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FIG. 2

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MODULATION OF CATHODE RAY DEVICES

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This invention relates to cathode ray devices and has among its principal objects to achieve high sensitivity in the control of the current output of such devices. Other objects are to render the modulation effect substantially independent of the focusing and beam deflection effects and likewise independent of variations in the load on the device. Still another object is to render the focusing effect itself independent of the load. Related objects are to provide apparatus which shall be rugged, inexpensive to construct and safe to operate.

In pursuance of these and other objects there are provided within a closed evacuated vessel means for projecting an electron beam, a target element disposed to be impinged by the beam, a conductive element disposed within the vessel out of the path of the electron beam but in position to receive secondary electrons emitted from the target, means for impressing a signal voltage between the secondary collector and the target, and means for utilizing the net target current, that is, the current of the primary electron beam reaching the target as diminished by the current flowing from the target to the collector. In addition, electrodes or other means arranged to accelerate and focus the primary electron beam on the target and also to define its cross-section into a desired form are preferably included, and it is advantageous to connect the accelerating electrode directly to the collector.

It is an important advantage of the invention that the usual beam-modulating electrode or grid may be entirely dispensed with, its function being otherwise supplied. The elimination of this electrode not only simplifies the design of the cathode ray device but also greatly increases the obtainable beam current.

In use a potential difference may be applied between the cathode and the target which is substantially constant and the signal may advantageously be impressed as a voltage across an impedance connected between the target and the collector. When the circuit includes a load connected to the target the source of potential may be connected from cathode to an anode, the load being connected between this anode and the target. The cathode-target voltage then differs from the voltage of the source of supply by the voltage drop across this load. Partial automatic compensation for spurious variations in load resistance results from the fact that a change in target potential due to a change in load resistance is immediately followed by a change in collector potential and restoration of the division

of beam current between target and collector to its prior value or thereabouts so that the net load current is not seriously altered. At the same time relatively small variations in the signal voltage result in wide variations in the secondary current flowing to the collector and so in the net current flowing to the target or through the load. Thus compensation for variation in load impedance and operation in the course of modulation take place substantially independently of one another. Since the secondary electron collector may be directly connected to the accelerating anode, it is a further feature of the invention that the electric field between the accelerating anode and the main body of the beam-receiving end of the tube is not altered either in magnitude or in configuration by the modulating voltage. Furthermore, the cathode-anode voltage remains constant. Therefore, while the modulation in accordance with the invention is highly active in modifying the collector current and the net target current, it has no direct effect on the intensity, concentration or focusing of the primary beam but only a small indirect effect due to load resistance which may easily be kept within practically unimportant limits.

The invention will be more readily understood by reference to the following description of a preferred embodiment thereof taken in connection with the accompanying drawing in which:

Fig. 1 is a schematic diagram of a cathode ray tube and associated circuit arrangement embodying the invention and employed as a facsimile recorder; and

Fig. 2 is a perspective view of a part of the apparatus of Fig. 1.

Referring now to the drawing, the invention is illustrated by reference to a cathode ray device of the type forming the subject-matter of copending application Serial No. 328,816, filed April 10, 1940, and of application Serial No. 328,819, filed April 10, 1940. It comprises an evacuated envelope or tube 10 containing a cathode 11, a beam-defining anode 12, an accelerating anode 14, a pair of beam-deflecting electrodes 15 and a beam-receiving target element 16 mounted at the end 17 of the tube which is remote from the cathode. This beam-receiving target 16 may comprise a plurality of discrete conductors 18 arranged in a row and extending through the tube wall 17. These conductors may advantageously be spaced about 0.01 inch apart, the cross-section of the exposed tip of each being of the order of 0.0015 inch square. The beam-receiving end of the tube, which may advanta-

geously be flattened out into the form of a blunt wedge with the target element running lengthwise of the long dimension thereof, may be lined with a conductive coating 19 such as that commonly known as "aquadag" or the like. To assist in visual adjustment of focus of the beam on the target element, fluorescent material may be spread on the glass between the exposed inner portions of the target conductors.

A simple and suitable construction for this target element forms the subject-matter of application Serial No. 328,819, filed April 10, 1940. Briefly, the individual conductors 18 are open loops embracing a rod-shaped support 23 of insulating material, such as glass. The support bearing its conductors is sealed into the end wall 17 of the tube, for example into a thickened boss 24 of the end wall, with the tips 25 of the loops exposed on the outer surface of the tube and to the outside air and a portion 26 of each loop intermediate its tips exposed to the interior of the vessel. An elongated conductor 27, for example a metal strip, may with advantage be placed inside of the inner exposed portions of the loops 18 but insulated from them, running parallel with the axis of the loop support 23 and connected to ground to serve as a collector for electrons, primary or secondary, which may find their way between the conductor loops. As a convenience in securely mounting this conducting strip in its proper position the supporting rod may advantageously be provided with a longitudinal channel 28 in the bottom of which the strip may be fixed as by delicately fusing the channel walls and allowing them to flow over the edges of the strip 27.

The target element 16 as a whole may advantageously be constructed by winding the supporting rod 23, which has previously been channeled and provided with the strip 27, with a coil of bare wire of rectangular cross-section, securely anchoring the ends of the coil, sealing the rod bearing its coil into the boss 24 of the end wall of the tube in a manner to leave the channel 28 and the strip 27 and the part 26 of the coil which overlies them exposed to the interior of the vessel, and finally grinding away the exterior surface of the vessel wall or boss to sever each turn of the coil and so convert the coil into a plurality of open loops with their tips flush with the outer surface of the vessel. The grinding may advantageously be carried out in a manner to provide two flat faces 29 separated by a ridge 30 of glass, with one row of loop tips 25 exposed in each face. The resulting construction is shown to an enlarged scale and in detail in Fig. 2.

It is contemplated that the tube may be utilized in various combinations and loaded in various ways. For example, it may be employed as a facsimile printer for forming impressions corresponding to receive image signals on a suitable medium. Such an arrangement is illustrated in Fig. 1, where an electrosensitive sheet 35 of paper or tape or the like is mounted on pulleys or rolls 36, which may be driven by any suitable mechanism, with its flat portion immediately adjacent to one of the ground faces 29 of the exterior wall of the vessel and in light contact with one row of loop tips 25 of target conductors. The portion of the electrosensitive tape 35 which contacts the row of target conductor tips is immediately backed by a substantially sharp edge of a wedge shaped or knife-edge shaped anode 37.

A battery 38 or other source of operating potential is provided to supply energy to the electrons of the cathode beam and project them on

the target 16. For this purpose the negative terminal of the battery 38 is connected to the cathode 11 and the positive terminal to the external knife-edge anode 37. It is preferred to connect the anode 37 to ground leaving the cathode at a negative potential, since parts of the operator's body necessarily come close to the target and the anode in the course of operation of the device, and it is deemed a safeguard from possible danger to ground those portions of the apparatus which are most likely to be touched.

The beam-defining anode 12 may advantageously contain a rectangular aperture 13 with its long axis perpendicular to the axis of the loop-supporting rod 23; that is, parallel or substantially parallel to the plane of any one of the open loops 18. This beam-defining anode 12 and the accelerating anode 13 may be connected to suitable potential sources and may be mounted at such positions with respect to each other and to the cathode as will permit the two electrodes together to operate, in accordance with the principles of electron optics, to direct an electron beam 20, for example, a beam of narrow rectangular cross-section, on the target 16. In the drawing no attempt has been made to depict the paths of the beam electrons with precision, but only to indicate their origin at the cathode, the restriction of the beam cross-section by a suitable electrode, and their impact on the target 16.

Any desired form and arrangement of the beam-defining and accelerating anodes which projects a narrow beam and focuses it on the target may be employed. For a full discussion of the principles underlying the construction and disposition of electrodes of the type shown and the choice of their operating potentials, reference may be made to United States Patent 2,217,197.

In the example shown in the figure, the beam-defining anode 12 is supplied with operating potential by a connection to a tap on the battery 38, whereas the accelerating anode 14 is directly connected to the conductive lining 19 which in turn is connected through a battery 45 and a constant resistor 46 to the external knife-edge anode 37 or, if the anode 37 is grounded, to ground.

Lateral deflection of the cathode beam along the row of target conductors may be secured in any desired manner, for example, by deflecting plates 15 to which a sweep voltage of appropriate wave form is applied. Such a voltage may be derived locally with apparatus associated with the tube or it may be received from a distant point and applied to the deflecting electrodes after appropriate amplification. Apparatus for this purpose is indicated by the block 44.

The path through which a modulating signal is supplied to the receiver tube may advantageously include an amplifier device, for example a triode 47. The incoming signal may be impressed across a resistor 51 to the terminals of which are connected the cathode 48 and control electrode 49 of the triode 47. The anode 50 of this triode is connected through a source of voltage, for example, a battery 52, to one terminal of the resistor 46, the opposite terminal being connected to the cathode 48 and also to the external knife-edge anode 37 of the cathode ray device. A bias battery 53 or the equivalent may be connected in the circuit of the control electrode 49 of this amplifier tube to adjust the anode current as desired; for example, to adjust the anode current to zero or some stipulated small value for a zero input signal voltage.

In operation the battery 38 may be selected or

adjusted to provide a cathode-anode voltage for the cathode ray device sufficient to cause the electrons of the primary beam 20 to impinge on the target element with comparatively high velocities and give rise to the emission of secondary electrons from the target element 16 due to bombardment thereof by the primary electrons of the cathode beam in substantial amounts. The secondary emission ratio need not by any means be the highest of which the target element is capable and an advantageous value of this ratio is unity or thereabouts. In an actual test a target voltage of the order of 5000 volts was employed with satisfactory results.

At the same time the battery 45 may be adjusted to a voltage such that all secondary electrons emitted from the target conductors drift toward and are collected by the conductive lining 19. With a secondary emission ratio of unity this results in the flow of zero current through the electrosensitive tape 35 to the external anode 37. A preferred adjustment is that at which the conductive lining 19 is maintained at or slightly above a threshold collection potential which in this case is the potential of the target element which, in turn, is substantially equal to the external knife-edge anode voltage in the absence of a voltage drop through the electrosensitive tape 35. The actual voltage of the battery 45 is, of course, determined in part by the magnitude of the drop across the resistor 46 due to the steady plate current of the tube 47 which it must compensate.

If, now, a signal voltage be impressed upon the input resistor 51 of the amplifier tube 47, current will flow in the anode circuit of this tube, resulting in a voltage drop across the resistor 46, and the conductive lining 19 of the cathode ray tube will fall below its previous value by the amount of this drop, and so below the threshold collection potential. This will reduce or reverse the electrostatic field between the target 16 and the conductive lining 19 so that the collection of secondary electrons is reduced or impeded. In such case, the current of the primary beam 20 will flow through the electrosensitive paper 35 to the external knife-edge anode 37 substantially undiminished by secondary electron emission, to leave impressions on those parts of the electrosensitive paper which are contacted by tips 25 of the target conductors 18 impinged by the cathode beam. Thus a variation in the signal voltage impressed on the amplifier, by varying the potential of the conductive lining of the cathode ray tube with respect to the target potential, varies the secondary electron collection ratio and therefore the net current flowing through the electrosensitive paper to the external anode and produces impressions on the paper of greater or less density according as the signal amplitude is high or low.

Modulation of the net beam current and therefore of the density of impressions on the paper after this fashion is very sensitive. Without definitely subscribing to any particular theory this is believed to be due to the fact that when the potentials are such that substantially all the secondaries are collected by the lining 19 but reach it with low velocities of a few electron volts, a reduction in the lining potential slightly in excess of this number of volts causes all electrons approaching the lining to turn back before reaching it. It is then somewhat below the threshold value for collection. This change is reflected in a change in the net current through the target 16

from zero to full value. As a practical matter it has been found that a potential change on the lining 19 of the order of one per cent of the cathode-anode potential is sufficient to reduce the current flowing through the target conductors and the sensitized paper from its full beam current value to zero, even with a paper whose resistance between a target conductor tip and the anode is of the order of 100,000 ohms.

Instead of adjusting the collector potential above the threshold collection value, the initial adjustments of the apparatus may of course be made in any other desired manner. For example the collector potential may be adjusted to be below the threshold value in the presence of a signal or an auxiliary adjusting voltage of a magnitude equal to the signal impressed across the resistor 46.

The above description of operation is based on the assumption that the signals the apparatus is destined to receive are printing signals. However, by merely interchanging the connections of the input terminals of the signal receiver device 47, or producing a phase inversion in any convenient way, the apparatus can be arranged to cause full beam current to traverse the sensitized tape 35, and therefore to print, when the signal is zero, and to collect all secondary electrons emitted from the target and cease printing when the signal voltage attains its maximum value.

In order to maintain a high potential on the beam-receiving target element and therefore a high impact velocity of the primary electron beam, it is desirable that the resistance of the electrosensitive paper 35 between each target conductor tip 25 and the knife-edge anode 37 which contact the paper on either side be comparatively low. To this end such electrographic recording papers, which usually contain an electrolytic substance, are sometimes moistened prior to use. Under favorable conditions the voltage drop across the paper from a single conductor tip to the knife-edge anode, due to a full beam current of 500 microamperes or so, the cross-section of the conductor being of the order of 0.0015 inch square, and the paper of the order of 0.002 inch thick, may be of the order of 50 volts which is inconsiderable in comparison with the 5000 volts or so which may be impressed between cathode and external knife edge. However, it may occasionally happen that, whether due to incomplete impregnation with the electrolyte or imperfect moistening or for other causes the resistance of the paper between the target conductor tip and the external knife-edge anode may be much greater, resulting in a voltage drop several times as great. Under these conditions, if the potential of the conductive lining of the cathode ray tube were to remain constant, the secondary electron collection ratio would be altered due to the altered electrostatic field between the target and the lining, and, therefore, by reason of the correspondingly increased collection of secondaries, the net current through the paper would be reduced and the density of the impression diminished. For example, a change, due to random paper resistance increase, from a 50-volt drop through the paper to a 100-volt drop, resulting in a target potential reduction of 50 volts, might well result in a change in the net current through the paper from its full value to zero. On the other hand, assuming full beam current to be flowing through target and paper, random reduc-

tions in paper resistance have practically no effect on the current.

The circuit arrangement of the invention provides partial automatic compensation for this tendency, since the increased secondary electron current will flow to ground through the resistor 46, producing a voltage drop across this resistor and, therefore, reducing the potential on the conductive lining 19 until the secondary electron collection ratio is at least partially restored to its original value. This readjustment will take place substantially instantaneously so that no great reduction in the intensity of the impressions on the electrosensitive tape is visible.

Moreover, this automatic compensation for variations in load resistance takes place entirely independently of the modulation, since, the ohm value of the resistor 46 being constant, there is no interaction between the voltages across it due to the plate current of the triode 47 and those due to the flow of secondary emission current to ground.

It will be observed that all special modulating electrodes are dispensed with in the novel tube. This by itself results in a very substantial increase in the available beam current over that which may be produced when the usual beam-modulating electrode is included in the tube in the path of the beam. Furthermore, the cathode-anode voltage remains constant at all times, and the cathode-target voltage remains equal thereto except for the relatively unimportant voltage drop across the load. This greatly adds to the invariance of the electron impact velocity on the target. In addition, the accelerating electrode 14 is directly connected to the lining 19 and thus the electric field in the region between this electrode and the target 16 remains unaltered as the potential of the lining is varied in the course of the modulation cycle, so that acceleration and focusing of the primary beam 20 are substantially independent of the modulation in accordance with the invention.

The arrangement shown schematically in Fig. 1 has been found in practice to operate successfully. However, it is not believed to be essential that the conductive lining be a single unbroken conducting surface and identical with the secondary electron collector. On the contrary, this lining may be subdivided into two or more electrically separate parts, one part serving principally as an electric shield and another part serving principally as the collector of secondary electrons. Likewise, it is within the spirit of the invention and scope of the appended claims that a separate electrode be employed as the collector of secondary electrons. For example, the conductive strip which underlies the interior of the exposed portion of the loops, and which is shown to be grounded in Fig. 1, might conceivably be employed for this purpose. Similarly, some other special electrode might be placed within the envelope adjacent the target but out of the path of the primary beam to serve as a collector of secondary electrons.

The apparatus has been described as including beam-deflecting and focusing elements whose operation is based on electrostatic principles. It is equally within the spirit of the invention and the scope of the appended claims that either beam deflection or focusing, or both, should be accomplished electromagnetically by the use of deflecting coils and focusing coils in well-known manner. Likewise, the electrosensitive paper has been described as an illustration of a system in which

the net current of an electron beam, i. e., the beam current diminished by the secondary emission current, is utilized as such by passing through a load impedance. In the case shown, this load is external to the cathode ray tube and subject to variations, but many of the advantages of the invention may equally be secured with a load impedance of constant value or with a load impedance built into and integral with the cathode ray tube structure itself.

What is claimed is:

1. In facsimile reproducer apparatus, a cathode ray device comprising a closed insulating vessel, an array of target elements within said vessel, means for projecting a beam of electrons upon said target elements in succession, an external electrode, an electrosensitive web-like element in contact with said external electrode, and conductors extending through the wall of said vessel from said target elements respectively and having their exterior terminals aligned with each other and with said external electrode and spaced from the latter to form a gap therebetween for receiving said web-like element in electrical contact with said external electrode and said conductors, a conductive circuit connection from said target elements to said beam projecting means including in series said external electrode, an area of said web-like element and a source of voltage, said source maintaining said target elements at a higher potential than said beam-projecting means and such that secondary electrons are emitted by said target elements under impact of said beam, an auxiliary electrode near said target elements, a source of variable electromotive force connected to said auxiliary electrode, and means for causing said source of variable electromotive force to vary between a value which causes secondary electrons from said target elements to flow to said auxiliary electrode in sufficient amount to prevent current flow through said web-like element and a value which permits substantial current to flow from said target elements through said conductive connection and said web-like element.

2. In facsimile reproducer apparatus, the combination of a cathode ray device comprising a closed insulating vessel, a target element extending through a wall of said vessel, means for projecting a primary beam of electrons upon said target with energies sufficient to cause the emission of secondary electrons from said target, an anode disposed externally of said device in position to receive current of said beam passing from the externally exposed portion of said target, a web-like element of electrosensitive material disposed between said exposed portion and said anode in position to be activated by current of said beam passing from said target to said anode, a return path from said anode to said beam-projecting means, a collector disposed out of the path of the primary beam within said vessel, and in position to collect secondary electrons emitted from said target on bombardment of said target by said beam, and means for impressing a signal on said collector to modify said collection of secondary electrons and hence the current traversing said web-like element in accordance with said signals.

3. The combination of a cathode ray device comprising a target electrode, means for projecting a beam of electrons upon said target with energies sufficient to cause the emission of secondary electrons from said target, an electro-

sensitive web-like element connected to said target, a circuit connection including a source of steady voltage from said web-like element to said beam-projecting means, a collector electrode, means including an impedance element connected between said collector electrode and said source to maintain the collector potential below the threshold value at which collection of secondaries commences, thus causing full beam current to flow through said web-like element substantially unchanged by variations in the resistance of said web-like element, and means for impressing a signal voltage across said impedance element to raise collector potential above said threshold value and cause collection of secondary electrons to alter the current traversing said web-like element in accordance with said signal.

4. The combination of a cathode ray device comprising a closed insulating vessel, a target

5 element extending through a wall of said vessel, the interior surface of said wall adjacent said target being provided with a conductive lining, means for projecting a beam of electrons upon said target with energies sufficient to cause the emission of secondary electrons from said target, an electrosensitive web-like element in contact with the externally exposed portion of said target, an external anode contacting said web-like element, a return path including a source of steady anode voltage from said anode to said beam-projecting means, means for maintaining the potential of said lining at a value such that secondary electrons are not collected by said lining, and means under control of a signal voltage for varying said lining potential between said value and a value at which secondary electrons are collected by said lining in substantial numbers.

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