

- [54] **CONCENTRATION AND GUIDANCE OF INTENSE RELATIVISTIC ELECTRON BEAMS**
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- [51] Int. Cl.: **H01j 29/58**
- [58] Field of Search: **328/228; 313/57, 63, 83 R, 313/85 R; 250/398, 500**

3,639,849 2/1972 Bennett..... 328/228

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Attorney, Agent, or Firm—William D. Hall

[57] ABSTRACT

The disclosure relates to an apparatus for producing pulsed and intense relativistic electron beams which by means of linear pinch techniques are focused down to less than 2 mm diameter and preferably less than 1 mm, thereby making possible the generation of an extremely high power density on a selected target. The beams are approximately 30-nsec with a current of 40 ka when 3.5 million volts are applied to the cathode. The disclosure is also concerned with an apparatus providing for the impingement of such beams upon targets which are adapted to make possible the production of transuranic elements in more than microgram quantities.

7 Claims, 5 Drawing Figures

- [56] **References Cited**
UNITED STATES PATENTS
- | | | | |
|-----------|---------|--------------|-----------|
| 3,510,713 | 5/1970 | Bennett..... | 328/228 X |
| 3,516,906 | 6/1970 | Bennett..... | 250/398 X |
| 3,526,575 | 9/1970 | Bennett..... | 250/500 X |
| 3,610,989 | 10/1971 | Bennett..... | 313/83 |

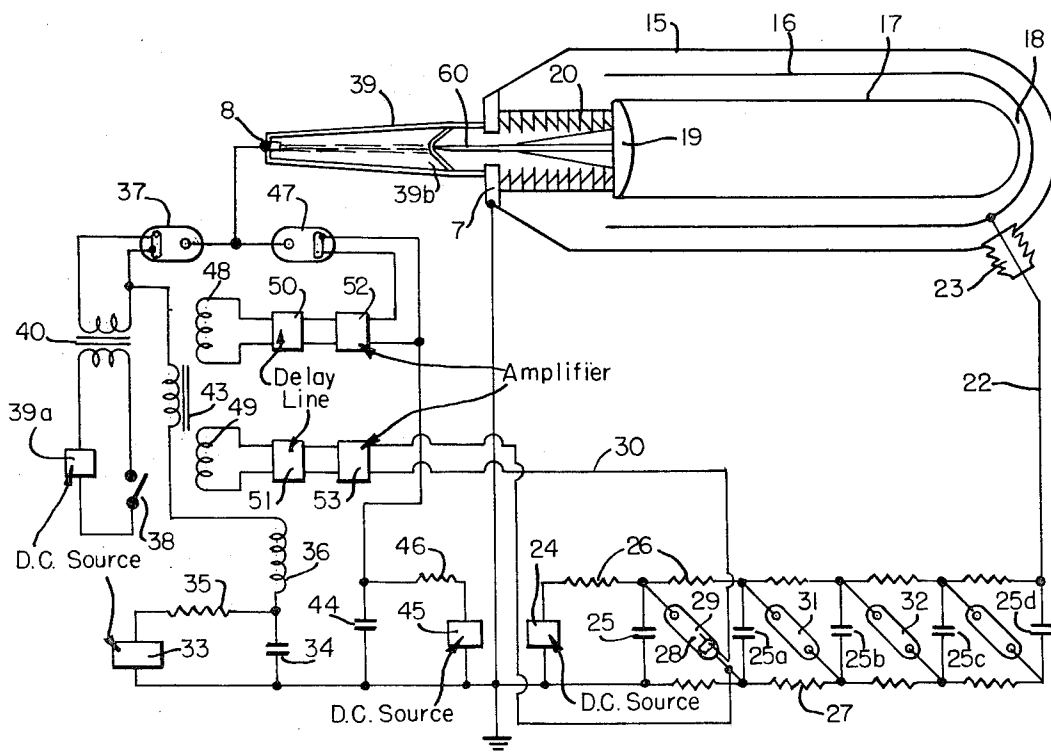


FIG. 1.

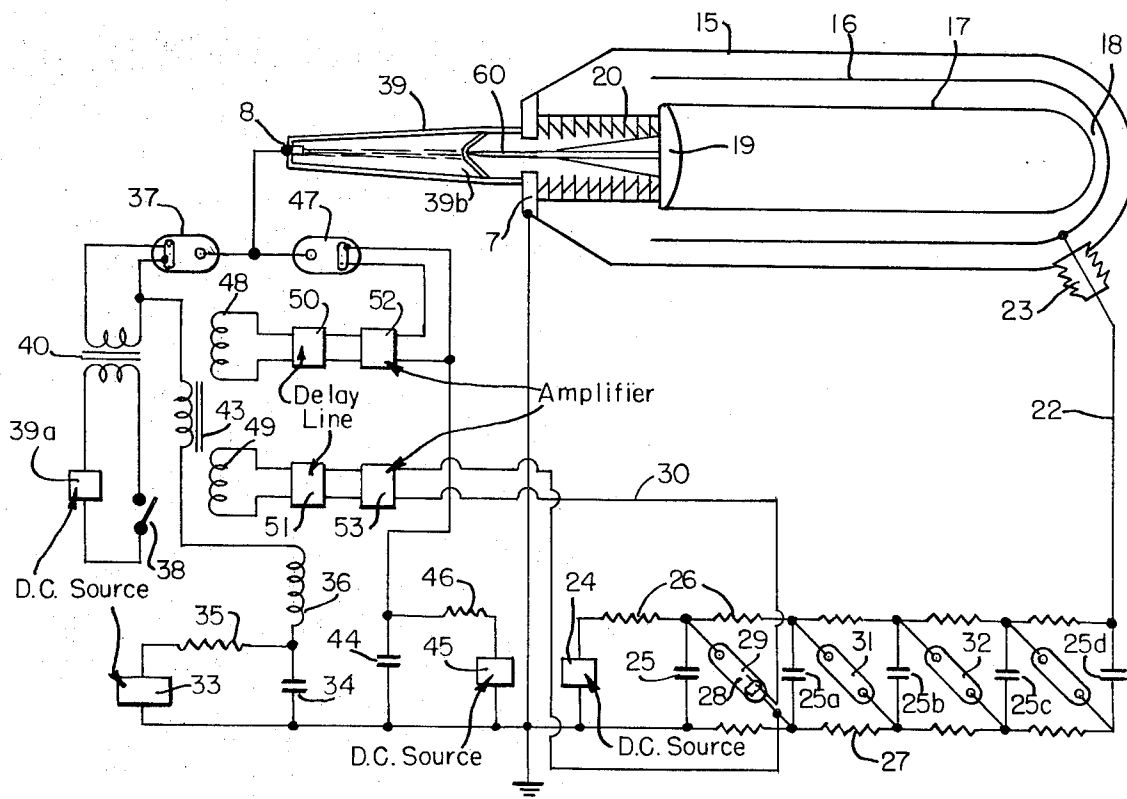


FIG. 2.

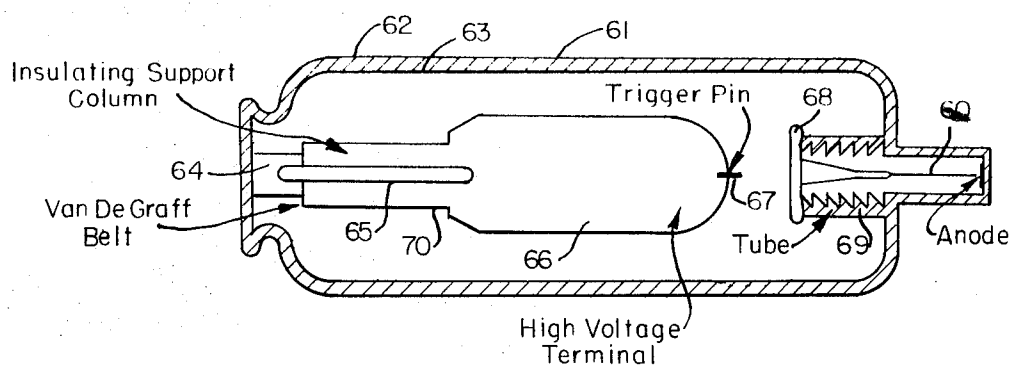


FIG. 3.

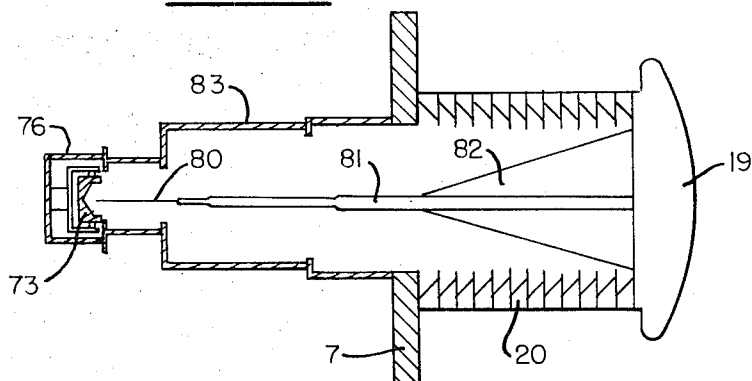
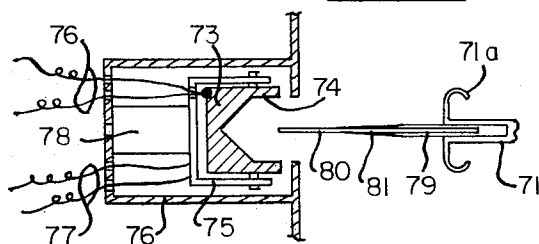


FIG. 4.



FIG. 5.



CONCENTRATION AND GUIDANCE OF INTENSE RELATIVISTIC ELECTRON BEAMS

BACKGROUND OF THE INVENTION

The prior art teaches that a linear pinch may be created by a pulse discharge. Such a linear pinch produces a self-magnetic field and tends to pinch and thus concentrate the flow of electrons within the pinch. In the prior art, this has made possible the production of high-density plasmas, a particular application of which includes the production of transuranic elements in greater than microgram quantities. Such elements are useful as nuclear fuels, radioactive tracer elements, and as radiation sources for the irradiation of various materials. My prior U.S. Pat. Nos. U.S. 3,510,713, issued on May 5, 1970, U.S. 3,516,906, issued on June 23, 1970, U.S. 3,526,575, issued on Sept. 1, 1970, U.S. 3,510,989, issued on Oct. 5, 1971, and U.S. 3,639,849, issued on Feb. 1, 1972, disclose various means and methods for producing an electron beam in alignment with a pinch wherein the pinch will narrow down and further concentrate the electron beam. The present application is a further improvement upon these previous arrangements.

Since machines have been developed for producing these pulsed intense relativistic beams, many varieties of field emitting cathodes have been tried in attempts to reduce electrode damage and increase the current to more than a spacing charge limited value which could be expected from a smooth cathode having the same overall dimensions. These attempts have included metal points, the ends of metal tubes, the end of a boron carbide rod with a much greater resistivity than that of metal, a flat plate with embedded bits of plastic flush with the face, and brushes with wire ends. None of these various forms have proved to be greatly superior to the rest when the interelectrode distance is short enough for the current to be space charge limited.

In a report to the National Research Council rendered in 1930 (unpublished) by W. H. Bennett, the inventor of record, a mechanism was proposed to account for the observed concentration of a discharge upon the surface of a dielectric extending between two electrodes in the direction of an applied high voltage electric field. The operation of the proposed mechanism was demonstrated experimentally by covering more than half of the distance over the dielectric surface between the electrodes with narrow metalized rings transverse to the direction of the field. It was found that this stopped the discharge over the surface and drove it away from the dielectric surface into the open gap and required the same voltage that would have been required if the dielectric had not been there, although more than half of the distance over the dielectric was short-circuited by metal.

SUMMARY OF THE PRESENT INVENTION

It is therefore an object of the present invention to provide an apparatus whereby the entire current of the intense relativistic beam, in some cases more than 200,000 amps, is carried in a thin layer of plasma just above the guide surface in an arrangement of charges and currents which is self-regulating with extreme speed and precision. The pinch effect tends to constrict the current and drive it into the guide or drive it until there is enough excess negative charge in or near the

guide surface to hold most of the beam away from the surface against the pinch effect forces.

It is another object of the present invention to eliminate the necessity for an ionized stream of gas to form the initial pinch for guiding the collimated and pulsed relativistic beam. In producing the intense relativistic beam, the present invention will enable (1) the production of transuranic elements in more than microgram quantities; (2) the production of thermonuclear fusion power in pulse processes so fast and in material of such high density that Bremsstrahlung losses no longer make the process uneconomical; and (3) the production of plasma solid state densities and stellar temperatures with which to investigate the physics of the interior of the stars and other matters of fundamental interest.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates the apparatus for forming the high energy relativistic electron beam, and the improved guide means for guiding the beam to the anode.

FIG. 2 illustrates an alternate means for generating an intense relativistic electron beam.

FIG. 3 is an enlarged view of the discharge portion illustrating the anode, the cathode, and the means for guiding the electron beam.

FIG. 4 is a diagrammatic illustration of an alternate means for guiding the electron beam.

FIG. 5 is a diagrammatic illustration of means for guiding the electron beam and a novel cathode for delivering the beam into a calorimeter.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

It has been found that the intense relativistic pulse discharges from the new and improved machines could be concentrated upon a dielectric surface and conveyed across a gap with a self-energizing pinch. In the present invention, a 2 mm pyrex glass rod 20 cm long was inserted in the center of the cathode as illustrated in FIGS. 3 and 5. Substituting glass tubing with the same outside diameter gave the same result. Larger tubing worked also up to approximately 1 cm in diameter. A glass ribbon 2 mm thick and 15 mm wide guided most of the beam along the flat faces of the ribbon to the cathode. From these and other observations it is evident that nearly the entire current of the beam, in some cases more than 200,000 amps, is being carried in a thin layer of plasma just above the guide surface in an arrangement of charges and currents which is self-regulating with extreme speed and precision. The pinch effect tends to constrict the current and drive it into the guide and does so until there is enough excess negative charge in or near the guide surface to hold most of the beam away from the surface against the pinch effect forces. There of course cannot be a pinch effect unless at least some of the space charge of the beam in the thin beam channel is neutralized by positive ions. Because the guide must have a negative charge, the ions in the beam channel must fall back towards the guide and be neutralized so that there must be a continuing supply of ions to the thin cylindrical beam channel either by ionization of residual gas, from ions knocked out of the guide, or by ionization of the beam of neutrals in the beam channel which have come from the guide. In the various embodiments to be hereinafter illustrated, the ions come from a variety of sources.

FIG. 1 illustrates one means for producing the intense relativistic electron beams. This means comprises a tank 15 within which are suspended two coaxial cylindrical electrodes 16 and 17. The rounded caps on 16 and 17 are held much closer to each other at gap 18 than the distance elsewhere between 16 and 17. At the other end of the inner electrode 17 is a high voltage electrode 19 which is supported on an insulated bushing 20. All of the tank except the inside bushing 20 is filled with an insulator such as oil, or other insulating gas or fluid. The inside of the bushing is evacuated to pressures less than one-tenth of a micron by means of suitable vacuum pumps.

The intermediate electrode 16 is charged to a high voltage through a wire connected at 22 which extends through bushing 23 into wall 15. This wire is connected to a source of high voltage shown in the lower part of FIG. 1, and may be constructed in any of many ways familiar to those skilled in the art.

In FIG. 1, a power supply 33 is used for charging a condenser 34 through a resistor 35. The condenser is connected through an inductance 36, and a transformer 43 to a triggered gap or thyatron or other high voltage valve 37. The device at 37 is triggered by closing the switch 38, which connects the high voltage from the power supply 39a, to the transformer 40. This supplies a potential to the anode 8 of the pinch tube 39 for the purpose described below.

The magnitude of the inductance 36 is selected to slow down the discharge in the pinch tube 39, enough to produce ionization throughout the tube but not enough to pinch down the discharge within less than about 10 to 100 microseconds, if at all. This is called a pre-ionization and assists in readying the conditions within the pinch tube 39, so that when condenser 44 is connected across the tube, a well-formed pinch will form promptly, i.e., within less than about 5 microseconds.

In one of the preferred forms of the invention, the pre-ionization is not utilized. Instead, the relativistic beam becomes self-pinching as it travels down the surface of the pinch guide 60. In this embodiment, the ions utilized in the pinch effect do not come from gas contained within the pinch tube 39, but rather from ions knocked out of the guide, or by ionization by the beam of neutrals in the beam channel which have come from the guide. The ionized gas column may be eliminated in this embodiment. The gas pressure in space 39b is in the order of 10^{-4} Torr. In FIGS. 2 and 3 it is contemplated that the entire tube will be evacuated to a vacuum.

The power supply 45 charges the condenser 44 through the resistor 46. The condenser is connected to the trigger gap or other thyatron 47 to apply high voltage in a steep pulse which will cause the residual gas in 39 to ionize and form into an ionized column which is axially aligned with the axis of the pinch guide 60.

The transformer 43 has two secondary windings 48 and 49. The output from the winding 48 is connected through a delay line 50 to the amplifier 52, which is connected to the triggering device 47. The other winding 49 is connected to a delay line 51, to an amplifier 53, which is connected to the triggering device 28, which fires the high energy pulse.

The delay in either 50 or 51 is set so that the high energy electron pulse from cathode 19 is produced just before the pinch within the tube 39 is drawn down to

its minimum diameter. For most dimensions of the machine, and values of electrical constants in the various parts of the complete equipment, the delay in delay line 51 should be set at 0, or this delay line should be removed and the delay line 50 should be set at some value less than about 10 microseconds.

The direct current supply 24 provides a potential on the order of 50,000 or more volts which charges a bank of condensers 25, 25a, etc., in parallel through high resistance 26 and 27 which are preferably more than 1,000 ohms each.

In FIG. 1, only five condensers 25, 25a, 25b, 25c, and 25d are shown together with their associated spark gaps 29, 31, 32, etc., and resistors 26, 27, etc. In actual practice, more condensers with associated components must be used and, for most applications, involve between 20 and 200 such stages. In the following description, it should be understood that a large number of stages are utilized rather than the five stages illustrated in FIG. 1.

The triggering device is illustrated at 28. It comprises a spark gap in which the outer one of the electrodes has a hole in it along the axis of the two electrodes. Inside the hole is held a wire, the end of which at 29 is near the opening towards the other electrode. This wire is insulated so that when a high voltage is suddenly applied to it through a wire 30, a small spark will jump from the end of 29 to the surrounding outer electrode. This causes a spark over the gap and suddenly connects the high voltage end of the first condenser 25 to the low voltage end of the second condenser 25a and applies a voltage across the next spark gap at 31 which is much greater than the break down voltage of that gap. This over-volts the next spark gap 32 even more, and so on, sparking over the next of the spark gaps and suddenly connecting all the condensers 25, 25a, 25b, 25c, and 25d, etc., in series, applying the total voltage to the intermediate electrode 16. Instead of the triggered gap described above, a thyatron or any of the high voltage valves familiar in the art may be used.

When the electrode 16 attains a sufficiently high charge by reason of the condensers 25, 25a, etc., being connected thereto, the high voltage discharges across the gap 18 to the tube 17 thus resulting in a discharge from the high voltage electrode 19, establishing a concentrated beam of electrons which is projected along the axis of tube 39 and over the surface of the pinch guide 60.

Coordinated with this discharge, another discharge is caused to occur between electrode 8 and the grounded electrode 7 through the residual gas in tube 39. This latter discharge, which will be referred to as a pinch, draws down into an ionized column within tube 39. The values of components 33-36 and 43-53 are so selected as to properly coordinate the two discharges. The coordination just referred to is mainly achieved by proper selection of delay lines 50 and 51 as explained above. The first thing to occur is the preliminary ionization of the residual gas in tube 39 due to the triggering of valve 37. The second discharge then occurs which results in the final ionization within tube 39 due to the triggering of valve 47 so that there exists within tube 39 a pinch which is drawn down to its optimum at the time of discharge from cathode 19.

Another alternate method of producing the high energy relativistic beam is by the well known methods used in Van De Graff electrostatic generators. This em-

bodiment is illustrated in FIG. 2. The entire apparatus is contained within a double wall or other insulating shell 61 which has a first outer shell 62 and an inner shell 63. The space between may be evacuated to a vacuum, or may be filled with an insulator such as oil, or other insulating fluids or gasses. A high voltage battery or other current generating source 64 is contacted by the Van De Graff belt 65 which in turn charges the high voltage terminal 66 into the megavolt range. When the electrode has attained a sufficiently high voltage, a high pressure spark-over occurs from trigger pin 67 to the cathode base member 68. The cathode base 68 is separated from the tube by means of an insulating cylinder 69. Likewise, a high voltage terminal for the Van De Graff generator is separated from the tube by means of an insulating column or support 70. If the high voltage means 64 comprises a battery of 50,000 volts, or other voltage generating means which will achieve a voltage in the range of 50,000 volts, the Van De Graff generator may accelerate its voltage to as high as 5 megavolts before it fires.

DESCRIPTION OF THE BEAM GUIDES

As was pointed out previously, one of the problems presented in pulsing high energy intense relativistic beams has been the electrode damage to the cathode when the high energy pulse is fired. A cathode which has been found to be particularly free from electrode damage and other destructive effects is one in the form of a door knob illustrated in FIG. 5. The cathode 71 is approximately 5 cm in diameter and is curved back upon itself at 71a to prevent or suppress the tendency for field emission to be discharged radially from the cathode support in a wasteful and destructive manner. The door knob cathode is constructed to minimize this by forming all parts of the cathode support structure with the large radii of curvature and using small radii of curvature only at the parts of the cathode from which the field emission is desired. The cathode itself may be formed of copper, steel, aluminum or chromium plated copper. In normal operation a pulse current of 40,000 amps and 30-nsec duration is obtained when 3.5 megavolts is applied to a cathode located approximately 5 cm from the anode plate. Assuming the current density is approximately the same as the space charge limited current density to be expected from a parallel plane electrode arrangement.

The object of the current invention is to provide a "guide pinch" means for concentrating this intense pulsed relativistic beam into a small diameter and thereafter guide the beam to a preselected target. This beam guide is illustrated at 80 in FIG. 5. The beam guide comprises a 2 mm pyrex glass rod approximately 20 cm long which is inserted in the center of the door knob cathode 71 illustrated in FIG. 5.

A test anode is also described in FIG. 5. In FIG. 5 the glass guide delivers the high energy beam into a calorimeter. The graphite cup 73 is held within a copper cup 74 which is in turn supported by a 0.001 inch stainless steel sheet 75 which serves as a current shunt for the high voltage beam. The potential across the shunt is the measure of the current delivered to a calorimeter. The temperature rise of the calorimeter is also recorded and measures the total amount of energy delivered. The potential received by the anode is measured via conductors 76 while the shunt current is measured

through the conductor 77. An insulating support means 78 provides the support for the calorimeter.

The beam guide disclosed in FIG. 5 is particularly efficient. It comprises an initial portion of 4 mm tubing 79 which is inserted into the door knob cathode, with 2 mm tubing 80 telescoping into the 4 mm tubing and extending the rest of the way to the anode. The middle draw portion 81 provides the transition for the beam guide. It has been found that this type of beam guide will deliver at least half of the stored energy to the calorimeter. It was quite apparent during tests of this invention that the entire current was carried in a thin layer of plasma just above the guide surface in an arrangement of charges and currents which was self-regulating with extreme speed and precision. The pinch effect tends to constrict the current and drive it into the guide and does so until there is enough excess negative charge in or near the guide surface to hold most of the beam away from the surface against the pinch effect forces.

This particular form of the pinch effect might be appropriately called the "guide pinch" and is characterized by pinched cylindrical shells supported above the guide by excess negative charges embedded in the guide and secondary electrons ejected from the guide and turned back to the guide by pinch effect magnetic fields.

If the spacing between the end of the guide 80 is too large (more than about 1 cm) some of the beam misses the cup and strikes the metallic end of the drift tube. From this it is evident that the guide pinch concentrates and holds the beam next to the guide as it travels the length of the guide. There must be a source of ions with which to neutralize some of the space charge of the beam over the distance from the guide end to the anode. Otherwise, the beam is dispersed sharply by space charge as it travels beyond the guide.

When the tube is operated at about 5 million volts, and the end of the guide is closer than 2.5 cm from the graphite, white-hot graphite particles are blasted out of the cup on a channel on axis in the graphite of about 0.5 mm in diameter and 2-6 mm deep. These hot graphite particles come back in some cases with sufficient force to shatter several centimeters of the glass guide. Those that miss the guide travel the full length of the tube, some 60-100 cm. It is believed that ions from the graphite have time to travel back and neutralize enough of the space charge to permit the beam to pinch to a diameter of less than 0.5 mm during enough of the pulse to allow the beam to blast out the narrow channel in the graphite.

The apparatus illustrated in FIG. 3 was developed to minimize the tendency for field emission to be discharged radially from the cathode support. It was desired to suppress the so-called "shank fire" by utilizing to the fullest the magnetic field due to the current in the cathode support. The apparatus is intended to sufficiently intensify the azimuthal magnetic field at the surface where field emissions might occur in order to turn the emitted electrodes back towards the surface. In this embodiment, the entire cathode 81 was made much smaller in diameter except for a conical transition 82 to the large diameter high voltage cap 19 which receives the high energy pulse. In this embodiment, the drift space was also extended by the insertion of a section of 10 cm diameter pyrex glass pipe 83 with a return current from the calorimeter carried with copper straps

outside the glass pipe. More than 50 percent of the energy stored in the generator was received in the calorimeter when 15 cm glass pipe section was used and when the length of the glass guide was also 15 cm. Less than one-half as much energy was delivered when both the glass pipe sections and the glass guide were lengthened to 90 cm. In this embodiment again, the ions which serve to suppress and pinch the plasma discharge come from the ionization of residual gas within the cylinder 83, or by ions knocked down to the guide, or by ionization of the beam of neutrals in the beam channel which have come from the guide.

While the embodiments illustrated in FIGS. 2-5, do not necessarily rely on the ionization of gas contained within the cylindrical tubing, they do not rely on the pinch effect magnetic field, and ions that were produced from one source or another.

As the high voltage electrons enter the pinch, they also comprise an increasing electron current and this induces electric fields which tend to produce electric currents in the opposite direction in the vicinity of the high voltage beam. The component of velocity in the reverse direction given to the pinch electrons by the induced electric fields produces a force upon these pinch electrons which is radially outwards due to the interaction of that velocity component with the self-magnetic field of the injected high voltage electron beam. This radially outward magnetic force is in addition to the outward electric force due to excess negative charge, mentioned above. This pinch effect was previously described in Physical Review, Vol. 90, page 398, 1953, in a paper entitled "Magnetically Self-Focusing Discharge."

The guide pinch means illustrated in FIGS. 1-5 are preferably formed of glass or fused quartz. These materials are preferred inasmuch as certain organic dielectrics may be partially decomposed by the plasma. Once this occurs, the decomposition components contaminate both the high voltage tube and the pumping system.

When the velocity of the pulsed beam approaches the speed of light, the electric current carried by the electrons becomes magnetically self-focusing. This tends to hold the electrons close to the glass rod or guide pinch means illustrated above. The propagation of the plasma streamers along the surface of the glass results in the very prompt (within the order of a nanosecond) production of ions by the impact of the high voltage electrons on the surface of the dielectric. These ions together with the high voltage electrons comprise a low density plasma in which the ions neutralize in large measure the space charge of the high energy electrons. The thickness of the plasma layer above the surface of the dielectric rod which is rendered conductive by vir-

tue of the ion sheath is of the order of one-sixteenth inch.

As was pointed out in my previous U.S. Pat. No. 3,526,575, which issued on Sept. 1, 1970, a sharply pinched intense relativistic electron beam can be used to (1) produce transuranic elements in more than microgram quantities, (2) produce thermonuclear fusion power in pulse processes so fast and in material of such high density that Bremsstrahlung losses no longer make the process uneconomical, and (3) produce plasma of solid state density and stellar temperatures with which to investigate the physics of the interior of the stars and other matters of fundamental interest.

I claim:

1. An electron beam apparatus comprising
 - a. electron beam producing means for concentrating an electron beam discharge having a self-magnetic field,
 - b. guide pinch means for directing and confining said discharge,
 - c. means for actuating said discharge.
2. Electron beam apparatus as claimed in claim 1 wherein said guide pinch further comprises a dielectric member within a tube, said member extending from a cathode electrode at one end of said tube to the vicinity of an anode electrode at the other end of said tube.
3. Electron beam apparatus as claimed in claim 2 wherein said dielectric member comprises a glass rod.
4. Electron beam apparatus as claimed in claim 1 wherein said guide pinch means is formed of a plurality of dielectric tubes of decreasing diameter, the smaller of said tubes terminating near an anode situated at the discharge end of said apparatus.
5. Electron beam apparatus comprising
 - a. electron beam producing means for concentrating an electron beam discharge having a self-magnetic field,
 - b. converging means aligned with said electron discharge for directing and converging said discharge, said converging means including a guide pinch means arranged to receive said discharge,
 - c. means for producing an electron guide beam in alignment with said discharge,
 - d. means for initiating said guide beam before said electron discharge is initiated.
6. Electron beam apparatus as claimed in claim 5 wherein said converging means comprises a converging tube, the first end of which is positioned to receive the beam from said cathode, the other end including a target for said beam.
7. Electron beam apparatus as claimed in claim 5 wherein a pinch means extends from said cathode to said first end of said converging means.

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