Aug. 19, 1952 H. M. WAGNER 2,607,861

SPACE CHARGE REACTION DEVICE

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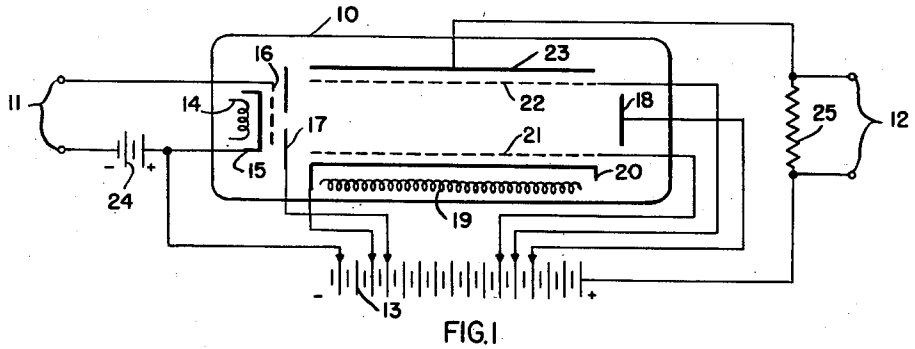


FIG.1

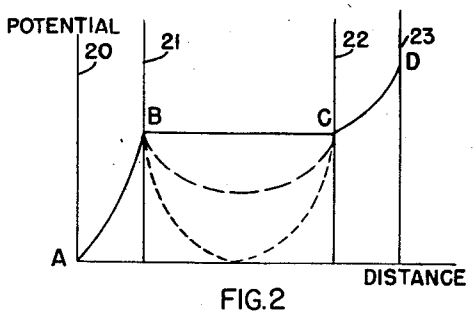


FIG.2

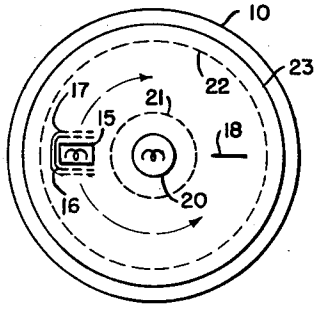


FIG.3

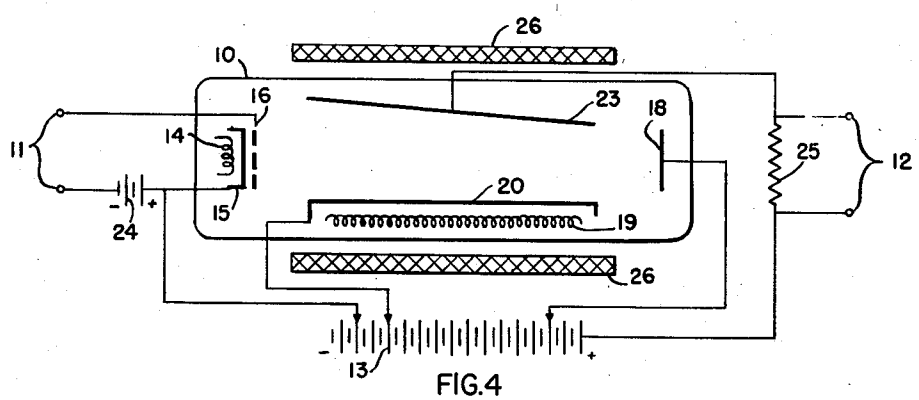


FIG.4

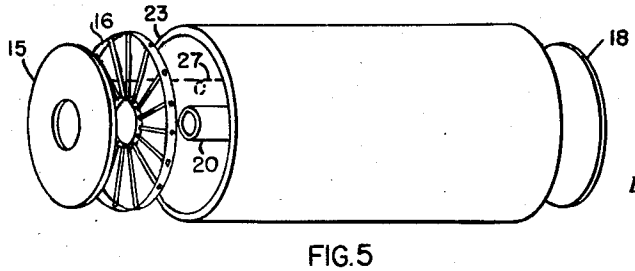


FIG.5

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SPACE CHARGE REACTION DEVICE

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The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment of any royalty thereon.

This invention relates to electron relay or amplifying tubes. In particular, it relates to electron tubes of a type wherein one electron stream is employed to control the flow of electrons in another electron stream. Particularly, the invention relates to a space charge reaction type of electron tube wherein an electron stream of small current is employed to control an electron stream of greater current.

A variety of vacuum tube arrangements have previously been proposed wherein two electron streams have been arranged to interact so that changes in one of the streams produce larger corresponding changes in the other electron stream. Most of these proposed devices, while producing some measure of control, have generally been ineffective to control a stream carrying relatively large currents.

A purpose of these attempts to control one electron stream by another electron stream is to avoid the use of a control or grid electrode so that the detrimental capacitive and inductive effects of the physical control element may be avoided. However, so far as is known, these attempts have for one reason or another proved of little value, particularly in producing a control of relatively large currents, which is the particular case where the reactance effects of physical grid elements are detrimental.

It is, accordingly, an object of the present invention to provide an electron relay of improved form wherein a first electron stream is controlled by a second electron stream which avoids some of the disadvantages and limitations of prior art proposals.

It is also an object of the present invention to provide a space charge reaction tube wherein an electron stream of small current density is utilized to control a second electron stream of larger current density.

In accordance with the present invention, a space charge reaction device is comprised of means for producing a first electron stream having a predetermined velocity characteristic, which characteristic comprises a region of normally constant velocity. Means are also provided for controlling the velocity of the stream in the mentioned region comprising a second electron stream traversing the region at a velocity of the same order as the aforementioned constant velocity and in a direction substantially orthogonal

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to the direction of the first electron stream. Means are also provided for varying the density of the second electron stream to produce corresponding variations in the first electron stream.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

In the drawing:

Figs. 1 and 4 are schematic drawings of a space charge reaction tube and associated circuit elements arranged for operation in accordance with the present invention; Fig. 2 is a diagram showing the potential gradient between electrodes in the Fig. 1 embodiment of the invention for use in describing the operation; Fig. 3 represents an alternative structural arrangement of Fig. 1 and Fig. 5 represents an alternative structural arrangement of Fig. 4.

Referring now more particularly to the drawing, in Fig. 1 there is shown a space charge reaction electron tube in accordance with a preferred form of the invention wherein the tube is comprised of an evacuated envelope 10 containing a source of electrons comprising a heater element 14, cathode 15, control grid 16 and accelerating electrode 17 to provide a source of electrons of predetermined velocity which traverse the tube and normally strike the collector electrode 18. The electrons from cathode 14 pass substantially in a direction orthogonal to another electron stream which is of larger total current and is provided by cathode 20 activated by heater 19. Accelerating electrodes 21 and 22 serve to produce a predetermined velocity characteristic for this electron stream in its traversal of the space to collector 23. The electrode 22 located in front of collector 23 is maintained at a potential which is generally the same as, or differs only slightly from, the potential of electrode 21. The space between electrodes 21 and 22 may be referred to as a region of depressed potential or a region of space charge, sometimes referred to as a virtual cathode. Operating potentials are provided by battery 13 and the connections therefrom to the several electrodes. Input signals are applied at terminals 11 between cathode 15 and control electrode 16 and battery 24 serves to provide suitable bias potential to the control grid 16. An output load for the tube is indicated by resistor 25 coupled between the anode electrode 23 and the positive terminal of

battery 13 and output terminals, labeled 12, are provided.

Considering now the operation of the system and referring also to Fig. 2, the potential gradient in a plane section between cathode 20 and electrode 23 is indicated for a condition corresponding to the absence of current flow by the solid line graph A, B, C, D. In this graph distances corresponding to the spacing of the electrode elements are indicated by similar reference numerals. The solid line graph, therefore, represents the potential gradient between the tube elements 20, 21, 22 and 23 when unaffected by the presence of an electron stream and it is evident from the graph that between electrodes 21 and 22 the gradient is zero; that is, the potential is normally constant in this region and the electrons passing through the perforations of accelerator 21 proceed to the perforations of electrode 22 at substantially constant velocity.

Consider now the effect of the electron stream originating at cathode 15 (hereafter to be referred to as the second electron stream) and traversing the space between accelerator 17 and collector 18 in a direction substantially orthogonal to an electron stream (hereafter to be referred to as the first electron stream) traversing the space between electrodes 21 and 22. It will be noted that the electrodes 20, 21, 22 and 23 associated with the first electron stream are much larger physically than the electrodes associated with the second controlling stream and that the distance between electrodes 17 and 18 is relatively long. It will also be noted that the potential between cathode 15 and collector 18, as indicated by the tapped positions on battery 13, is somewhat higher than the potential difference between cathode 20 and electrode 21, so that the second or controlling electron stream proceeds between electrodes 17 and 18 at a velocity of the same order and preferably slightly higher than the normally constant velocity of electrons between electrodes 21 and 22. Because of the relatively long path from 17 to 18 and the comparable velocity of the streams, the electrons of the controlling second stream remain within the space charged region of the controlled first stream a relatively long time. With a chosen initial setting of bias battery 24, the effect of the controlling electron stream upon the first electron stream is to provide a new curve for the potential gradient between electrodes 21 and 22, as indicated by the long dashed line curve between the points A and B in Fig. 2. This curve represents a setting of the bias on grid 16 for proper operation of the device. It will be clear that if control grid 16 is made more negative, the operating gradient of the tube may reach the limit indicated by the short dashed line between points B and C of Fig. 2. In operation, then, with a signal voltage applied between cathode 15 and control grid 16, the curve of potential varies between the short dashed line curve and the solid line curve with the long dashed line curve indicating a center value of operation.

The velocity of the electrons traversing the space between electrodes 21 and 22 will, of course, vary as the square root of the potential in this region. It will be clear, therefore, that varying the density of the electrons in the controlling electron stream operates to produce corresponding variations in the velocity of the controlled electron stream. It follows, therefore, that a signal applied to the input terminals 11 produces a corresponding variation in the velocity of the controlled electron stream. This variation in velocity in accordance with the input signal results in a so-called bunching of the electrons, so that, in effect, the electrons in the controlled stream are modulated in accordance with the applied signal and since this is a stream of greater current, an amplified signal is produced across the output impedance 25.

The arrangement in Fig. 1 has implied that planar electrodes will be employed. It is evident, of course, that other forms of the device might be more economical of space and have constructional advantages and Fig. 3 illustrates by a cross section diagram one cylindrical form which the tube may take. Here, and throughout the specification, similar reference numerals are employed to indicate similar elements. Thus, in Fig. 3, the envelope 10 has located within it and arranged in concentric fashion, the cylindrical electrodes 20, 21, 22 and 23, which provide the first electron stream and within the space between electrodes 20 and 21 the cathode 15, control grid 16 and accelerating electrode 17 are located on one side of cathode 20 and collector 18 is located on the opposite side of cathode 20. The lines having arrowheads indicate that the electrons from cathode 15 travel in circular paths from each face of cathode 15 to collector 18 and generally, due to the operating potential chosen for collector 18, these electrons constituting the second electron stream will traverse the region between electrodes 21 and 22 in a direction substantially orthogonal to the direction of the radial flow of electrons in the first electron stream. An alternative arrangement for providing a cylindrical tube structure wherein the second electron stream is orthogonal to the first electron stream would be an arrangement similar to that shown in Fig. 5, and which will be more fully explained with reference to the embodiment shown in Fig. 4, and presently to be described.

Referring now particularly to Fig. 4, the arrangement there shown is comprised of the same elements as shown in Fig. 1, except that the two electrodes 21 and 22 associated with the first electron stream and the accelerating electrode 17 of the second electron stream have been omitted, and in place thereof a focusing coil 26 is provided which is energized from a direct current source, not shown, to provide a magnetic field which is coaxial with the normal direction of the second electron stream between cathode 15 and collector 18. As is well known, the coaxial magnetic field will cause a rotation of the electrons in the second electron stream such that the stream converges to impinge on collector 18, while impingement of these electrons on electrode 23 is reduced or avoided. In effect, the magnetic field is equivalent in its end result to the electrodes 21 and 22 as employed in Fig. 1, so that the second electron stream traverses a space charge region between cathode 20 and electrode 23 to control the velocity of the electrons in this space. Accordingly, as in the Fig. 1 arrangement, an input signal applied at terminals 11 operates to control the velocity and, accordingly, to provide corresponding variations in the density of a larger electron current flowing between electrodes 20 and 23.

It will be noted that in the described operation of both the Fig. 4 and Fig. 1 arrangements of the present invention the second or controlling electron stream has a lower current and a velocity of the same order or preferably slightly higher than the velocity of the first electron

stream and that, because of the physical size of the electrodes associated with the first electron stream, the traversal of the space by the electrons in the second electron stream may take a relatively longer time interval. It will be clear that if the length of the electrodes 20 and 23 is relatively long, the time taken for this traversal may be such as to prevent operation of the device at very high frequencies. This defect may be overcome, for example, by varying the spacing between cathode 20 and anode 23, as indicated in Fig. 4, by tilting electrode 23 so that the spacing is greater where the second electron stream enters, than where it leaves this region to impinge upon collector 18. This variation of the spacing, as shown, causes the control effect of the second electron stream at the entering region of this space to be delayed relative to its effect at the exit part of the region. Compensation by varying the transit time for the first electron stream is therefore accomplished progressively along the path in the direction of flow of the second electron stream.

Fig. 5 illustrates a cylindrical form of the Fig. 4 arrangement, wherein the cathode 20 and anode 23 have concentric cylindrical form and arrangement, while the electrodes 15, 16 and collector 18 associated with the second electron stream are shown as planar elements to provide for the second electron stream a relatively long path in traversing the region between electrodes 20 and 23 in a direction orthogonal to the electrons of the first stream. The second electron stream for one particular group of electrons is indicated in dotted line 27 to show the rotation of the stream due to the magnetic field as it progresses through the space charge region. The rotation may be in small spirals as indicated, or the magnitude of the magnetic field may be adjusted so that the electrons in the second electron stream rotate or gyrate completely around the cathode 20 as they progress through the space charge region to collector 18.

In each of the embodiments shown in Figs. 1, 3, 4 and 5, the arrangements provide means for producing a first electron stream between electrodes 20 and 23 which has a predetermined velocity characteristic comprising a region of normally constant velocity and the electrodes 15, 16 and 18 and their orientation are such as to provide means for controlling the velocity of the first electron stream in the region of normally constant velocity which comprises a second electron stream traversing the region between the electrodes 20 and 23 at a velocity of the same order as the aforementioned constant velocity and in a direction substantially orthogonal to the direction of the first electron stream. The grid 16 provides means for varying the density of the second electron stream to produce corresponding variations in the velocity and density of said first electron stream.

It will be clear that a primary effect of the second electron stream upon the first stream is a control of velocity which results in so-called bunching of the electrons in their traversal of the region between electrode 21 and anode 23. Accordingly, it is preferable to space the anode 23 a suitable distance from electrode 22 to permit adequate electron drift so that the bunching process is completed. In addition to the bunching produced by control of the velocity of the first electron stream, there is also density control by the second electron stream acting in effect as an electron control grid to turn back a portion of the electrons of the first electron stream, so that the employment of spacing to accomplish bunching by drift of the electrons need not be entirely relied upon.

The electrodes associated with the first electron stream have been illustrated and described as plane or curved surfaces. It will, however, be evident to those skilled in the art that resonant type electrodes may be employed, particularly where operation in a chosen narrow band of high frequencies is contemplated. For example, the anode 23 may be in the form of a resonant cavity. In Figs. 1 and 4 this form of cavity anode would be, for example, an elongated tube or waveguide section having its axis parallel with the direction of flow of the second electron stream and having a longitudinal slot facing cathode 20 whereby the electrons of the first stream may pass into the cavity. A cavity output coupling circuit would then be provided in known manner.

While there has been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A space charge reaction device comprising means for producing a first electron stream extending a predetermined distance in a direction orthogonal to the direction of flow of said stream, said stream having a predetermined velocity characteristic comprising a region of normally constant velocity, means for controlling the velocity of said stream in said region comprising a second electron stream traversing said region at a velocity of the same order as said constant velocity and in said direction orthogonal to the direction of said first electron stream, said predetermined distance being chosen to provide a relatively long transit time for electrons of said second stream, and means for varying the density of said second electron stream to produce corresponding variations in the velocity and density of said first electron stream.

2. A space charge reaction device comprising means for producing a first electron steam extending a predetermined distance in a direction orthogonal to the direction of flow of said stream, said stream having a predetermined velocity characteristic comprising a region of normally constant velocity, means for controlling the velocity of said stream in said region comprising a second electron stream traversing said region at a velocity of the same order as said constant velocity and in said direction orthogonal to the direction of said first electron stream, said predetermined distance being chosen to provide a relatively long transit time for electrons of said second stream, means for modifying the transit time of the electrons in said first electron stream progressively along said predetermined distance to compensate for the said relatively long transit time for electrons of said second stream, and means for varying the density of said second electron stream to produce corresponding variations in the velocity and density of said first electron stream.

3. A space charge reaction device in accordance with claim 2 wherein said modifying means comprises cathode and anode electrodes associated with said first electron stream and positioned to

have progressively decreased spacing therebetween in the direction of flow of said second electron stream.

4. A space charge reaction device comprising a plurality of concentrically positioned cylindrical electrodes for producing a first electron stream extending in a predetermined circular direction orthogonal to the radial direction of flow of said stream, said stream having a predetermined velocity characteristic comprising a region of normally constant velocity, means for controlling the velocity of said stream in said region comprising a second electron stream traversing said region at a velocity of the same order as said constant velocity and in said direction orthogonal to the direction of said first electron stream, and means for varying the density of said second electron stream to produce corresponding variations in the velocity and density of said first electron stream.

5. A space charge reaction device comprising means for producing a first electron stream extending a predetermined distance in a direction orthogonal to the direction of flow of said stream, said stream having a predetermined velocity characteristic comprising a region of normally constant velocity, means for controlling the

velocity of said stream in said region comprising a second electron stream traversing said region at a velocity of the same order as said constant velocity and in said direction orthogonal to the direction of said first electron stream, said predetermined distance being chosen to provide a relatively long transit time for electrons of said second stream, means for varying said second electron stream in accordance with an input signal to produce corresponding variations in the velocity of said first electron stream, and means responsive to said velocity variations to reproduce said signal.

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