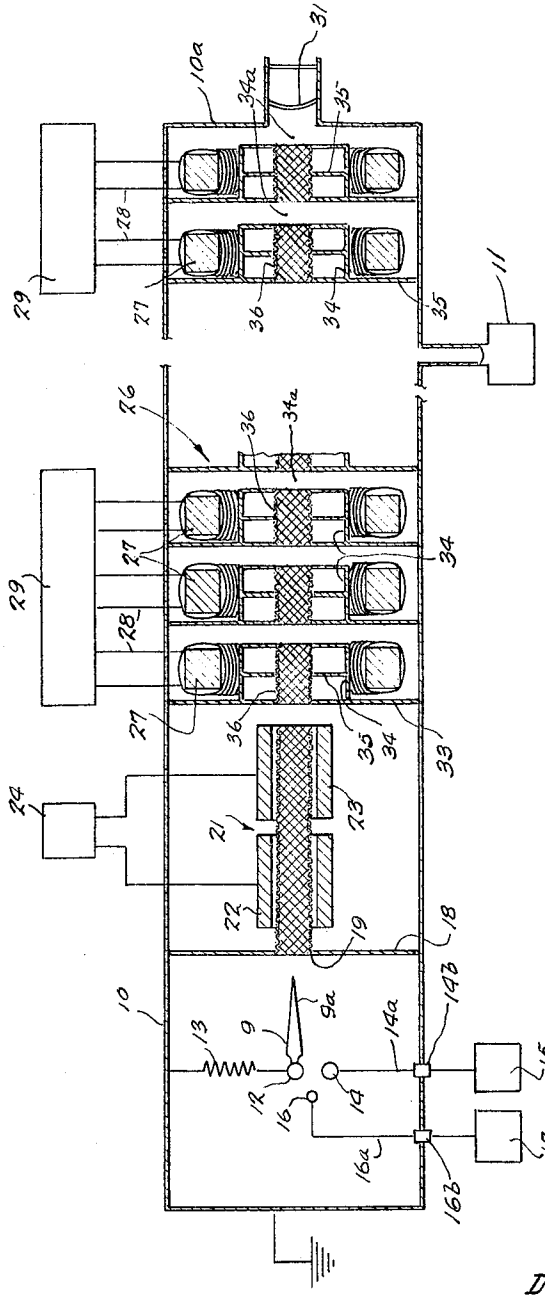
Aug. 30, 1966 D. W. KERST 3,270,243

APPARATUS FOR THE ESTABLISHMENT AND ACCELERATION OF A NARROW HIGH CURRENT BEAM

Filed March 21, 1961



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United States Patent Office 3,270,243 Patented August 30, 1966

3,270,243

APPARATUS FOR THE ESTABLISHMENT AND ACCELERATION OF A NARROW HIGH CURRENT BEAM

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Filed Mar. 21, 1961, Ser. No. 97,232
6 Claims. (Cl. 315—15)

This invention relates to the establishment and acceleration of a beam of particles and more particularly to methods of and apparatus for providing and accelerating an intense narrow beam of electrons.

The establishment and acceleration of intense narrow beams of charged particles, such as electrons, has in the past proven difficult and, under certain conditions, impossible. Efforts to produce such beams have been hampered because high intensity sources of electrons have not been available. Moreover, the acceleration of a narrow beam of high electron intensity has not been feasible because of instabilities due to space charge effects (i.e., intrinsic repulsive forces between beam electrons) and the like.

Accordingly, it is a prime object of the present invention to provide a method of and apparatus for establishing and accelerating an intense narrow beam of electrons.

Another object of the invention is the provision of a method of establishing and accelerating an intense beam of electrons whereby adverse space charge effects and the like are substantially eliminated.

A more specific object of the invention resides in a method of establishing a beam of electrons which is neutralized and confined in a narrow configuration during the passage thereof through an accelerating field.

Other objects and advantages of the present invention will become apparent when considered in conjunction with the accompanying drawing wherein the figure is a diagrammatic representation, partially in cross-section, of an apparatus which may be satisfactorily utilized to establish and accelerate a narrow high intensity beam of electrons in accordance with the provisions of this invention.

In general, a preferred method of establishing and accelerating an intense beam of electrons contemplates the emission of an intense cloud of electrons by a cold cathode. Thereafter in accordance with the provisions of this invention, a dense beam is extracted from the cloud of electrons and focused in a narrow beam. The focused beam is subsequently accelerated through a glow discharge plasma containing substantially equal numbers of electrons and positive ions whereby the beam is space charge neutralized and maintained in the narrow configuration.

Referring now in detail to the beam forming and accelerating apparatus illustrated in the figure, a cold emission cathode **9**, which is preferably formed of an electron emitting material such as tungsten (wolfram), is suitably mounted within and in spaced relation to the wall of an evacuated accelerating tube **10** that has an ionizable gas supplied thereto from a source **11**. The cathode **9** is proportioned with a sharp cone-shaped end section or tip *9a* and is suspended within the accelerating tube **10** so that the longitudinal axis thereof is aligned with the longitudinal axis of the tube.

A terminal **12** is secured to the base of the cold emission cathode **9** and is maintained in electrical contact with the grounded wall of the accelerating tube **10** through a resistor **13**. Positioned in spaced relation to the cathode **9**, the cone-shaped tip of which is directed toward the outlet extremity of the tube **10**, is a high voltage electrode **14**. A conductor **14***a* extends from the electrode **14** to a highly negative source of potential **15** through a gas-tight insulating bushing **14***b* that is mounted in the wall of the tube **10**. A trigger probe **16** is disposed between the electrode **14** and the cathode **10**. This trigger probe is selectively supplied with potential from a pulsing source **17** through a conductor **16***a*. The conductor **16***a* extends through a gas-tight insulating bushing **16***b* that is also mounted in the wall of the accelerating tube.

The potential difference that exists between the terminal **12** and the negative electrode **14** is insufficient to effect the establishment of an arc discharge between these members. However, the magnitude of this potential difference is sufficient to maintain an arc discharge subsequent to the establishment thereof, which is accomplished by the selective operation of the pulsing source **17**. More particularly, the magnitude and duration of the voltage pulse supplied to the trigger probe **16** is sufficient to initiate a discharge between the probe and the terminal **12**. Thereafter, as the pulse is dissipated, the high negative potential on the electrode **14** attracts and effects the transfer of the arc from the probe **16** to the electrode. With the arc established between the terminal **12** and the electrode **14**, a complete path for current flow is provided from the source **15** to the grounded wall of the accelerating tube **10** through the resistor **13**.

The passage of current through the resistor **13** results in the development of voltage thereacross. Inasmuch as the resistor **13** offers a substantial amount of impedance to this flow of current, the developed voltage is substantially equal in magnitude to the highly negative potential supplied by the source **15**. Because the resistor is maintained in electrical contact with the cathode through the terminal **12**, the negative potential developed across the resistor is supplied to the tip of the cathode **9**.

A plate **18** is positioned in spaced relation to the highly negative cone-shaped tip of the cathode **9**. The plate is mounted within the accelerating tube **10** normal to the longitudinal axis thereof and is maintained in electrical contact with the grounded wall of the tube. Consequently, the plate is substantially more positive than the tip *9a* of the cathode **9**. The unique cone-shaped configuration of the tip *9a* coupled with the difference of potential between the cathode and the plate **18** results in the establishment of an intense electrical field which is concentrated at the tip of the cathode. The resulting high potential gradient at the surface of the cathode **9** results in the emission of an extremely high current and intense flow of electrons away from the cone-shaped tip and toward the plate **18**.

The electrons emitted from the tip of the cathode are passed through a circular aperture **19** which is formed in the plate **18**. The center of radius of the circular aperture **19** lies on a line defined by the longitudinal axis of the gas filled tube and, as illustrated, is spaced in close proximity to the cathode **9**. The diameter of the aperture is chosen in accordance with the calculated magnitude of the angle of spread of the electrons being emitted from the cone shaped tip of the cathode. Accordingly, substantially all of the electrons attracted toward the plate **18** pass through the aperture and into a focusing system generally designated by the numeral **21**. The function of the focusing system is to optimize or adjust the product of the beam diameter times the angle of spread of the electron paths.

The focusing system **21** includes a pair of electromagnets **22** and **23** that are supplied with power from a suitable source **24**. As illustrated, these focusing members are positioned in spaced relation to the plate **18** and in alignment with the aperture formed therein. The electromagnetic focusing accomplished by the members **22** and **23** substantially minimizes the spread of the beam just prior

to the transmittal thereof to an accelerating section **26** of the tube **11**. Accordingly, the beam advanced into the accelerating section **26** will be substantially confined to a narrow path in the region of the longitudinal axis of the tube. While in the illustrated embodiment, focusing of the beam is accomplished electromagnetically, modifications of the structural features of the focusing system **21** could be readily accomplished so that electrostatic focusing of the electron beam could also be utilized.

As shown in the figure, the accelerating section **26** of the tube **11** includes a plurality of ring-type magnetic cores **27** which are suspended in spaced relation to the wall of the tube and generally normal to the longitudinal axis thereof. The center of each of the ring-type magnetic cores lies on the longitudinal axis of the tube, and each has a conductive member **28** wound around the entire surface thereof. The conductive members **28**, which are preferably wound in a single layer about the surface of the cores **27**, have exciting current supplied thereto from a current source **29**. The passage of exciting current through the conductive members results in the establishment of a magnetic field about each of the cores having lines of flux which induce or set up individual axial electric accelerating fields in a direction away from the electromagnetic focusing members **22** and **23** and toward a target **31** which is mounted at the outlet extremity of the tube **10**.

The current source **29** also includes a conventional high frequency current generating system which is selectively rendered effective to initiate or "tickle" a glow discharge in the region adjacent the longitudinal axis of the accelerating tube **10**. More particularly, the intermittent passage of high frequency pulses of current through the conductors **28** results in the breaking down and ionization of the gas supplied from the source **11** to the accelerating region of the tube **10**. Consequently a glow discharge plasma, which contains substantially equal numbers of electrons and positive ions is established in the region surrounding the longitudinal axis of the tube. As will be hereinafter described, this glow discharge plasma, and more accurately the positive ions of the glow discharge plasma, function to neutralize the beam of electrons transmitted through the accelerating section of the tube subsequent to the focusing thereof by the electromagnets **22** and **23**.

The magnitude of both the exciting and ionizing or glow discharge-producing currents is limited so that an arc discharge is not established within the tube. Consequently, the exciting current, which establishes the individual axial accelerating fields, and the high frequency ionizing current, which is intermittently applied to the conductors **28**, coact to effect both the acceleration and neutralization of the electron beam while substantially eliminating the adverse effects which might result from the creation of an arc discharge in the tube. The preionized glow discharge, which can be initiated or "tickled" in a variety of ways, will not convert into an arc discharge for several microseconds after the main exciting or accelerating field is established. Accordingly, all of the emitted electrons will be accelerated through the glow discharge before any arc discharge is created in the tube.

As illustrated, a plurality of circular plates **33**, which are electrically connected to the grounded wall of the tube **10** and mounted generally normal to the longitudinal axis thereof, are spaced along the length of the tube from the inlet of the accelerating section **26** to the outlet of the section adjacent to the target **31**. One each of the plates **33** is mounted between each of the ring-type magnetic cores **27** and each has a circular aperture provided therein so that the focused electrons passing through the accelerating section are not obstructed thereby.

Secured to and extending from each of the plates **33** is a cylindrical section **34** which is positioned in spaced and concentric relation to the inner surface of each of the magnetic cores **27**. These cylindrical sections **34** have a diameter which is larger than the diameter of the aperture provided in each of the plates **33** but smaller than that of the inner cylindrical surface of the magnetic cores **27**.

Extending inwardly from each of the cylindrical sections **34** normal to the longitudinal axis of the tube are a plurality of disc-like baffle members **35**. The inner diameter of each of the disc-like baffle members **35** is substantially equal to the diameter of the aperture provided in the plates **33**. The baffle members **35** function to preclude the occurrence of an arc discharge within the tube subsequent to the preionization of the gaseous medium maintained therein. More partciularly, these baffle members limit the distance through which stray electrons can travel and further preclude the establishment of an electron avalanche and the undesirable beam destroying effects that would result from an arc discharge.

A plurality of metallic screen segments **36**, which in a preferred embodiment of the invention are cylindrical in shape, is mounted along the longitudinal axis of the tube. The screen segments are preferably positioned in electrical contact with the innermost edge of the disc-like baffle members **35** and the aperture defining surfaces of the plates **33**. Accordingly, the screen segments, which are concentric with the ring-type magnetic cores **27**, define a cylindrical region wherein the positive ions of the glow discharge plasma effect neutralization of the beam of electrons accelerated and transmitted therethrough toward the target **31**. As illustrated, the individual screen segments **36** are spaced from each circular plate **33** associated with the following cylindrical section **34**. The purpose of this spacing is to provide an eccelerating gap **34***a* and to preclude short circuiting of each of the magnetic cores **27**.

The target **31** is preferably a thin foil member which is framed across a projecting cylindrical end portion of the accelerating tube **10** normal to the longitudinal axis thereof. The target is made of a material which functions to pass the narrow beam from the accelerator while precluding the scattering thereof. One such material which may be satisfactorily utilized for this application is beryllium. The beam which is formed and accelerated through the tube and which is transmitted therefrom through the target **31** may be utilized in any number of applications where a narrow beam of accelerated particles is required.

A preferred method of establishing and accelerating a high current beam of electrons and transmitting the beam through the beryllium foil target **31** is initiated by ionizing the gaseous medium confined in the region defined by the screen segments **36**. As previously described the ionization of the gas is effected by passing a high frequency current of preselected magnitude from the source **29** through each of the conductive members **28** that surround the ring-type magnetic cores **27**. Thereafter, the passage of exciting current through the conductive members **28** results in the establishment of an accelerating electric field along the longitudinal axis of the tube.

Subsequently, the selectively operable pulsing source **17** is rendered effective to effect the establishment of an arc discharge between the terminal **12** of the cathode **9** and the electrode **14**. The high field established between the tip **9***a* of the cathode and the plate **18** results in the emission of a high current beam of electrons which are advanced through the aperture **19** provided in the attracting plate **18**. The electrons emitted from the tip of the cathode, after travelling through the aperture **19**, are focused by the electromagnets **22** and **23**, and the focused beam is transmitted to the accelerating section **26** of the tube.

When the focused beam enters the accelerating field established by the excited cores **27**, the neutralizing glow discharge plasma produced near the longitudinal axis of the tube by the intermittent passage of a high frequency current through the conductor **28** effects neutralization

of the beam. More particularly, as the beam is accelerated through the plasma the electrons therein are repulsed and pass through the cylindrical screen segments which are disposed in concentric fashion about the longitudinal axis of the tube. Accordingly, an abundance of positive ions formerly associated with the repulsed plasma electrons remains in the path of the beam and effects neutralization of the beam of electrons. This neutralization accomplished by the positive plasma ions substantially eliminates the intrinsic repulsive forces between beam electrons. Accordingly, as the beam advances through the accelerating field the narrow configuration thereof is maintained until the entire length of the accelerating section **26** has been traversed and the beam is transmitted through a foil target for use in some suitable external application. Additional focusing of the neutralized and accelerated beam by a focusing system similar to the focusing system **21** might be required to preclude the establishment of instabilities within the beam after passing through the target **31**.

In the preferred embodiment of the invention, the accelerator tube **10** is approximately 1000 cm. in length and has a diameter of approximately 25 cm. The cold cathode **9** is proportioned so that a plurality of emissions having a duration of 1 microsecond can be effected prior to the replacement thereof. An ionizable gas which is supplied to the tube from the source **11** is maintained therein at a pressure of approximately 10^{-2} mm. or less. Approximately 250 ring-type magnetic cores, which establish an electric accelerating field of approximately 20 kv./cm. within the tube and thereby effect the acceleration of the beam therein, are arranged along the length thereof so that the beam of electrons passing through the tube has approximately 5 mev. of energy imparted thereto. Neutralization of a beam having a radius of approximately 1 mm. and containing 10^3 to 10^5 amperes of electrons can be effected by approximately 10^7 ions per cubic centimeter which are attainable in a moderate preionized glow discharge. These factors as well as the remaining structural features of the tube, for example, the location of the baffle members **35**, insure that a beam of 10^3 to 10^5 amperes of electrons can be passed through the accelerator for 1 microsecond without the preionized glow discharge becoming an arc discharge.

It should be clearly understood that the foregoing is merely illustrative of a preferred method of and apparatus for creating a narrow beam of accelerated electrons. Numerous modifications of the contemplated mode and of the apparatus for accomplishing the same could be devised by those skilled in the art without deviating from the spirit and scope of the invention. Various features of the invention are set forth in the accompanying claims.

I claim:

1. Apparatus for providing and accelerating an intense narrow beam of electrons which comprises an elongated closed cylindrical housing having a foil target mounted at one extremity thereof adjacent the longitudinal axis thereof, a cold emission cathode mounted within said housing adjacent the other extremity thereof, said cathode having an elongated cone-shaped tip directed along the longitudinal axis of said housing toward said foil target, beam focusing means positioned within said housing in coaxial relation with the longitudinal axis thereof and in spaced relation to the cone-shaped tip of said cathode, means interposed between said cathode and said focusing means for effecting a high field emission of electrons from the tip of said cathode and for directing the emitted electrons to said beam focusing means, a plurality of spaced-apart ring-type cores mounted within said housing in concentric relation with the longitudinal axis thereof, said cores being disposed transversely of the longitudinal axis of said housing and spaced between said focusing means and said foil target, and means for selectively energizing said cores so as to establish a glow discharge within said housing adjacent the longitudinal axis thereof and create an accelerating field in the direction of the outlet extremity of said housing, said glow discharge functioning to neutralize the focused beam of electrons emanating from said focusing means and being accelerated toward said target along the longitudinal axis of said housing so that the beam of electrons is maintained in a narrow configuration.

2. Apparatus for providing and accelerating an intense narrow beam of electrons which comprises an elongated closed cylindrical housing having a foil target mounted at one extremity thereof adjacent the longitudinal axis thereof, a cold emission cathode mounted within said housing adjacent the other extremity thereof, said cathode having an elongated cone-shaped tip directed along the longitudinal axis of said housing toward said foil target, beam focusing means positioned within said housing in coaxial relation with the longitudinal axis thereof and in spaced relation to the cone-shaped tip of said cathode, a plate mounted within said housing in electrical contact therewith between said cathode and said focusing means, said plate having an aperture formed therein adjacent the longitudinal axis of said housing, means for establishing a high negative potential on said cathode relative to said plate, the substantial difference in potential between the tip of said cathode and said plate effecting a high field emission of electrons from the tip of said cathode toward said beam focusing means, a plurality of spaced-apart ring-type magnetic cores mounted within said housing in concentric relation with the longitudinal axis thereof, said magnetic cores being disposed transversely of the longitudinal axis of said housing and spaced between said focusing means and said foil target, and means for selectively energizing said magnetic cores so as to establish a glow discharge within said housing adjacent the longitudinal axis thereof and create an accelerating field in the direction of the outlet extremity of said housing, said glow discharge functioning to neutralize the focused beam of electrons emanating from said focusing means and being accelerated toward said target along the longitudinal axis of said housing so that the beam of electrons is maintained in a narrow configuration.

3. Apparatus for providing and accelerating an intense narrow beam of electrons, which apparatus comprises an elongated housing having a target mounted at one extremity and along the longitudinal axis thereof, a cathode mounted within said housing adjacent the other extremity thereof, said cathode having an elongated cone-shaped tip directed along the longitudinal axis of said housing and toward said target, beam focusing means positioned within said housing in coaxial relation with the longitudinal axis thereof and in spaced relation to the cone-shaped tip of said cathode, means interposed between said cathode and said beam focusing means for effecting a high field emission of electrons from the tip of said cathode and for directing the emitted electrons into said beam focusing means, beam neutralizing means mounted within said housing between said beam focusing means and said target, and means for selectively energizing said beam neutralizing means so as to establish a glow discharge within said housing adjacent the longitudinal axis thereof and create an accelerating field in the direction of said target, said glow discharge functioning to neutralize the focused beam of electrons emanating from said focusing means and being accelerated toward said target along the longitudinal axis of said housing so that the beam of electrons is maintained in a narrow configuration.

4. Apparatus for accelerating electrons in an intense narrow beam which apparatus comprises a housing, means for supplying gas to the interior of said housing, means for ionizing a portion of said gas within said housing, means for effecting an emission of electrons in a narrow beam directed into said gas ionized by said means for ionizing, and energizing means operable subsequent to said means for ionizing, said energizing means being operable to establish an electron accelerating field within said ionized gas in the path of said narrow beam of elec-

trons to accelerate the electrons in said beam, said electrons produced by the ionizing of said gas being repelled out of the path of said beam by electrons in said beam, leaving unrepulsed positive ions of said gas in the path of said beam which act to keep the beam electrons in a narrow beam as they are accelerated.

5. Apparatus according to claim 4 including pulsing means for actuating said means for effecting an emission of electrons as the accelerating field is first being established by said energizing means and prior to the breakdown of said gas by said accelerating field.

6. Apparatus according to claim 4 wherein said means for effecting an emission of electrons in a narrow beam includes a cold emission cathode having a sharp tip disposed within said housing, means for effecting high field emission of electrons from said tip, and beam focusing means for focusing at least a portion of the electrons emitted from said tip into a narrow beam.

References Cited by the Examiner

UNITED STATES PATENTS

3,036,233	5/1962	Petrie et al.	313—63 X
3,052,088	9/1962	Davis et al.	313—63 X
3,099,768	7/1963	Anderson	313—39 X

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