

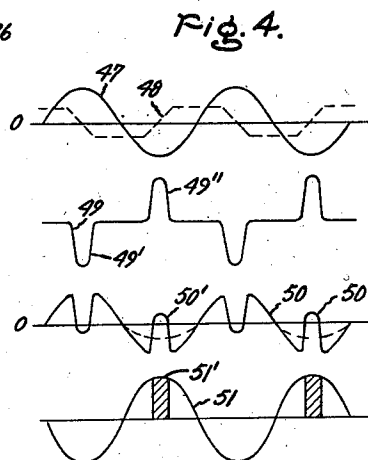
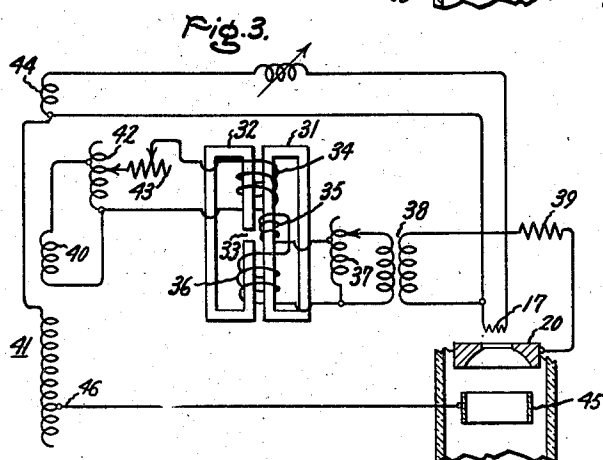
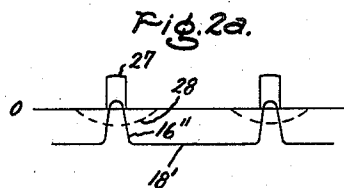
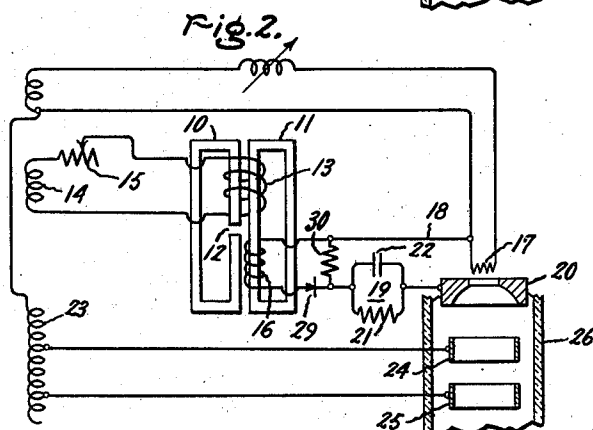
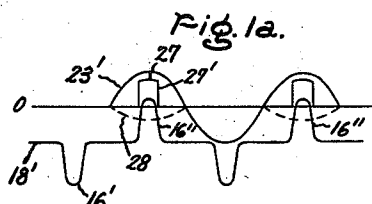
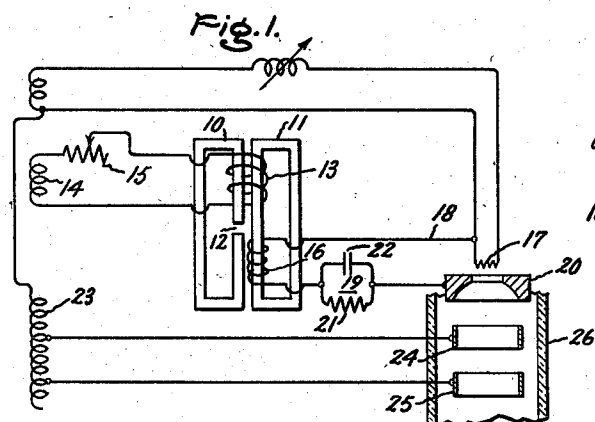
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BIAS FOR ELECTRON BEAM EQUIPMENT

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BIAS FOR ELECTRON BEAM EQUIPMENT

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This invention relates to apparatus for biasing electron beam equipment.

While this invention may take a variety of forms, it is ideally suited for biasing high voltage electron beam equipment such as cathode ray apparatus, providing electrons having energies of the order of 1 million volts or more, and X-ray apparatus and, by way of example, is particularly described in connection with these forms of equipment.

In conventional equipment for providing high energy electrons in the form of an electron beam, an electron gun, including an electron emitting filament and a control or focusing electrode, provides electrons. Electrons from the filament pass through the control electrode and are then accelerated by high potentials applied to a plurality of accelerating electrodes to provide a beam of high energy electrons.

One variety of electron beam equipment utilizes a resonance transformer wherein successively higher accelerating potentials, from successive taps on a resonance transformer, are applied to accelerating electrodes arranged along the beam path. In this form of apparatus, electrons are accelerated by the positive portions of the voltage wave from the resonance transformer. It is apparent that electrons accelerated with this form of equipment have a wide range of energies which range from those energies associated with the relatively low positive potential portions of the accelerating voltage wave to those associated with and accelerated by the peak portion of the accelerating voltage wave. Since the accelerating wave has a substantially sine wave form it is further apparent that the electron energy distribution follows the same function.

Many of the resulting low energy electrons cannot penetrate the end window of electron beam apparatus. These electrons do no useful work and result in undesirable heating of the end window. In electron beam equipment, it is general practice to focus the electrons in the beam electrostatically and/or electromagnetically. The wide range of electron velocities resulting from the range of accelerating voltages renders focusing of the beam extremely difficult. Since the electron energies vary over a wide range and many of the electrons cannot be utilized, the efficiency of the electron beam tube equipment is relatively low.

Therefore, it is apparent that it would be particularly desirable to provide apparatus for biasing electron beam equipment so that a beam of electrons having substantially the same energy is obtained. With such a beam substantially all of the electrons may be accelerated so that they are able to penetrate the end window of the tube and so that only those electrons are present which have nearly the maximum range of penetration for useful work. The efficiency of such equipment is improved and the heating of the end window is substantially reduced. In addition, since the electrons have nearly the same energy, the electron current density is more uni-

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formly distributed over the cross-section of the beam and the beam diameter can be more easily adjusted by means of a focusing coil.

Therefore, an object of this invention is to provide improved apparatus for biasing electron beam equipment so that a beam of electrons having substantially the same energy is obtained.

It is also an object of this invention to provide improved apparatus for biasing electron beam equipment so that beam current flows in said equipment during a short portion only of the cycle of the accelerating voltage applied to the equipment and so that electrons having substantially the same energy are obtained.

According to an aspect of this invention there is provided a novel solution to the problem of obtaining, in electron beam equipment, electrons having substantially the same energy. This solution is in the form of apparatus for biasing electron beam equipment, of the type including an electron gun having a control electrode and a source of voltage applied to the equipment for accelerating electrons from the gun, comprising a source of peaked voltage applied to the control electrode. The peaked voltage has the proper phase, amplitude, and periodicity with respect to the accelerating voltage so that electrons flow in the equipment during a short portion only of the cycle of the applied accelerating voltage, thereby providing a beam of electrons having substantially the same energy.

Other objects and important aspects of this invention will become apparent from the specification and claims when taken with the figures of the drawing, wherein Figures 1 and 1a illustrate an embodiment of this invention and wave forms associated therewith; Figures 2 and 2a illustrate another embodiment of this invention and associated wave forms; Figure 3 illustrates a preferred embodiment of this invention; and Figure 4 illustrates wave forms useful in explaining the operation of the embodiment illustrated in Figure 3.

Figure 1 illustrates a peaking transformer including core members 10 and 11 of magnetic material. Core 10 is provided with a gap 12 and core 11 includes considerably less magnetic material than core 10. Therefore, core 11 saturates at a much lower value of magnetizing current than core 10. A winding 13 provides the magnetizing force to cause flux to circulate in cores 10 and 11. Coil 13 is energized by energy source 14 which may consist of end turns on a high voltage transformer. Since the reluctance of the magnetic circuit formed by core member 10 is reflected back to energizing coil 13 and to energy source 14, the current in coil 13 is conveniently adjusted by varying the spacing of air gap 12. The phase of the energizing current with respect to the current applied to the transformer energizing coil 14 is adjusted by variable resistor 15.

A secondary winding 16 is coupled to core 11 only. One end of coil 16 is connected to filament 17 through lead 18 and the other end of coil 16 is connected through self-biasing network 19 to control or focusing electrode 20. The self-biasing network consists of resistor 21 and capacitor 22. The equipment is provided with transformer secondary 23 which provides high potential accelerating voltages to accelerating electrodes 24 and 25 which are arranged along the beam path and in insulating housing 26 of the beam equipment.

The filament is continuously heated and electrons from the filament are accelerated by potentials applied to electrodes 24 and 25 from transformer secondary 23. Some electron current is collected by electrode 20 whenever it becomes positive with respect to the filament 17. After approximately one cycle of accelerating voltage, the positive peak voltage output of coil 16 charges capacitor 22

so that the plate nearest the peaking transformer is positive and the plate furthest from the transformer is negative thereby applying a negative bias to control electrode 20. Resistor 21 has a high resistance so that a relatively long time, compared to the period of the applied accelerating potential, is required for charge to leak off capacitor 22. Therefore, a substantially constant negative bias is applied to electrode 20, in addition to the alternating voltage from winding 16.

Since transformer secondary core member 11 is saturated during a major portion of the magnetizing force applied by coil 13 the voltage output of coil 16 has a peaked characteristic centered about the region of most rapid change of flux which is substantially 180° out of phase with the energizing current applied to coil 13. The phase of the peaked voltage output of coil 16 is controlled by adjusting variable resistor 15 so that the positive peaks occur during the positive half cycle of the substantially sine wave accelerating voltage applied by coil 23 and during the period when the applied accelerating potential is at a maximum value. The negative bias, provided by network 19, and the peaked voltage from coil 16 bias electrode 20 so that electrons flow in the beam equipment during a short portion of the positive half cycle of the accelerating voltage only and so that substantially no electrons flow during the remainder of the accelerating voltage cycle.

Figure 1a illustrates the voltage characteristics associated with the apparatus illustrated in Figure 1. Line 18' is representative of the bias potential applied to electrode 20. Negative peaks 16' and positive peaks 16'' are representative of the potential observed across transformer secondary 16 when superimposed upon the negative bias provided by network 19. Curve 23' is representative of the accelerating potential applied to one or more of the accelerating electrodes 24 and 25. The curve 27 is representative of electron current that is permitted to flow.

It will be noted that electrode 20, which focuses the electron beam and acts as a control electrode, is located in proximity to the filament so that it has a much greater control effect upon the electrons emitted by filament 17 than do the accelerating electrodes; for example, 100 times the control exerted by electrodes 24 and 25. In view of this relative spacing of the accelerating electrodes and electrode 20, the critical bias voltage line 28 may be drawn to approximately the same scale as the bias voltage applied to control electrode 20. If the bias potential on electrode 20 exceeds the critical bias, represented by line 28, electron current flows. It is also noted that accelerating voltage curve 23' is drawn to approximately 1/100 of its true value in amplitude in order to provide a simplified illustration. Where bias voltage line 18' crosses critical bias voltage line 28, electrons from filament 17 pass electrode 20 and are accelerated. Thus, it is apparent that the apparatus illustrated in Figure 1 limits the beam current to a short portion only of the cycle of the applied accelerating voltage. It will be noted that negative peaks 16' serve no useful purpose since they occur during the negative half cycle of the accelerating potential. These negative peaks necessitate heavy insulation between filament 17 and control electrode 20.

Self-biasing networks have, prior to this invention, been utilized in an effort to limit the beam current to short periods of the accelerating potential cycle; however, these networks provide a substantially sinusoidal bias to the control electrode so that the resulting current flow is not sharply cut off. This results in a beam current characteristic having sloped sides rather than the square wave characteristic having steep substantially vertical sides 27', as illustrated in Figure 1a.

In order to overcome the necessity for heavy insulation between the filament 17 and electrode 20, a rectifier

may be introduced into the bias circuit to eliminate the negative portion of the output of the peaking transformer secondary coil 16. Figure 2 illustrates such an apparatus wherein components which are similar to those illustrated in Figure 1 are designated by the same reference numerals. The apparatus includes a rectifier 29 and resistor 30 connected to eliminate the negative peaks from the output of peaking transformer secondary winding 16.

Figure 2a illustrates the current characteristic obtainable with this apparatus. It is apparent from these curves that the maximum potential difference between electrode 20 and filament 17 is greatly reduced so that considerably less insulation between these two members is necessary. With the exception of the operation of the rectifier-resistor circuit 29-30 to eliminate the negative peaks from the output of coil 16, the operation of the apparatus illustrated in Figure 2 is the same as the operation of the apparatus illustrated in Figure 1.

It is noted that in the apparatus illustrated in Figures 1 and 2, a fixed negative bias, from a direct current source for example, may be substituted for the self-biasing network 19. In addition, a separate source of variable biasing potential can be applied to the peaking transformer rather than utilizing end turns coupled to the source of accelerating potential. For example, any source of peaked voltage, having the same periodicity as the accelerating voltage, and combined with an appropriate negative bias source, may be applied to electrode 20, to obtain an electron beam with electrons having substantially the same energy.

Figure 3 illustrates apparatus which provides the desired sharp cut off electron beam tube bias without the necessity of utilizing a separate biasing network or rectifying circuit. There is illustrated a peaking transformer with normally saturated core 31 and normally unsaturated core 32. Core 32 has a high reluctance gap 33. The transformer is provided with an energizing winding 34, a peaked output winding 35, linking core 31 only, and a tertiary winding 36 linking cores 31 and 32. Windings 35 and 36 are connected in series phase opposition and are connected across filament 17 and focusing electrode 20 through variable ratio transformer 37, transformer 38, and current limiting resistor 39.

Energization for the peaking transformer is provided by end turns 40 of accelerating transformer 41 through variable ratio transformer 42 and variable resistor 43. Filament heater potential is provided by end turns 44 of transformer 41 and accelerating potential is applied to accelerating electrode 45 from tap 46.

Gap 33, variable resistor 43 and variable ratio transformer 42 control the amplitude and phase of the energizing current applied to coil 44 and thereby the amplitude, width and phase of the peaked voltage across winding 35. The wave form of voltage across tertiary coil 36 is substantially the same as that applied to coil 34. Variable ratio transformer 37 controls the amplitude of the potential applied to transformer 38 and thereby the magnitude of the bias applied between filament 17 and electrode 20. It is readily apparent that variable ratio transformer 42, variable resistor 43, variable ratio transformer 37 and transformer 38 can be eliminated for any specific application through proper design of the transformer elements or replacement of the variable components with fixed components.

A consideration of the curves shown in Figure 4 will aid in understanding the operation of this embodiment. Curve 47 is representative of the voltage appearing across the terminals of coil 36. Curve 48 is representative of the flux in core 31. It will be noted that this flux is 90° out of phase with the voltage induced in coil 36 and that a voltage output is observed across coil 35 only during the periods of rapid flux change. This results in peaked voltage characteristic curve 49 having negative peaks 49' and positive peaks 49''.

Voltage curve 47 has been shifted 180° in phase from

its actual phase relationship with respect to flux characteristic 48 so that the series connected phase opposition resultant voltage obtainable from the combined outputs of windings 35 and 36 can be illustrated easily by adding these voltages to obtain curve 50. Curve 50 has positive voltage peaks 50' which are adjusted to correspond with the positive peak portions of the high potential accelerating voltage illustrated by curve 51. Portions 51' are the only portions during the accelerating potential cycle when the electrons flow from filament 17.

A consideration of the curves illustrated in Figure 4 indicates that relatively low negative peaks are present so that only light insulation is necessary between filament 17 and electrode 20. The maximum voltage between filament 17 and electrode 20 is only slightly larger than that needed for proper biasing.

The turns ratio of coil 35 to the turns ratio of coil 36 is selected so that the peak induced voltage of coil 35 exceeds that of coil 36 by approximately 40%. Thus, when these two windings are connected in phase opposition, the voltage produced as a bias permits electrons from filament 17 to flow in the apparatus in the middle only of the useful half cycle of the accelerating potential from transformer 41. During the inverse half cycle of the accelerating potential, the focusing electrode becomes positive with respect to filament 17. Resistor 39 prevents excessive current flow, during this period and during the useful half cycle of the accelerating voltage, which would spoil the bias wave form.

In the practice of this invention, limiting the electron current flow to the highest 30° to 80° of the positive half cycle of the accelerating potential produces beneficial results. That is, from approximately plus or minus 15° on either side of the peak value of the sinusoidal accelerating potential to approximately plus or minus 40° on either side of this peak value. For example, with beam current flow limited to plus or minus 40° on either side of the peak value, the lowest speed electrons are accelerated by approximately 76% of the potential applied to the electrons accelerated by the peak value of the accelerating potential, i. e. the cosine of 40° is approximately 0.76. If the flow of beam current is limited to plus or minus 15° either side of the peak value, the lowest speed electrons are accelerated by approximately 97% of the potential applied to electrons accelerated by the peak value of the accelerating potential.

As the period during which electrons are accelerated is reduced, the filament temperature must be increased in order to provide a ready supply of electrons to be rapidly drawn away from the filament during this short period. In view of the cosine relationship of the emission period it is apparent that little is gained by decreasing the emission angle to less than 30°, particularly in view of the necessity of continuously maintaining the filament at a high operating temperature thereby reducing its life.

Apparatus of the type illustrated in Figure 3 has been utilized with equipment for accelerating electrons to energies of the order of 1 to 1.5 million volts. This specific apparatus includes a main magnetic core having a cross-section of $\frac{3}{4}$ inch by $1\frac{1}{2}$ inches with 2 air gaps of $\frac{3}{16}$ inch formed of transformer steel laminations. The saturated core is made of strip steel laminations with a cross-section of $\frac{7}{16}$ inch by $1\frac{1}{2}$ inches. The main energizing winding 34 is wound with 350 turns, coil 35 has 974 turns, and coil 36 has 700 turns. The step up transformer 38 is rated at 100 volts to 2000 volts at 180 cycles per second.

By adjusting variable ratio transformer 42, the saturation of core 31 is controlled and thereby the width of the induced voltage peaks obtainable from winding 35. By adjusting these voltage peaks the electron current interval in the electron beam equipment is controlled. The amplitude of the bias voltage is controlled by variable ratio transformer 37 and a final bias voltage of the order of 1000 volts is obtained from small step up transformer 38.

Resistor 39 for limiting the current during the inverse half cycle of the accelerating voltage is 1 megohm and phase control variable resistor 43 is 25 ohms.

In view of the foregoing, it is apparent that the apparatus of this invention permits beam current flow in electron beam equipment to occur only during a short interval of the cycle when the sinusoidal accelerating voltage is highest. This type of operation results in a beam of high energy electrons having substantially the same energy, thereby eliminating those electrons which cannot penetrate the end window. Electrons flow only during those periods when voltage is present to accelerate them to have nearly the maximum range of penetration for useful work. Thus, the efficiency of the beam apparatus is improved, beam focusing is made easier, the utility of the beam is increased, and the heating of the window is reduced.

When apparatus in accordance with this invention is applied to high voltage X-ray equipment, the efficiency is raised, the X-ray output is increased and the quality of the radiation is improved, since all of the electrons have approximately the same energy. At 1 million volts peak, a 51% increase in X-ray output for the same average current is obtainable and at 1.5 million volts peak the increase observable is at least 69%.

Thus, this invention contributes a novel solution to the problem of obtaining increased efficiency and improved quality of the output of electron beam apparatus.

While this invention has been described in connection with specific embodiments, by way of example, it will be apparent to those skilled in the art that it is subject to a wide variety of modifications and alterations without departing from the spirit thereof; therefore, it is intended in the appended claims to cover all modifications and variations which come within the true spirit and scope of this invention.

What I intend to claim and protect by Letters Patent of the United States is:

1. Apparatus for biasing electron beam equipment, comprising an electron gun having a control electrode means supplying cyclically varying voltage to said equipment for accelerating electrons from said gun, said means supplying to said control electrode peaked voltage having proper phase, amplitude and periodicity with respect to said accelerating voltage so that electrons flow in the beam during a short portion only of a cycle of the applied accelerating voltage providing a beam of electrons having substantially the same energy.

2. In electron beam equipment, including a source of accelerating voltage and an electron gun having a control electrode, apparatus for biasing said electron beam equipment comprising a peaking transformer coupled to said accelerating voltage source, means connecting said transformer to said control electrode, said peaked voltage having proper phase and amplitude with respect to said accelerating voltage so that electrons flow in said equipment during a short portion only of a cycle of the applied accelerating voltage.

3. Apparatus for biasing electron beam equipment, including an electron gun having a control electrode and a source of cyclically varying voltage applied to said equipment for accelerating electrons from said gun, said apparatus comprising a source of peaked voltage connected to said control electrode, and a source of bias voltage connected to said control electrode, said peaked voltage being of proper amplitude with respect to said bias voltage and of proper phase and periodicity with respect to said accelerating voltage so that electrons flow in the beam during a short portion only of the cycle of the applied accelerating voltage.

4. Apparatus for biasing electron beam equipment, including an electron gun having a control and focusing electrode and a source of voltage applied to said equipment for accelerating electrons from said gun, comprising a peaking transformer, a resistance-capacitance bias network coupling said peaking transformer output to said

electrode, said peaked voltage having proper phase and periodicity with respect to said accelerating voltage so that electrons flow in said equipment during a short portion only of the cycle of the applied accelerating voltage to provide a beam of electrons having substantially the same energy.

5. Apparatus for biasing electron beam equipment, comprising an electron gun having a control electrode, a source of cyclically varying voltage applied to said equipment for accelerating electrons from said gun, means supplying peaked voltage, rectifying means connecting said peaked voltage to said electrode and means supplying bias voltage to said electrode, said peaked voltage being of proper amplitude with respect to said bias voltage and of proper phase and periodicity with respect to said accelerating voltage so that electrons flow in the beam during a short portion only of a cycle of the applied accelerating voltage.

6. Apparatus for biasing electron beam equipment, including an electron gun having a control and focusing electrode and a source of voltage applied to said equipment for accelerating electrons from said gun, comprising a peaking transformer, a resistance capacitance bias network and a rectifier, the output of said transformer, the bias network and said rectifier being connected in circuit with said electrode to provide a control bias to said electron gun having substantially no negative voltage peaks and being of proper phase and periodicity with respect to said accelerating voltage so that electrons flow in said equipment during a short portion only of a cycle of the applied accelerating voltage to provide a beam of electrons having substantially the same energy.

7. Apparatus for biasing electron beam equipment including an electron gun having a control electrode and a source of cyclically varying voltage applied to said equipment for accelerating electrons from said gun, said apparatus comprising a source of peaked voltage, a source of substantially sine wave voltage having the same periodicity as said peaked voltage connected to said peaked voltage source to provide a resultant bias voltage output for said control electrode so that current flow in the beam is substantially limited to a short portion only of a cycle of the accelerating voltage.

8. Apparatus for biasing electron beam equipment including an electron gun having a control electrode and a source of cyclically varying voltage applied to said equipment for accelerating electrons from said gun, said apparatus comprising a source of peaked voltage, a source of substantially sine wave voltage having the same periodicity as said peaked voltage connected in series with said peaked voltage source, means connecting said voltage sources to said control electrode to provide a bias voltage for said electron gun so that current flow in the beam is substantially limited to a short high voltage portion only of a cycle of the accelerating voltage to provide a beam of electrons having substantially the same energy.

9. Apparatus for biasing electron beam equipment, including an electron gun and a source of accelerating voltage connected to said equipment to accelerate electrons from said gun, comprising first and second magnetic cores, said second core normally having a lower reluctance than said first core, a first winding linking both cores, means supplying energizing current to said first winding to maintain said second core in a substantially saturated condition during a substantial portion of each cycle of said energizing current, a second winding linking the second core only and a third winding linking both cores, said second and third windings being series connected to provide bias necessary for limiting beam current flow in said equipment to a short portion only of the cycle of the accelerating voltage.

10. Apparatus for biasing electron beam equipment, including an electron gun having a control and focusing electrode and a source of accelerating voltage connected to said equipment to accelerate electrons from said gun, comprising first and second magnetic cores, said second core normally having a lower reluctance than said first core, a first winding linking both cores, means supplying energizing current to said first winding to maintain said second core in a substantially saturated condition during a substantial portion of each cycle of said energizing current, a second winding linking the second core only and a third winding linking both cores, said second and third windings being series connected in phase opposition, and means connecting the combined output of said second and third windings to said electrode to provide the bias necessary for limiting current flow in said equipment to a short high voltage portion only of a cycle of the accelerating voltage applied to the equipment to provide a beam of electrons having substantially the same energy.

11. A bias source comprising first and second magnetic cores, said second core normally having a lower reluctance than said first core, a first winding linking both cores, said second core being maintained in a substantially saturated condition during a substantial portion of each cycle of said energizing current when said energizing current is applied to said first winding, a second winding linking the second core only and a third winding linking both cores, said second and third windings being series connected to provide short positive voltage peaks during a short portion only of alternate half cycles of a source of energizing voltage applied to said first winding.

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