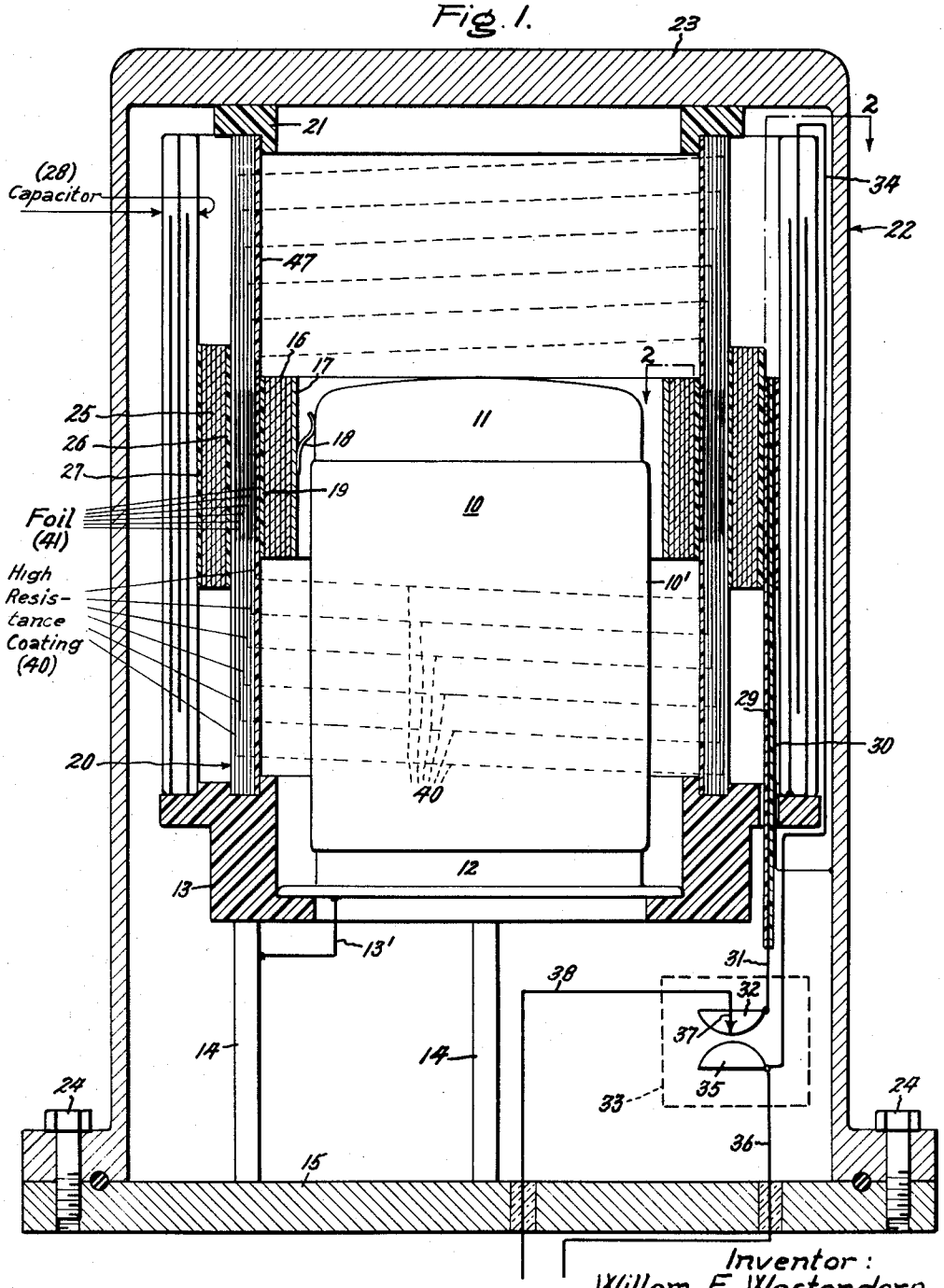
May 31, 1960 W. F. WESTENDORP 2,939,086

HIGH VOLTAGE TRANSFORMER

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Fig. 1.

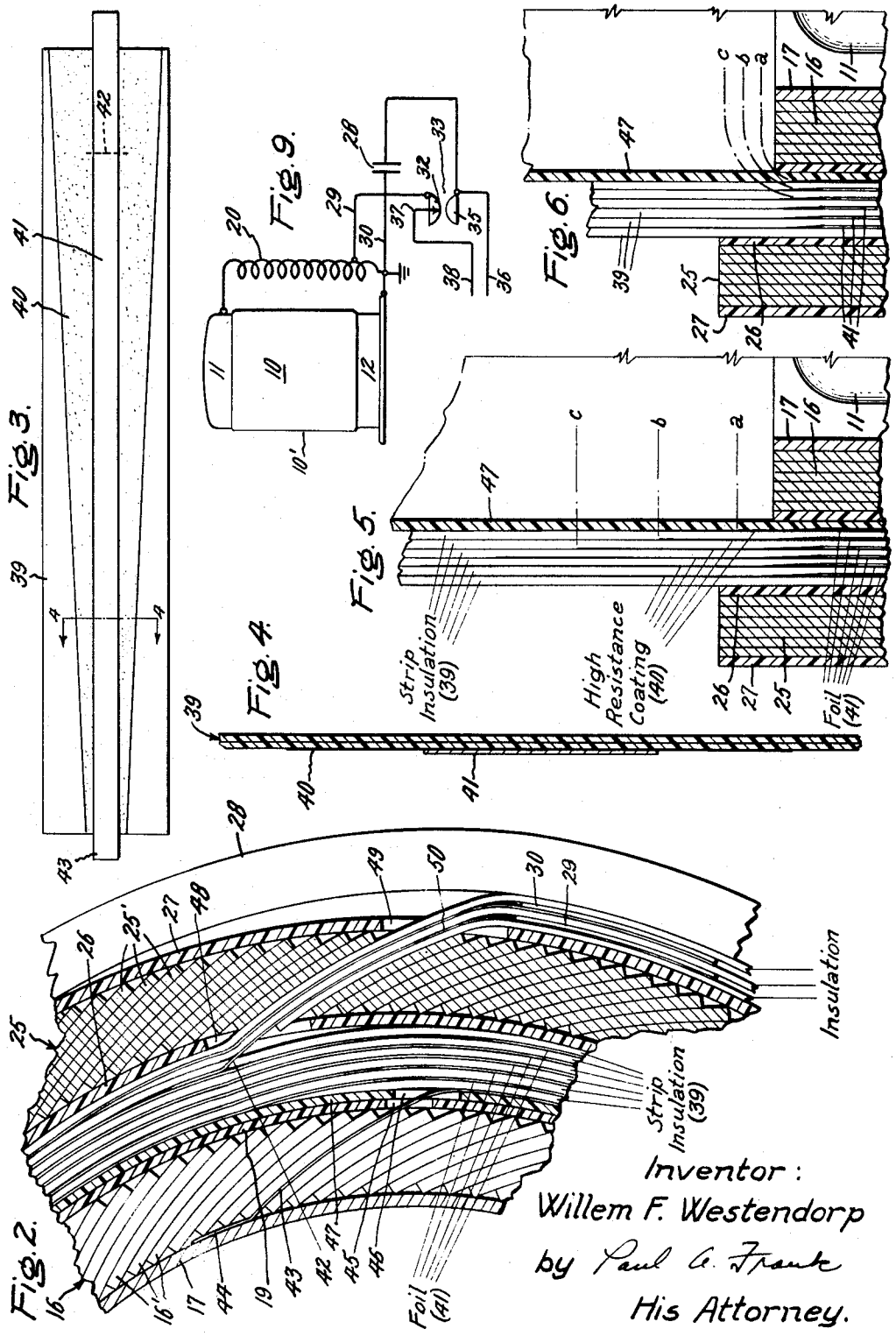


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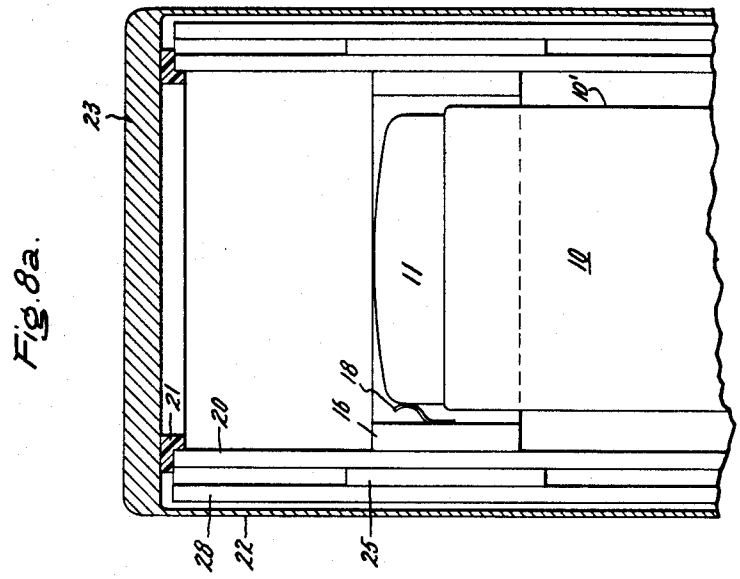


Fig. 8a.



Fig. 8b.

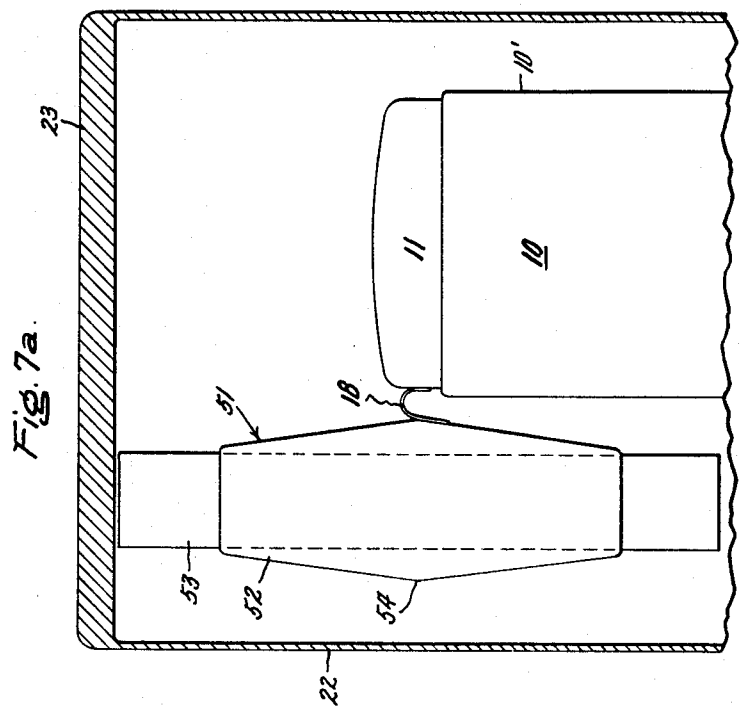


Fig. 7a.

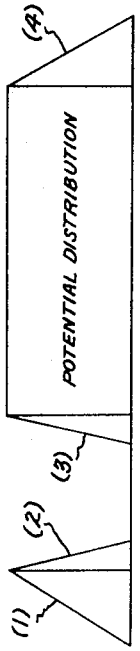


Fig. 7b.

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HIGH VOLTAGE TRANSFORMER

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5 Claims. (Cl. 328—233)

This invention relates to high voltage transformers and associated apparatus. While transformers in accordance with this invention may be utilized with a wide variety of apparatus, they are well suited for pulsed operation with high voltage charged particle accelerating apparatus and are particularly described in this connection.

High voltage accelerating apparatus generally includes a high potential electrode and a low potential electrode defining therebetween an accelerating region. The high potential terminals of a transformer are connected to these electrodes and pulsed energy is supplied to the transformer. Accelerating apparatus of this type may utilize voltage pulses of the order of 300 kilovolts with a pulse duration of the order of a fraction of a microsecond.

The high peak voltage of these pulses results in extremely high potential gradients. Therefore, accelerating apparatus of this type is generally enclosed in a container or enclosure which is formed of conducting material. This enclosure is maintained at or very near ground potential so that the hazards to operating personnel are minimized. Generally the entire accelerating apparatus including a power supply, spark gaps, pulse transformer and accelerator tube are contained within the enclosure. This results in a number of high voltage gaps within the enclosure having high voltage gradients thereacross that must be insulated with some form of dielectric, for example, a gas or solid dielectric. Therefore, it is apparent that it is particularly desirable to provide a transformer for use in a charged particle accelerating apparatus which minimizes the number of high potential gaps which must be insulated.

In any transformer it is necessary to provide sufficient insulation between the high potential portion of the transformer winding and the magnetic core which is maintained at low or ground potential. Therefore, it is apparent that it would be particularly desirable to provide a transformer winding assembly wherein the likelihood of potential breakdown of the transformer is minimized while at the same time providing maximum flux linkage with the transformer winding with minimum power consumption.

Therefore, it is an object of this invention to provide an improved charged particle accelerating apparatus.

Another object of this invention is to provide an improved transformer.

It is also an object of this invention to provide an improved transformer having a substantially constant potential gradient field between the windings thereof to minimize electrical breakdown.

A further object of this invention is to provide a pulsed transformer having a part of the transformer core at low potential and a part of the transformer core at high potential.

An additional object of this invention is to provide an improved accelerating apparatus having a minimum number of high potential gradient gaps whereby the probability of electrical breakdown is minimized.

According to an important aspect of this invention there is provided in an accelerator apparatus including a high potential electrode and a low potential electrode defining an accelerating region. A transformer, having an inner magnetic core member which is maintained substantially at the potential of the high potential electrode, is located in proximity to the accelerating region. A conducting winding assembly having a substantially constant potential gradient field is coupled to this inner core. An outer magnetic core is coupled to the winding assembly and is maintained substantially at the potential of the low potential electrode so that the probability of potential breakdown in the apparatus and the physical size of the apparatus are minimized.

Other objects and important aspects of this invention will become apparent from the following specification and claims when taken with the figures of the drawing wherein Figure 1 illustrates a preferred embodiment of this invention; Figure 2 illustrates a detailed section 2—2 of Figure 1; Figures 3 and 4 show development and elevation layouts respectively of the transformer winding of this invention; and Figures 5 through 9, inclusive, show diagrammatic illustrations useful in explaining this invention.

Figure 1 illustrates an accelerator tube **10** having a high potential electrode **11** and a low potential electrode and base member **12** separated by a suitable dielectric sleeve **10'**. The electrodes define an accelerating region therebetween. The accelerator tube is supported by support member **13** which is supported by rods **14** from conducting base **15**. Surrounding the upper portion of the accelerator tube is the inner magnetic core **16**. The core **16** is provided with an inner conducting member **17** which is conductively connected to high potential electrode **11** through spring connector **18**. The outer surface of inner core **16** is provided with an insulating coating **19**. The inner core is supported by winding assembly **20** which is tightly wrapped around the inner core and is supported by insulating support member **13**. In order to provide the necessary rigidity to winding **20** an upper cap **21** is partially inserted into the winding assembly and forces the winding assembly down onto support **13**.

Conducting enclosure **22** having a heavy conducting top member **23** is drawn down against cap member **21** by bolts **24** to thereby complete a rigid, and if desired, hermetically sealed enclosure for the accelerator tube and the associated apparatus. The outer magnetic core **25** tightly surrounds winding assembly **20** and is provided with an inner insulating retainer member **26** and an outer insulating retainer member **27**. A cylindrical capacitor **28** surrounds core **25** to provide a partial support for the outer core and an energy storage device for the primary circuit of the transformer.

Leads from the winding assembly **20** are brought out through outer core **25** and make contact with metal strips **29** and **30**. These strips form the primary leads to the transformer. Strip **29** is connected to the outside turn of the winding assembly and makes contact through lead **31** to spark gap contact **32** of spark gap assembly **33**. Lead **30** is connected to the outer low potential end of the foil winding of the winding assembly and is conductively connected to conducting base **15** by a lead **13'** and to one side of capacitor **28** which is shown in semi-schematic form. The other side of capacitor **28** is connected by lead **34** to spark gap discharge contact **35**. Electrical power to charge capacitor **28** is provided through conducting base **15** and lead **36** which penetrates base member **15** through any satisfactory form of insulating bushing. Auxiliary electrode **37** is connected through lead **38** to a suitable trigger source which provides the necessary potential to initiate breakdown of the spark gap **33**.

Figure 2 illustrates, in detail, the construction of the

transformer proper. The inner core **16** is formed by placing a plurality of silicon strip steel members **16'** between the boundaries defined by inner brass retaining member **17** and outer insulating retaining member **19**. Any suitable magnetic material may be utilized for the core members. For example, the steel strips may be formed of cold rolled high silicon sheet steel approximately 2 mils thick which has been annealed in pure dry hydrogen to obtain high permeability characteristics. These strips of steel are driven between cylinders **17** and **19** until a tightly packed array is obtained. The outer core is formed in a similar manner by driving steel strips **25'** between insulating retaining members **26** and **27**.

In order to obtain an understanding of the formation of the winding assembly reference is made to Figures 3 and 4 as well as the showing in Figure 2 of the drawing. The winding assembly is prepared by forming on top of a plurality of strips **39**, of dielectric material, a tapered high resistance coating **40**. For example, the dielectric material may consist of solid sheets of polyethylene or may consist of any other satisfactory insulating material. A plurality of sheets are used so that there will be little probability of punctures in one sheet registering with punctures in a second sheet thereby minimizing the probability of potential breakdown. In this embodiment four layers of 5 mil thick polyethylene are utilized.

At one end of the polyethylene sheets the high resistance coating is approximately as wide as the inner magnetic core **16** is long. This coating tapers uniformly toward the other end of the sheet where it has a width approximately the same as the width of polyethylene sheet **39**. The resistivity of the coating is chosen so that the edges of the coating can be charged within a short time to the same potential as aluminum foil sheet **41**; for example, a charging time of the order of .01 microsecond.

In addition, the resistivity must be high enough so that only a small amount of energy is dissipated in the coating by eddy currents introduced by the magnetic flux, for example a loss of less than 1 watt second. Within these limitations a surface resistivity of from 100 to 1000 ohms "per square" of the coating is satisfactory. Such a coating can be obtained by spraying a dilute solution of conducting material in an inherent binder onto the polyethylene sheet. For example, a dilute solution of material, commonly known as aquadag, is sprayed on to the sheet to obtain the correct resistivity.

On top of the high resistance coating a thin strip of conducting foil **41** is placed. A slit **42**, through which the necessary connecting lead to the outside turn is passed, is formed in the polyethylene and high resistance coating.

The winding assembly is formed by connecting end **43** of aluminum foil **41** to brass cylinder **17** at region **44**. This connection may be formed by any suitable means such as spot welding or soldering. Strip **41** extends through window **45** in insulating cylinder **19** and through window **46** in insulating cylinder **47**. The laminations **16'** are then driven into place between members **17** and **19** with foil end **43** passing between two laminations. The winding is continued, in this example, in a clockwise fashion up to the end which is brought through window **48** in cylinder **26** and through window **49** in outer insulating cylinder **27** to make contact with copper strip **30**. The other terminal of the primary winding of the transformer is formed by passing foil **50** through slit **42** in the polyethylene and suitably bonding it to foil strip **41** by spot welding or other satisfactory means. The other end of foil **50** is connected to copper strip **29**. The laminations **25'** of the outer core are then driven into place.

It will be noted that in the practice of this invention there are only two small air gaps in the magnetic circuit between inner core **16** and outer core **25**. Since the cross section of the flux in the short air gap is far greater than in the iron, as can be shown by appropriate flux plotting, the magnetization current required by this transformer core is relatively small.

Figures 5 and 6 illustrate the specific advantages obtainable with the graded potential distribution in the solid dielectric provided by the practice of this invention. Figure 5 shows equipotential planes *a, b, c* extending from the ends of high resistance coating **40**. These are effected since, the edges of the high resistance coating are charged to the potential of the foil strip, in this embodiment, within .01 microsecond. Therefore, substantially uniformly spaced equipotential planes are provided between ground and the transformer inner magnetic core and thereby with respect to the high potential electrode. It is apparent that the likelihood of potential breakdown in this transformer is greatly lessened by the presence of the graded potential within the solid dielectric.

This is readily apparent from a consideration of the showing in Figure 6 of the drawing wherein equipotential lines *a, b* and *c*, in a winding without the high resistance coating **40**, are seen to be very closely grouped about the outer corner of inner magnetic core **16** and relatively close to the high potential electrode **11** of the accelerator tube thereby increasing the likelihood of potential breakdown.

It is apparent that the same potential distribution could be obtained by means of a tapered aluminum foil of the same dimensions as the high resistance coating. However, this would result in the magnetic flux being prevented from taking the shortest path from core to core by the shielding effect of the metal foil. The flux would have to pass up and around the top of the winding and down and around the bottom of the foil winding. In this case substantially all of the primary power would be wasted in the magnetization of the elongated magnetic gaps.

Figures 7 and 8 illustrate a further advantage of the practice of this invention. In these figures like members are designated by the same reference numerals. Figure *7a* illustrates a form of accelerator apparatus wherein accelerator tube **10**, having high potential electrode **11**, is oriented in proximity to high potential bar transformer **51** which includes a high potential winding **52** on core **53**. Figure *7b* shows the potential distribution that could be expected in such an apparatus. A high potential gradient (1) exists between the inner surface of enclosure **22** and the outer high potential surface **54** of bar transformer **51**. A high potential gradient (2) exists from surface **54** to the surface of core **53**. A similar high potential gradient (3) exists between the transformer core and the outer surface **54** of the winding **52**. Also there is a high potential gradient (4) from high potential electrode **11** to the inner surface of enclosure **22**.

Figures *8a* and *8b* illustrate apparatus incorporating the practice of this invention wherein there is only one region of high potential gradient, the region (1) through the winding assembly **20**. That is, a gradient exists in the winding assembly only. As has already been discussed, the application of the tapered high resistance coating to the solid dielectric of the winding assembly provides a substantially uniformly graded potential throughout the dielectric winding so that the likelihood of potential breakdown is substantially minimized.

Thus, in the assembly illustrated in Figure 8, relatively little protection against arc-breakdown within the enclosure is necessary and the physical size of the enclosure can, accordingly, be reduced. The concentric arrangement of the transformer winding assembly and cores with respect to the accelerating region also reduces the physical size of the apparatus.

Figure 9 illustrates an equivalent schematic circuit of apparatus incorporating this invention wherein like portions are designated by like reference numerals. In this embodiment the winding assembly **20** consists of a twenty-three turn autotransformer wherein the base **12** of the accelerator tube **10** forms a low potential electrode and is maintained at ground potential. One side of capacitor **28** is maintained at ground potential and the

other side is coupled to electrode 35 of spark gap 33. The outer turn of the winding assembly is connected to electrode 32 of the spark gap 33 and auxiliary triggering electrode 37 is provided with a trigger pulse through lead 38. Power to charge capacitor 28 is provided through lead 36. When a trigger pulse causes an arc-breakdown between electrodes 32 and 35, current flows through the single primary turn of winding assembly 20 and provides a high voltage short duration pulse between high potential electrode 11 and low potential electrode 12. It will be appreciated that the terms high potential electrode and low potential electrode are relative terms used to define the potentials with respect to a given potential, for example ground, in that a high potential may be a high negative potential with respect to ground or alternatively a high positive potential with respect to ground.

It will be readily apparent that this invention has been described with particular reference to a specific embodiment thereof; however, it should also be appreciated that the practice of this invention can be carried out with a wide variety of accelerating apparatus and that the novel features of this invention may be incorporated in any number of different types and varieties of structures without departing from the spirit and scope of this invention.

The specific materials herein discussed are also given merely by way of example and are not considered to be limiting since any satisfactory conducting material can be used to form the transformer winding and any form of conducting high resistance material can be used to obtain the desired graded potential in the dielectric of the winding assembly. For example, the conducting high resistance coating can have a tapered resistance characteristic from the center of the winding toward the ends thereof in order to obtain a particular desired potential distribution. It is also possible to obtain a distributed uniformly graded potential characteristic by other means than forming a high resistance conducting coating on sheet dielectric material and then wrapping it into a circular form. For example, the winding 41 may have a tapered resistance characteristic varying from high conductivity near the center portions thereof to very low conductivity at the outer ends so that a high resistance conducting coating is not necessary.

In view of the foregoing, it is apparent that there is provided a novel accelerating apparatus and transformer construction wherein the necessary size of the accelerating apparatus is greatly reduced as a result of the practice of this invention and that a novel means of minimizing the likelihood of potential breakdown within the transformer is also provided. That is, only one high potential gradient region exists in the specific transformer and accelerator tube apparatus herein described.

While this invention has been described in connection with accelerator apparatus, it will also be readily apparent that this invention can be practiced to provide high potentials for other purposes than accelerating charged particles, with similar attendant advantages.

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 claim as new and desire to secure by Letters Patent of the United States is:

1. In an accelerator apparatus including an accelerating region comprising a high potential electrode and a low potential electrode, a transformer system comprising an inner magnetic core, a lead for electrically connecting said inner magnetic core to said high potential electrode, a sheet of insulating material, high resistivity material coated on said sheet in the form of a trapezoidally-shaped pattern, said high resistivity material having a resistivity value such that the charging time constant of said high resistivity material is of the order of 0.01 microsecond, and a conductor in electrical contact with the bisecting

center line of said trapezoidally-shaped high resistivity material and electrically connected to said magnetic core at the small end of said trapezoidally-shaped high resistivity material, said insulating material and said conductor being wound about said magnetic core and said high potential electrode to form a winding assembly with the edge of said high resistivity material extending progressively greater distances in a direction away from said magnetic core and said high potential electrode as said winding progresses outwardly from said inner magnetic core.

2. The transformer system as defined in claim 1 and an outer magnetic core surrounding said winding assembly and electrically connected to said conductor at the large end of said trapezoidally-shaped high resistivity material, and a lead for connecting said outer magnetic core to said low potential electrode.

3. In combination, a pair of axially spaced electrodes defining a particle accelerating region, a transformer for impressing a high voltage across said electrodes comprising a magnetic core section surrounding one of said electrodes, a multi-layer winding surrounding said core section having insulation between successive layers thereof, a second magnetic core section surrounding said winding, and means energized from said winding and displaced progressively greater axially distances from successive layers of said winding to provide substantial uniform potential gradients between successive layers of said winding and the other of said electrodes.

4. In combination, a pair of axially spaced electrodes defining a particle accelerating region, a transformer for impressing a high voltage across said electrodes comprising a magnetic core section surrounding one of said electrodes, a multi-layer winding surrounding said core section having insulation between successive layers thereof, a second magnetic core section surrounding said winding, voltage distribution means comprising a high resistance coating of trapezoidal shape wound in contact with the winding and having the smaller end thereof connected to the end of the winding adjacent the inner magnetic core and the larger end connected to the end of the winding adjacent said second magnetic core to provide a voltage distribution means extending progressively greater distances from successive layers of said winding to provide substantially uniform potential gradients between said voltage distribution means and a generally planar conducting member axially displaced from said winding and extending transverse to the axis of said apparatus and maintained at the potential of the other end of said winding.

5. In an accelerator apparatus including a high potential electrode and a low potential electrode longitudinally spaced therefrom to define an accelerating region, a generally cylindrical transformer system surrounding said high potential electrode including an inner magnetic core, means for maintaining said inner magnetic core at the potential of said high potential electrode, a multilayer winding surrounding said inner magnetic core and including a plurality of conducting turns each separated from adjacent turns by a layer of insulation, voltage distributing means positioned between said layers of insulation and terminating at progressively greater distances from said inner core in a longitudinal direction proceeding from the inner to the outer core, means for maintaining said voltage distribution means at substantially the same voltage as the turn opposite which it is positioned, conducting enclosing means including an end closure spaced longitudinally from said high potential electrode in a direction opposite from said low potential electrode, said layers of insulation and said voltage distribution means extending longitudinally in both directions from said core in the direction of said closure means and said low potential electrode means respectively.

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