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3,189,785

PRE-INTERACTION CYCLOIDAL BEAM DEFLECTION IN CROSSED-FIELD TUBE

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4 Claims. (Cl. 315-39.3)

This invention relates to electron beam devices and, more particularly, to electron guns for use in crossed-field electron beam devices.

The most widely known type of crossed-field device is the conventional magnetron. Although the conventional magnetron has wide utility as an oscillator, efforts to use it as an amplifier have, for the most part, been unsuccessful, largely because of instability problems. Many of these problems can be overcome through the use of a fat, elongated cathode, and an elongated anode, rather than the cylindrical cathode and anode of conventional magnetrons. In this type of device, a magnetic field is produced which is perpendicular to a D.-C. electric field produced between the anode and cathode. The anode also constitutes a slow wave structure; a wave propagating along the anode is thereby allowed to interact with electrons which are emitted by the cathode and focused by the crossed fields. The electrons are either collected by the anode or by a collector at one end of the interaction region which is defined by the anode and cathode. By comparison to the traveling wave tube, however, this type of crossed-field amplifier is often unsatisfactory because of the large cathode area from which electrons are emitted. A comparatively large quantity of power is necessary for heating the cathode and, further, the noise problems resulting from cathode surface imperfections are effectively multiplied.

The next significant step in the evolution of a stable, efficient crossed-field amplifier was the development of devices which utilize an electron gun now known to workers in the art as the "Charles gun." In devices using this type of electron gun, an interaction region is defined between a slow wave circuit anode and a negatively biased flat electrode, now referred to in the art as a sole plate. Crossed electric and magnetic focusing fields are produced in the interaction region as in the aforementioned devices. An electron beam is formed by the Charles gun which comprises a cathode adjacent one end of the interaction region which is directed at a 90 degree angle with respect to the tube axis. Crossed fields in the electron gun cause the electrons to describe substantially one-half a cycloid before entering the interaction region. In the interaction region the electric and magnetic fields are balanced with respect to the beam velocity so that the electrons follow a substantially rectilinear trajectory therethrough.

As will be explained more fully hereinafter, the Charles gun is incompatible with the requirements of high beam current and low beam velocity which are desirable, for example, in a crossed-field parametric amplifier of the type disclosed in my copending application Serial No. 822,128, filed June 22, 1959, now abandoned. An alternative to the Charles gun is the filamentary cathode which is disclosed in my aforementioned copending application. Although this cathode is capable of producing a high-current low-velocity beam, it is relatively inefficient when a high magnetic field is required because some of the electrons emitted therefrom tend to follow trochoidal trajectories around the circular cathode periphery (such as in a magnetron), rather than being projected along a desired rectilinear trajectory.

It is an object of this invention to produce a substantially rectilinear electron beam in a crossed-field device.

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It is another object of this invention to produce a substantially rectilinear electron beam of high current and low velocity in a crossed-field device.

It is a further object of this invention to produce a substantially rectilinear electron beam of high current and low velocity in a crossed-field device in which a very high magnetic field is used.

These and other objects of my invention are attained in one illustrative embodiment thereof comprising an electron gun for projecting a rectilinear electron beam into an interaction region that is defined between an elongated anode and a flat negatively-biased sole plate. The beam is focused by the combined action of an electric field between the anode and sole plate and a magnetic field which extends throughout the device; the electric field, magnetic field, and direction of rectilinear beam flow being mutually perpendicular. An electromagnetic wave is introduced into the interaction region which interacts with the electron beam to become amplified.

It is a feature of this invention that the crossed fields in the electron gun be so chosen that electrons, upon leaving the cathode of the electron gun, are forced to follow cycloidal trajectories.

It is another feature of this invention that the cathode be displaced from the axis of the interaction region and be directed at an angle of 180 degrees with respect to the direction of rectilinear beam flow.

It is still another feature of this invention that the anode and sole plate be so positioned that the emitted electrons enter the interaction region after completing substantially one cycloid of their trajectory in the electron gun. Under these conditions, the electron beam will enter the interaction region with a very small velocity and yet, a very large beam current can be drawn from the cathode even if a high magnetic field is utilized.

These and other objects and features of this invention will be more fully understood with a consideration of the following detailed description, taken in conjunction with the accompanying drawing, in which:

FIG. 1 illustrates an electron gun of the prior art; and FIG. 2 is a schematic illustration of an electron beam device embodying the principles of my invention.

FIG. 1 illustrates the operation of the aforementioned "Charles gun." The electron gun 12 comprises a cathode 13, a positive electrode 14 and a negative electrode 15. An interaction region 17 is defined between an anode 18 and a sole plate 19. A uniform magnetic field B is produced throughout the device which extends "into the paper" as indicated by the crosses labeled B. An electric field E is produced in gun 12 by electrodes 14 and 15 while an electric field E' is produced in interaction region 17 by anode 18 and sole plate 19.

The purpose of electron gun 12 is to inject an electron beam into interaction region 17 at such a velocity that the beam will thereafter follow a substantially rectilinear trajectory. A rectilinear trajectory is obtained when the upward force f_1 on an electron due to electric field E' is equal to the downward force f_2 produced by the magnetic field B. Because the force produced by the magnetic field is directly proportional to the longitudinal velocity v of the beam, the beam must be injected into interaction region 17 at a predetermined velocity. This velocity v is determined from the equations:

$$f_2 = evB \quad (1)$$

where e is the charge of an electron; and

$$f_1 = eE' \quad (2)$$

Setting equation (1) equal to equation (2):

$$evB = eE' \quad (3)$$

and:

$$v = E'/B \quad (4)$$

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The crossed fields in the electron gun 12 are of predetermined relative strengths to cause the electrons to follow cycloidal trajectories. If electric field E were extended along interaction region 17, the trajectory of an exemplary electron would be that shown by dotted curve 21. As is seen from FIG. 1, this electron enters the interaction at the highest point in its cycloidal trajectory. At this point, the electron velocity v can be shown to be:

$$v = \frac{2E}{B} \quad (5)$$

From Equations 4 and 5, one can see that the relationship between E and E' is:

$$E' = 2E \quad (6)$$

For many applications, it is desirable that the electron beam enter the interaction region with a very low velocity. This is particularly true of cyclotron wave parametric amplifiers such as that disclosed in my aforementioned copending application, wherein a high magnetic field in the interaction region is often necessary. From Equation 5, one way of producing a low injection velocity is to use a low electric field E in the electron gun. This, however, reduces the quantity of beam current that can be drawn from the cathode. Of course, a high magnetic field permits the use of a higher electric field, but this, in turn, requires a very small emissive cathode area. The radius r of the circle describing the aforementioned cycloidal trajectory is directly proportional to the velocity v and inversely proportional to the flux density B. When B is large and v is small, the radius r therefore becomes very small. It is self-evident that the emissive surface of the cathode must in turn be fairly small with respect to the radius r if all of the electrons are to be injected into the interaction region at a point somewhere near the highest point of their cycloidal trajectories. Therefore, a low velocity beam can be produced in a high magnetic field only if cathode 13 is extremely small. As a result, not only is the beam current which can be produced severely limited, but also, the manufacturing problems involved in constructing such small structures may make the Charles gun totally impracticable.

Referring now to FIG. 2, there is shown schematically a crossed-field electron beam device 21 which embodies the principles of the present invention. Device 21 is of the general type disclosed in my aforementioned copending application and comprises an electron gun 22 and a collector 23 at opposite ends of an evacuated envelope 36 of a suitable material. An interaction region 24 is defined between anode 25 and sole plate 26. A magnetic field which extends "into the paper," as designated by crosses B, is produced by well-known means. A battery 29 biases anode 25 positively with respect to sole plate 26 to produce an electric field E' which is transverse to magnetic field B. The crossed fields are adjusted such that a low velocity electron beam formed by gun 22 flows through interaction region 24 with a substantially rectilinear trajectory which is coincident with the tube axis 30.

In accordance with the teachings of my aforementioned application, signal and pump wave energy is introduced, via a coaxial cable 31, into interaction region 24. The magnetic field is properly adjusted so that the signal and pump waves produce fast cyclotron waves on the beam and thereby couple together in such a way as to produce a parametrically growing signal wave. Fast cyclotron wave noise energy is transferred to the waveguide defined by anode 25 and sole plate 26 and is transmitted to a dissipative impedance 33. The parametrically amplified signal wave is removed by coaxial cable 35 and transmitted to an appropriate load.

Electron gun 22 comprises a cathode 37, a positive electrode 38 and a negative electrode 39. Electrodes 38 and 39 are biased by means of battery 29 to produce an electric field E which is transverse to magnetic field B. Electric field E is adjusted with respect to magnetic field

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B to force the emitted electrons to follow a cycloidal trajectory of a predetermined radius. More particularly, the crossed fields are adjusted such that the emitted electrons describe substantially one complete cycloid before reaching an aperture 40 in electrode 39 where they are allowed to drift into interaction region 24. It can be shown that the distance y that an electron in crossed fields travels during one complete cycloid, and therefore the average vertical distance between the cathode and the tube axis 30, is:

$$y = \frac{2\pi Em}{B^2 e} \quad (7)$$

where m is the mass of an electron.

Dotted curve 41 has been included to show the trajectory of an exemplary electron if electric field E was unperturbed by aperture 40. From a consideration of this imaginary trajectory one can appreciate that the velocity of the beam is very low at the entrance to interaction region 24, regardless of what its velocity may be at the highest point of its cycloidal trajectory. Further, if desired, a high electric field E may be used in the electron gun for producing a high beam current.

The electrical connections shown are merely illustrative of one way of producing the desired electric fields E and E'; in practice, it is usually advantageous to provide certain modifications depending upon the particular requirements involved. For example, a lower potential on negative electrode 39 than on cathode 37 may enhance emission characteristics; a separate electrode may be used at the entrance to the interaction region to produce various velocity characteristics on the beam. Alternatively, electrode 39 may be designed in various ways to shape the electric field at aperture 40 and thereby optimize entrance conditions. Further, in certain oscillators it is often desirable that the beam electrons follow trochoidal, rather than rectilinear trajectories so that certain electrons impinge upon, or "skim" the anode 25; my invention is advantageous in such devices for producing a large radius of curvature of the trochoidal trajectories.

It is to be pointed out that the above-described devices are intended to be merely illustrative of the utility of the inventive concepts involved. Various other arrangements may be devised by those skilled in the art without departing from the spirit and scope of my invention.

What is claimed is:

1. An electron beam device comprising a cathode for emitting electrons, a first electrode adjacent said cathode, a second electrode parallel to said cathode and said first electrode, means for biasing said second electrode positively with respect to said first electrode, a sole plate and an anode defining therebetween an interaction region, said interaction region being adjacent one end of said first electrode and extending away from said second electrode, and means for producing a magnetic field transverse to said electric field thereby causing the emitted electrons to follow substantially cycloidal trajectories, said electric field being of such a predetermined strength with respect to said magnetic field as to cause said electrons to enter said interaction region upon the completion of substantially only one cycloidal cycle.

2. A crossed-field electron beam device having a central axis and comprising a pair of elongated electrodes parallel with said axis, means for producing between said pair of electrodes a first electric field which is transverse to said axis, means for producing a magnetic field which is transverse to said axis and said first electric field, an electron gun comprising a cathode and means for producing a second electric field which is substantially parallel with said axis and transverse to said magnetic field, said cathode being displaced from said axis by a means distance y which is substantially determined by:

$$y = \frac{2\pi Em}{B^2 e}$$

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where E is the strength of the second electric field, B is the strength of the magnetic field in the electron gun, m is the mass of an electron, and e is the charge on an electron.

3. An electron beam device comprising an elongated anode and an elongated sole plate defining a linear interaction region therebetween, means for producing a first electric field between said anode and sole plate, means for introducing electromagnetic wave energy to an input end of said interaction region, means for removing electromagnetic wave energy from an output end of said interaction region, said anode and said sole plate comprising means for propagating electromagnetic wave energy from the input end to the output end of the interaction region, means adjacent said input end for injecting an electron beam into said interaction region comprising a cathode, a first flat electrode and a second flat electrode, said cathode comprising means for emitting electrons in a direction diametrically opposite the direction of propagation of said electromagnetic wave energy, said first electrode having two apertures therein and being substantially parallel to said second electrode, one of said apertures surrounding the central axis of said linear interaction region and the other aperture surrounding said cathode, means for producing a second electric field between said first and second electrodes, and means for producing a magnetic field throughout said interaction region and said injecting means that is transverse to both said first and second electric fields.

4. The electron beam device of claim 3 wherein the

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mean distance between said two apertures is substantially equal to

$$\frac{2\pi Em}{B^2 e}$$

where E is the intensity of said second electric field, B is the flux density of said magnetic field, e is the charge on an electron and m is the mass of an electron.

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