameter of 24 mms. at its right hand end, but at its left hand end it is ex-

panded, as shown, to a diameter of 28 mms. The lead-in wires d_1, d_2 for the sections of the cylinder are of tungsten of 3.2 mms. diameter, and are taken out through a side branch X of the tube. The axial length of the cylinder is 20 mms. Its right-hand edge is located at a distance of 3 mms. from the wires g' of the positive accelerating grid G_2.

The next electrode E is what has been referred to as the "permeable electrode." It consists of two grids carried by circular frames e of nickel wire of 1.5 mm. diameter, these frames being connected together and spaced apart by polygonal slats e_1 of sheet nickel of .15 mm. thickness. Each frame has two segmental plates e_2, this construction being adopted to assist in the dissipation of heat. The grid wires e_3 of the two grids which lie in planes 10 mm. apart, are not continuous, but are interrupted at the middle, as seen in Figure 5 in order to assist in the dissipation of heat generated in the wires by the beam current.

The electrodes A, B, G_1, G_2, and E are each provided with two supports which are taken out through the right hand seal H of the valve. These supports, 1,2, 3,4, 5,6, 7,8, and 9,10 are shown clearly in Figure 5, and they also appear in Figure 1. Their transverse relationships are, however, shown clearly in Figure 3, in which the different supports are numbered as in Figure 5.

The next electrode F is called the anticross-field grid and has a flat circular frame f_1 of sheet nickel of 0.15 mm. thickness with vertical tungsten wires f_2 of 0.4 mm. diameter and spaced 3 mm. apart. These wires lie in a plane at a distance of 5 mm. from that of the wires e_3 of the left hand grid of the electrode E. The electrode F has a number of radial connections, shown clearly in Figures 5 and 6, in order to provide the lowest possible resistance and inductance in these connections, especially at very high frequencies; the connection c being rigidly secured to the frame f_1, and the other connections d being flexibly connected to the frame to allow the latter to adjust itself in position to some extent. As shown in Figures 1 and 4, these connections are sealed into glass tubes t, which in turn are sealed into the glass wall l of the bulb.

The electrode E is maintained at a positive potential of 2500 volts in the particular example being considered, while the cross-field grid F is maintained at a lower positive potential of 400 volts.

The frame f_1 is furnished with vanes or partitions f_3 of sheet nickel of 0.15 mm. thickness extending from the frame f_1 to the left in Figures 1, 2 and 5. There are two vertical partitions leaving a central cell or compartment between them and there are four horizontal partitions leaving two lateral cells or compartments. These compartments are designed to receive the targets or output electrodes. These consist of electrodes T, T_1 of carbon. The main target T is mounted so that its right hand end extends into the central compartment between the partitions f_3, while the side targets T_1 are mainly housed in the side compartments. The faces of these targets are spaced at a distance of 1.5 mm. from the wires f_2 of the grid F. The purpose of the wires f_2 is to screen the target electrodes T, T_1 from the effects of the preceding electrodes which the electron stream has passed so that any alterations in the voltages on those preceding electrodes due to current flowing in the load circuits shall not materially affect the current arriving at the target electrodes.

The main target T approximates to a tapering rectangular shape, and is supported on a stem s of tungsten of 6 mm. diameter. This extends into an aperture in the rear of the target, and the target is secured by the fact that the head of a steel screw u is copper welded to the stem s, and the screw u is engaged by a nut v recessed into the target T; thus, the latter is firmly supported from the right hand seal S.

The side targets are carried on supports z which are bent round and fixed to the targets by screws y. The supports z are taken out of the tube laterally in the same plane as the supports c and d of the electrode f, as seen in Figures 1 and 2.

Figure 7 shows a circuit diagram illustrating a typical method of use of the valve for medium frequency operation. The input circuit K is connected to apply its oscillating voltages to the deflecting electrodes D_1, D_2. The side targets T_1 are connected to positive voltage of 800 volts with respect to the cathode, and they and also the anticross-field grid F are connected to earthed condensers c_1, c_2, c_3. The output circuit L is taken from the main target T.

The electron stream is drawn from the cathode A which may be heated by a 12 volt supply, by the accelerating grid G_2, maintained at 1200 volts positive and is subjected to the converging field due to the cathode shield B which may be maintained 100 volts negative. The beam is deflected and concentrated by the electrodes D_1 and D_2. Then by the action of the anode system an output of double frequency appears in the circuit L. The electrode E is held at 2500 volts positive and the anticross-field grid F at 400 volts positive. The side targets T_1 are kept at 800 volts positive and the main target T is supplied from the positive 2500 volts supply.

The electrode F is maintained at a voltage lower than the lowest voltage attained by any of the targets T, T_1 in order to prevent secondary emission from any of the targets from reaching any electrode except the target in question or one of the other targets. Furthermore, the purpose of the vanes or partition f_3 of the electrode F is to prevent secondary electron emission from any one of the targets T, T_1 from reaching any other target so that secondary emission from one of the targets must find its way back to the same target. The electrode F has been referred to as an anti-cross-field grid because of this action. When the electron beam falls upon a target connected to a load circuit, the voltage on that target falls, with the result that a cross electrostatic field is set up between that target and the adjacent targets in a direction across the tube transversely to the electron stream. The vanes f_3 are provided to prevent this cross-field from causing secondary emission from any target to pass to another target. The negative grid G_1 which shields the positive grid G_2 may be kept nine volts negative or, in some cases, for the sake of simplicity, it may be connected to the cathode. Its voltage may, however, be varied and the grid used for modulating the alternating current output.

I claim:

1. A device of the character described comprising an electron emitting cathode having a substantial effective emitting area, an accelerating electrode of mesh-like configuration spaced from the cathode by a distance small in comparison with the transverse dimensions of the cathode and maintained at positive potential

relative thereto, a second electrode enclosing the path of electrons passing through said accelerating electrode, said second electrode being maintained at a mean potential positive relative to said cathode and being of substantially axially-symmetric configuration to produce a substantially axially-symmetric electrostatic field at high densities in the electron stream passing through said second electrode when the electron stream is undeflected, a further electrode permeable by electrons without substantial interruption thereof arranged in the electron path beyond said second electrode and maintained at higher positive voltage than said second electrode and an anode between which and said cathode are interposed the remaining electrodes.

2. An apparatus according to claim 1 in which a cathode shield electrode encloses said cathode to produce a converging field acting on electrons emitted by the said cathode.

3. An apparatus according to claim 1 in which said second electrode is in the general form of a cylinder of appreciable length relative to its diameter and is coaxial with the undeflected path of the electron stream.

4. An apparatus according to claim 1 characterized by a negative electrode of mesh-like configuration interposed between said cathode and said accelerating electrode with its cross members alined with the cross members of the accelerating electrode to shield the latter from electrons emitted by said cathode.

5. An apparatus according to claim 1 in which said second electrode consists of two separate and distinct sections of substantially semi-cylindrical form.

6. An apparatus according to claim 1 in which said anode consists of a plurality of mutually shielded targets of which at least one serves as an output electrode.

7. An apparatus according to claim 1 in which said second electrode is in the form of a cylinder of appreciable length relative to its diameter and is coaxial with the undeflected path of the electron stream and in which said anode consists of a plurality of mutually shielded targets, of which at least one serves as an output electrode.

8. An apparatus according to claim 1 characterized by a negative electrode of mesh-like configuration interposed between said cathode and said accelerating electrode with its cross members alined with the cross members of the accelerating electrode to shield the latter from electrons emitted by said cathode and in which said anode consists of a plurality of mutually shielded targets, of which at least one serves as an output electrode.

9. An apparatus according to claim 1 in which said second electrode consists of two separate and distinct sections of substantially semi-cylindrical form, and in which said anode consists of a plurality of mutually shielded targets, of which at least one serves as an output electrode.

10. An apparatus according to claim 1 characterized by a negative electrode of mesh-like configuration interposed between said cathode and said accelerating electrode with its cross members alined with the cross members of the accelerating electrode to shield the latter from electrons emitted by said cathode, and in which the general electrode consists of two separate and distinct sections of substantially semi-cylindrical form.

11. An apparatus according to claim 1 characterized by a negative electrode of mesh-like configuration interposed between said cathode and said accelerating electrode with its cross members alined with the cross members of the accelerating electrode to shield the latter from electrons emitted by said cathode and in which the anode consists of a plurality of mutually shielded targets, of which at least one serves as an output electrode.

12. An apparatus according to claim 1 in which said second electrode is in the form of a cylinder of appreciable length relative to its diameter and is coaxial with the undeflected path of the electron stream, and in which a negative electrode of mesh-like configuration is interposed between said cathode and said accelerating electrode with its cross members alined with the cross members of the accelerating electrode to shield the latter from electrons emitted by said cathode.

13. An apparatus according to claim 1 in which said second electrode is axially sub-divided for the purpose of applying to the sub-divisions deflecting potentials.

14. A device of the character described comprising an electron emitting cathode having a substantial effective emitting area, an accelerating electrode of mesh-like configuration spaced from the cathode by a distance small in comparison with the transverse dimensions of the cathode and maintained at positive potential relative thereto, a second electrode enclosing the path of electrons passing through said accelerating electrode and maintained at a mean potential positive relative to said cathode, a further electrode permeable by electrons without substantial interruption thereof arranged in the electron path beyond said second electrode and maintained at a higher positive voltage than said second electrode, said second electrode and said further electrode being of substantially axially-symmetric configuration to produce an electrostatic field of such shape that the electron beam is maintained in focus even when it is deflected and an anode between which and said cathode are interposed the remaining electrodes.

15. An apparatus according to claim 14 in which said second electrode is in the general form of a cylinder of appreciable length relative to its diameter and is coaxial with the undeflected path of the electron stream.

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