United States Patent

Criswell et al.

[15] **3,681,604**

[45] **Aug. 1, 1972**

[54] **PORTABLE X-RAY GENERATING MACHINE**

[72] Inventors: **Daryl L. Criswell; Clarence V. Sebold,** both of Ann Arbor, Mich.

[73] Assignee: **The Bendix Corporation**

[22] Filed: **Aug. 17, 1970**

[21] Appl. No.: **64,485**

[52] **U.S. Cl.** **250/93,** 250/102, 307/106, 310/5

[51] **Int. Cl.**.....**H05g 1/24**

[58] **Field of Search** 250/93, 102, 90; 307/106; 310/5

[56] **References Cited**

UNITED STATES PATENTS

3,551,677	12/1970	Brewster	250/102
3,432,664	3/1969	Robison	250/102

OTHER PUBLICATIONS

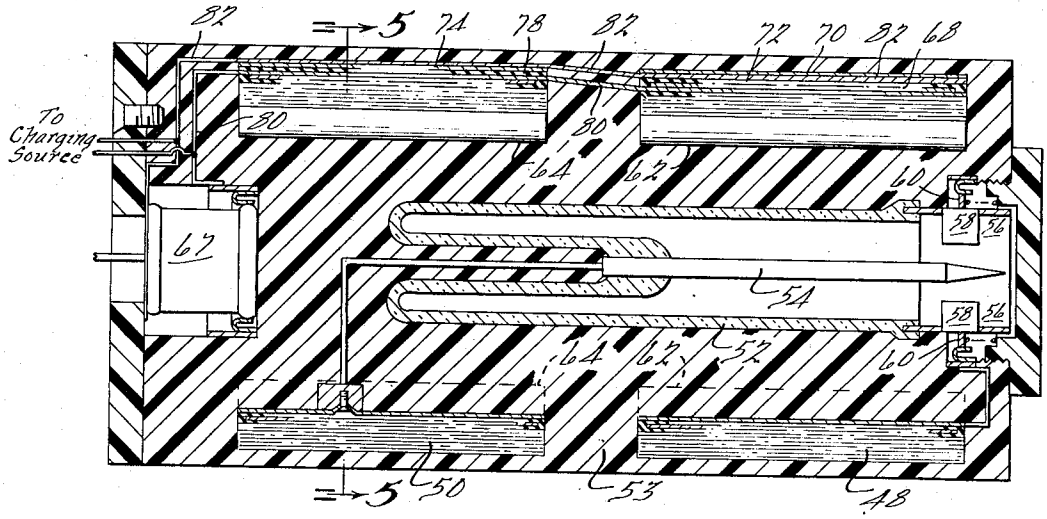
" Novel Principle of Transient High Voltage Generation" Atch and Howell, Procedings Inst. Elec. Engr. Vol. 111 No. 4, 1964 p. 849- 855

Primary Examiner—James W. Lawrence
Assistant Examiner—C. E. Church
Attorney—William F. Thornton and Plante, Hartz, Smith and Thompson

[57] **ABSTRACT**

A portable X-ray generating machine having an X-ray tube and two spiral generator power sources connected to each other and to the X-ray tube. One generator supplies a positive potential to the anode of the X-ray tube, and the other generator supplies a negative potential to the cathode of the X-ray tube. A potential drop is thus provided across the X-ray tube during operation that is approximately twice as large as the potential output of any one spiral generator. A number of embodiments illustrating different arrangements of the X-ray tube and spiral generator elements are illustrated and described. The various embodiments include different configurations of material having a high magnetic permeability placed about the spiral generators. This material increases the output of the generators from that which could be obtained if no such material were present, and in at least one embodiment also increases the safety of the device by preventing the induction of a current in any element in the vicinity of the X-ray generating machine that could be potentially harmful to an operator.

15 Claims, 7 Drawing Figures



PATENTED AUG 1 1972

3,681,604

SHEET 1 OF 4

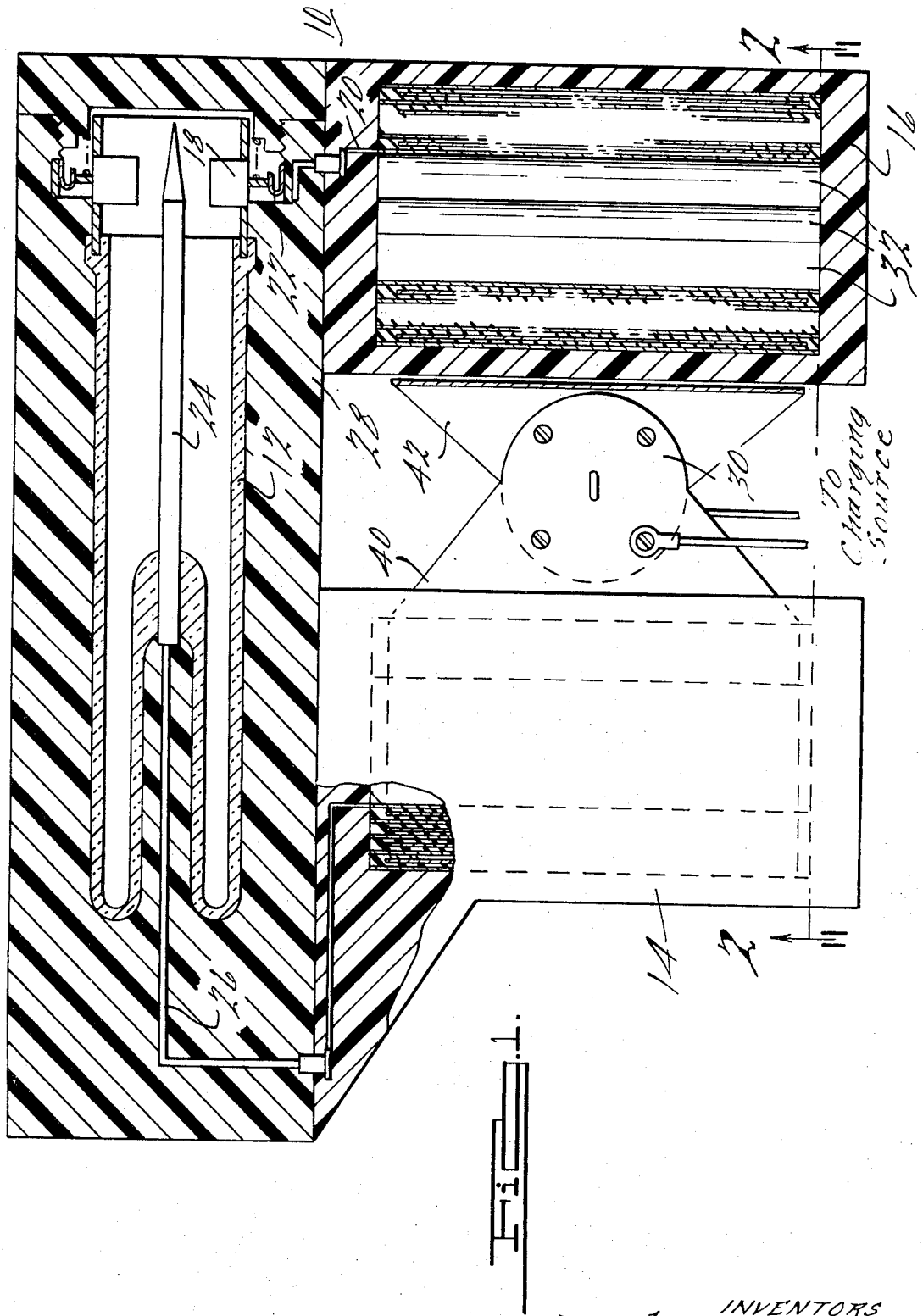
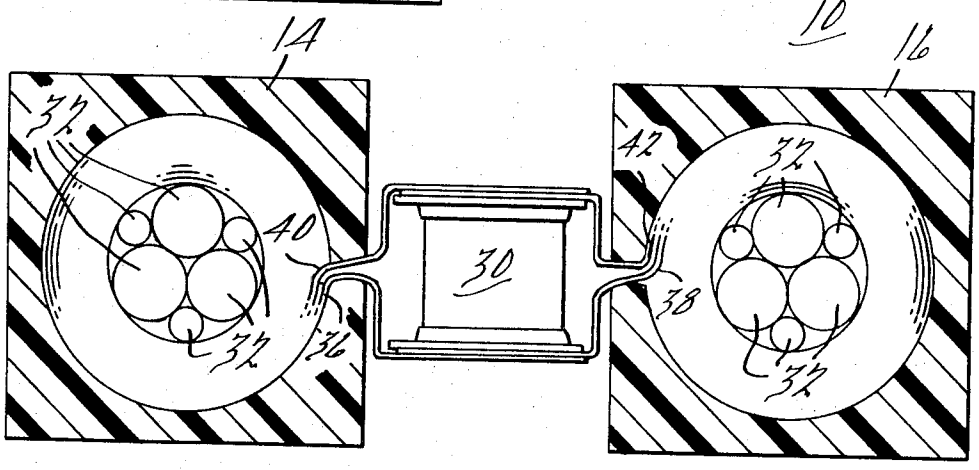


Fig. 1.

INVENTORS
Daryl L. Criswell
Clarence V. Sebold
BY
William J. Thompson
ATTORNEY.

Fig. 2.



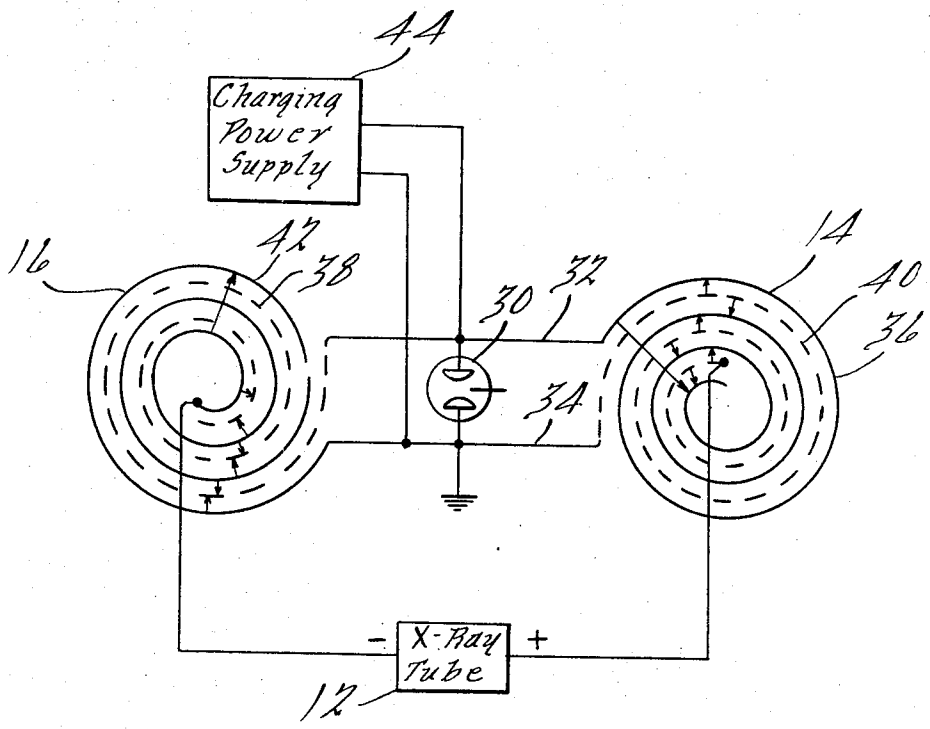


Fig. 3.

INVENTORS
Daryl L. Criswell
Clarence V. Sebold
BY
William F. Thornton
ATTORNEY

Fig. 5.

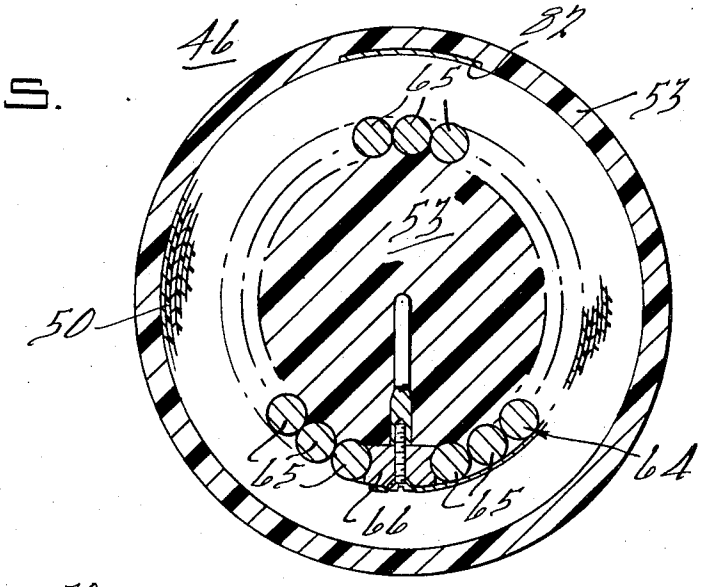
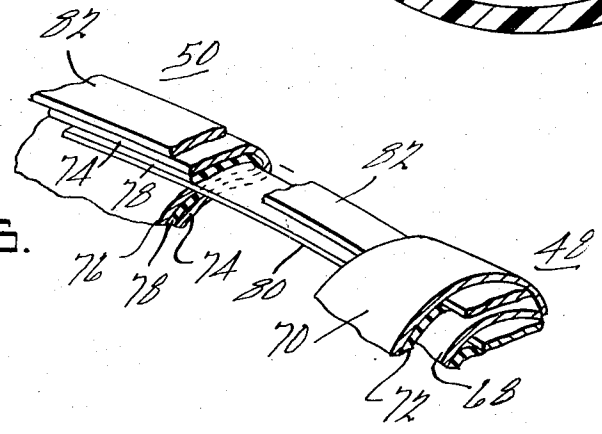


Fig. 6.



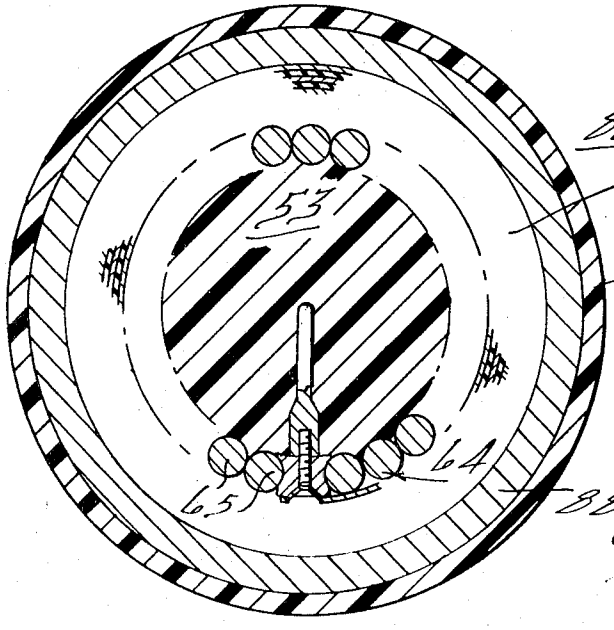


Fig. 7.

INVENTORS.
Daryl L. Criswell
Clarence V. Sebold
BY
William F. Thornton
ATTORNEY

PATENTED AUG 1 1972

3,681,604

SHEET 4 OF 4

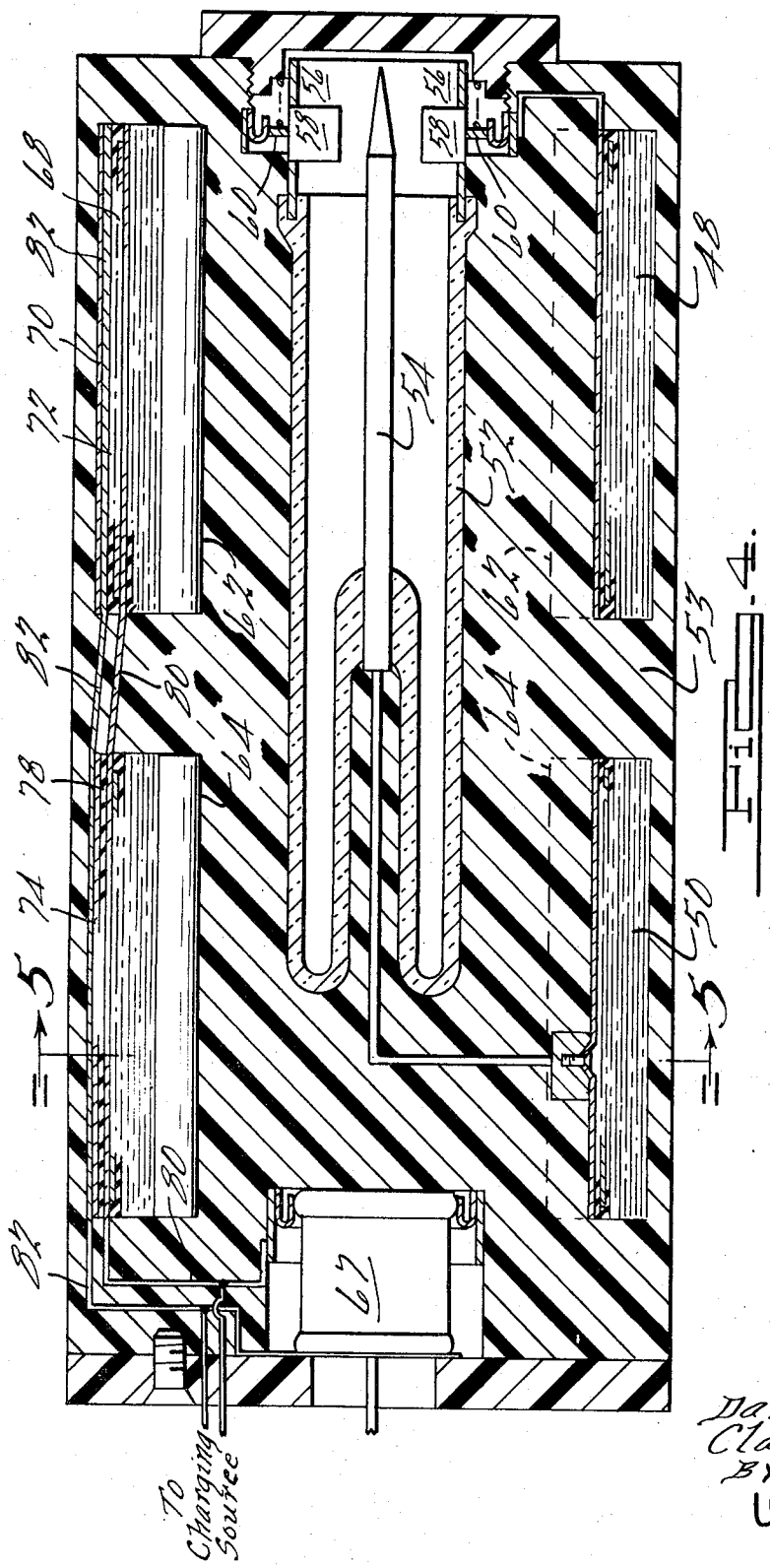


Fig. 4.

INVENTORS
Daryl L. Criswell
Clarence V. Sebold
BY
William J. Thomas
ATTORNEY

PORTABLE X-RAY GENERATING MACHINE

CROSS REFERENCE TO RELATED APPLICATION

This invention is related to the invention disclosed in U.S. Pat. No. 3,643,094, "A Portable X-Ray Generating Machine," Donald A. Courtois, filed May 18, 1970, and assigned to The Bendix Corporation.

BACKGROUND OF THE INVENTION

1. Field of the Invention

X-ray technology.

2. Prior Art

The combination of an X-ray tube and a spiral generator power source is shown in the cross-referenced U.S. Pat. No. 3,643,094. However, that reference does not teach the use of two spiral generator power sources with a single X-ray tube. That patent also does not teach the use of any material having a high magnetic permeability to increase the spiral generator power output and to prevent electric coupling between the spiral generator and other electrically conductive elements.

U.S. Pat. No. 1,991,236, "Electrostatic Generator," R. J. Van de Graaff does show two generators, which have come to be referred to by those in the generator art as Van de Graaff generators, connected to opposite ends of an X-ray tube. One generator supplies a positive voltage to the tube, while the other supplies a negative voltage. That is, positive charges are continuously supplied to the globe of one Van de Graaff generator, and negative charges continuously supplied to the globe of the other. A Van de Graaff generator differs from a generator such as the spiral generators used in this invention in that a spiral generator does not produce a continuous output but instead operates in pulse mode and produces a high voltage pulse from a short time interval on being triggered or activated. Because of this basic difference between a Van de Graaff generator and a spiral generator, the Van de Graaff reference does not provide any teaching concerning the solution of a number of problems which must be solved before two spiral generators can be used with a single load. These problems include the manner of connecting two spiral generators to each other and to a triggering mechanism so that both generators will produce an output voltage at the same time, and the manner of connecting two spiral generators to each other so that upon being triggered, one generator will produce a positive output voltage and the other a negative output voltage.

R. A. Fitch and V. T. S. Howell, "Novel Principle of Transient High-Voltage Generation", *Proceedings, The Institution of Electrical Engineers*, Volume III, No. 4, April, 1964, teach that the size of a spiral generator can be reduced by using a ferromagnetic core. However, they also indicate that the use of a ferromagnetic core introduces insulation complications. No suggestions of methods of overcoming any insulation complications are provided. It is believed that no working device including a ferromagnetic core has ever been built. In addition, there is no suggestion in the spiral generator art to build any device with a spiral generator having both a material with a high magnetic permeability and an operating element such as an X-ray tube placed within the core of the generator.

SUMMARY OF THE INVENTION

The portable X-ray generating machine of this invention includes a plurality of spiral generators connected to each other and to an X-ray tube so that a potential drop can be maintained across the X-ray tube that is larger than the potential output of any one generator. Each embodiment illustrated herein includes an X-ray tube and two spiral generators with one generator connected to the anode of the X-ray tube and the other to the cathode of the X-ray tube. The two spiral generators are connected to each other and to a spark-gap switch that triggers their operation. Each spiral generator includes an inner and an outer conductive foil. The conductive foils of each generator are separated by a layer of insulating material. The inner conductive foil of each generator is connected to the outer conductive foil of the other. The generators are connected in this manner so that upon being triggered, one generator will produce a negative output potential and the other will produce a positive output potential.

This invention also includes the use of a material having a high magnetic permeability to increase the spiral generator power output. The output potential of a spiral generator is limited by the size of the magnetic field, produced by current flowing from the generator, that can be maintained in the area around the generator. A material having a high magnetic permeability material will support a large magnetic field and thus maximize the generator power output. In one embodiment, the entire core section of two spiral generators is filled with a material having a high magnetic permeability and also a high electrical resistance. It has been found that no special insulating material is needed to insulate this core material from the spiral generator when the core has a high electrical resistivity. In other embodiments, a cylindrical layer of material having a high magnetic permeability is provided around the inside surface of the spiral generator and an X-ray tube is placed within this layer. This cylindrical layer increases the spiral generator output both by supporting a large magnetic field, and also by preventing inductive coupling between the generator and the conductive portions of the X-ray tube. If inductive coupling is allowed to occur between the generator and any conductive portion of the X-ray tube, that portion will act as a shorted turn of the generator and sharply reduce the generator output. In another embodiment, a cylindrical layer of material having a high magnetic permeability surrounds the spiral generator and prevents inductive coupling between the generator and any conductive element in the vicinity of the generator.

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects, features and advantages of this invention which are defined by the appended claims become apparent from a consideration of the following description and the accompanying drawings in which:

FIG. 1 is a partially cutaway cross-sectional view of an X-ray generating machine including two spiral generators connected to an X-ray tube;

FIG. 2 is a cross-sectional view of the device of FIG. 1 taken along the plane of line 2—2 to show the core sections of the spiral generators;

FIG. 3 is a circuit diagram that illustrates the electrical circuit of both the embodiment shown in FIGS. 1 and 2 and the embodiment shown in FIG. 4;

FIG. 4 is a cross-sectional view of an X-ray generating machine that includes two spiral generators placed in line with each other and having an X-ray tube disposed within the core sections of the two generators;

FIG. 5 is a cross-sectional view of the X-ray generating machine of FIG. 4 taken along the plane of line 5—5 to illustrate the layer of high magnetic permeability material within the core of one of the spiral generators;

FIG. 6 is a perspective view of a portion of the spiral generators of the device shown in FIG. 4 that illustrates the manner in which the two spiral generators are connected to each other in order to achieve the electrical relationship between the generators illustrated by the circuit diagram of FIG. 3 in an embodiment having two spiral generators in line with each other;

FIG. 7 is a cross-sectional view of an X-ray generating machine similar to that of FIG. 5 but also including a layer of material having a high magnetic permeability material surrounding the outer surface of the generator to further increase generator output and prevent electrical coupling with nearby objects.

DETAILED DESCRIPTION OF THE DRAWINGS

FIGS. 1 and 2 illustrate a portable X-ray generating machine **10** that includes an X-ray tube **12** connected to two spiral generators **14** and **16**. Generator **16** is connected to the cathode **18** of the X-ray tube **12** by line **20** and spring contacts **22**. Generator **14** is connected to the anode **24** of the X-ray tube **12** by line **26**. X-ray tube **12**, spiral generators **14** and **16**, and the conductive paths connecting those elements are all incased in a non-conductive polyester housing **28**. The housing **28** is a rigid structure that holds the elements in place and also insulates the various elements and conductive paths connecting those elements and thus prevents the voltages supplied to the X-ray tube from short circuiting or reaching and harming an operator. The two spiral generators are connected to each other and to a spark-gap switch **30** that triggers their operation.

As can best be seen from FIG. 2, the core sections of the spiral generators **14** and **16** are filled with ferrite rods **32**. Ferrite is selected as an example of a material that has a high magnetic permeability and also has a high electrical resistance. The term "ferrite" refers to a number of metallic compounds of the formula:

$$X\,Fe_2\,O_4$$

where X is typically selected to be a material such as manganese, iron, cobalt, nickel, copper, cadmium, zinc or magnesium and can be any divalent metallic ion having the proper ionic radius to fit the spherical structure of the above formula. The rods **32** need not have a high electrical resistance, but if they are formed from an electrically conductive material, they must be insulated from the spiral generators so that no short-circuit electrical path will be available to the generator voltage output. The rods **32** increase the output of the spiral generators from the output that would be available if no material having a high magnetic permeability were present by increasing the magnitude of the magnetic field that can be maintained within the core areas of the generators **14** and **16**. That is, one of the factors limiting the value of the electrical current that can be provided by any generator is the magnitude of the magnetic field associated with that electric current that can be maintained in the vicinity of the current. A material having a high magnetic permeability will support a larger magnetic field and will thus provide a larger electric current than will a material having a low magnetic permeability. The output gain provided by the rods **32** appears primarily as an increase in the number of amperes of current transmitted through the X-ray tube **12** during operation. Increasing the current transmitted through the X-ray tube **12** increases the dosage of the X-ray output of that tube and thus increases the resolution of the X-ray photographs formed with the generating machine **10**.

FIG. 3 is a circuit diagram of the X-ray generating machine **10** that illustrates the manner in which the spiral generators **14** and **16** are connected to each other, to the spark-gap switch **30** and to the X-ray tube **12**. The spiral generators **14** and **16** are formed from two conductive sheets or foils **32** and **34** wound to form the two cylindrically shaped generators. Conductor **32** forms the outer foil **36** of generator **14** and inner foil **38** of generator **16**, whereas conductor **34** forms the inner foil **40** of generator **14** and outer foil **42** of generator **16**. As used herein, the outer conductive foil of a spiral generator is defined to be the foil whose outermost turn has a larger radius and is outside of the outermost turn of the outer or inner conductive foil of that generator over a major portion of the circumference of that generator. The inner and outer conductive foils of each of the generators **14** and **16** are separated from each other by a layer of an insulating material that is not shown in order to avoid undue confusion in the drawings. The drawings also show only several turns of the conductive foils of each spiral generator in order to avoid confusion and detract from the invention by illustrating a known element of the combination of this invention in excess and unnecessary detail.

In operation, a charging voltage is supplied to conductor **32** from power supply **44**. In a typical embodiment of the generating machine **10** each spiral generator will have about 30 turns, and a charging voltage on the order of +6,000 to +10,000 volts is supplied from the power supply **44**. A high voltage potential on the order of 100,000 volts is provided across the X-ray tube **12** by triggering the spark-gap switch **30** to short the conductors **32** and **34**. When this is done, a transmission wave propagates back and forth between the conductive foils of each generator and produces a potential of about −50,000 volts at the inner end of the foils of generator **16** and a voltage of about +50,000 volts at the inner end of the foils of generator **14**. It is substantially easier to transmit 2 voltages having absolute values of 50,000 volts to the X-ray tube **12** than it would be to transmit a 100,000 volt potential to that tube as is required when only one generator is connected to the X-ray tube. A 50,000 volt potential is easier to insulate and is substantially less likely to break down insulating material than is a 100,000 volt potential.

FIG. 4 illustrates a second embodiment 46 of an X-ray generating machine that differs from the device 10 in that it includes two spiral generators 48 and 50 placed in line with each other so that they encircle different portions of an X-ray tube 52. The elements are held in place and electrically insulated from each other by a molded, electrically non-conductive housing 53. The X-ray tube 52 includes an anode 54 and cathode 56. The cathode 56 includes a plurality of vanes 58 and a flange section 60 that encircles the tube 52. Annular rings or layers 62 and 64 of ferrite rods are disposed between the X-ray tube 52 and the generators 48 and 50, respectively. These layers not only increase the output of the generators 48 and 50 by maintaining a large magnetic field, but also prevent electric coupling between the generators and conductive surfaces within the generator cores. For example, ferrite layer 62 prevents electromagnetic coupling between generator 48 and the annular flange portion 60 of the X-ray tube cathode. If an electromagnetic coupling is allowed to occur between these two elements, a short circuit electric current will be induced in flange 60 that will substantially degrade the output of generator 48. As is illustrated in FIG. 4, the ferrite layer 62 need not screen all direct paths between a conductive surface placed within the core of the spiral generator and all portions of that generator in order to prevent electromagnetic coupling between that conductive surface and the encircling spiral generator.

A cross-sectional view of the generating machine 46 that illustrates the layer 64 of ferrite material is provided by FIG. 5. Layer 64 comprises a plurality of ferrite rods 65 and a block 66 of non-conductive material that separates at least two of the ferrite rods forming the layer 64 along their entire length so that the ferrite material forms an open instead of a closed electric path. With this construction, it is unnecessary to insulate the ferrite material from the spiral generator 50 even for an embodiment in which an electrically conductive ferrite material is used for the layer 64. That is, in the design illustrated in FIG. 5, layer 64 simply acts as an additional turn of the spiral generator 50 and does not present a closed, short-circuit electrical path to the generator output voltage. As is illustrated in FIG. 4, when the ferrite layers 62 and 64 are placed in contact with the spiral generators 48 and 50, those layers must be separated and electrically insulated from each other so that they do not provide a closed electric circuit between the two generators 48 and 50. Because of the high output voltages provided by the generators 48 and 50, the spiral generators will be short circuited if connected with each other even by a material having a very high electrical resistance. However, the two layers 62 and 64 can be replaced by a single layer formed from long ferrite rods if that single layer is spaced and electrically insulated from the two spiral generators.

The inner foil of each of the spiral generators 48 and 50 (FIG. 4) is connected to the outer foil of the other generator so that generator 48 will supply a negative output voltage to cathode 56 and generator 50 will supply a positive voltage to anode 54 when a spark-gap switch 67 is triggered. A novel manner of providing such a connection between two spiral generators in line with each other is illustrated by the partially cutaway, perspective view of the connection between generators 48 and 50 provided by FIG. 6. As is seen from that figure, generator 48 comprises an inner conductive foil 68, and an outer conductive foil 70 that is separated from foil 68 by an electrically insulating layer 72. Generator 50 comprises an inner conductive foil 74 and an outer conductive foil 76 that is separated from the foil 74 by an electrically insulating layer 78. The two generators are connected to each other by conductive lines 80 and 82 which also extend to spark-gap switch 67, as is shown in FIG. 4. Conductors 80 and 82 are connected to generator 48 in a straightforward manner with conductor 80 placed in contact with the inner foil 68 of generator 48, and with conductor 82 placed in contact with the outer foil 70 of generator 48. The insulating foil 72 separates conductor 82 from the inner foil 68. Conductor 80 extends across the surface of the outer conductive foil 76 of spiral generator 50 and thus connects the inner foil of generator 48 to the outer foil of generator 50. The outer foil 76 of generator 50 is cut off and does not extend beyond conductor 80. However, the insulating layer 78 and inner conductive foil 74 are not cut off at this point but are instead folded over across the top of conductor 80 with the insulating layer 78 separating conductive foil 74 from conductor 80. Conductor 82 extends across the top of foil 74 and thus connects the outer foil 70 of generator 48 to the inner foil 74 of generator 50.

FIG. 7 is a view very similar to that of FIG. 5 of an X-ray generating machine 86 that is similar to the device 46 shown in FIGS. 4 and 5. The generating machine 86 differs from device 46 only in that it includes not only a first layer 64 of material having a high magnetic permeability placed around the inner surface of a spiral generator 50, but also includes a second layer 88 of material having a high magnetic permeability encircling the outer surface of generator 50. The material forming layer 88 also has a high electrical resistance so that no special insulation of layer 88 from the spiral generators of the machine 86. That is, the voltages at the outside of the generators are low enough, with the outside surface of one generator remaining at ground and the outside surface of the other not exceeding the charging potential during charging or operation of the generator, so that a high resistance layer 88 can contact both spiral generators of the generating machine 86. Layer 88 will not break down or provide a conductive path that would degrade generator output. The only insulation requirement for layer 88 is that it be electrically separated from layer 64 so that there is no closed electrical path across the generator 50. Such an electrical path would short the generator output. The portions of layers 64 and 88 in line with the generator 50 are separated by the generator itself. The non-conductive housing 53 also electrically separates layer 88 from the layers 62 and 64 disposed inside the generators and prevents the formation of an electrical path around the edges of the generators that would connect those layers. The ferrite layer 92 increases the output of generator 90 by maintaining a larger magnetic field about that generator than could be maintained in the absence of the ferrite. Layer 88 also prevents electromagnetic coupling between generator 50 and nearby objects, and thereby prevents the degradation of the generator output that will occur if there is a coupling between that generator and a ground surface. The

prevention of such coupling also protects persons in the vicinity of the generating machine **86** by preventing a potentially harmful current from being induced in any nearby conductive or semi-conductive material.

Having thus described several embodiments of this invention, what is claimed is:

1. An X-ray generating machine comprising:
an X-ray tube;
a spiral generator encircling at least a portion of said X-ray tube, said spiral generator being electrically connected to said X-ray tube; and
a layer of material having a high magnetic permeability disposed between said X-ray tube and said spiral generator to prevent inductive coupling between said generator and said X-ray tube.

2. The combination set forth in claim **1** in which said material having a high magnetic permeability also has a high electrical resistance.

3. The combination set forth in claim **2** in which said layer of material having a high magnetic permeability is formed from a plurality of small diameter ferrite rods.

4. The combination set forth in claim **1** in which said material having a high magnetic permeability forms a first cylindrical layer that is broken along the entire length of the cylinder by an electrically non-conductive material that separates said high magnetic permeability material so that said high magnetic permeability material forms an open surface.

5. The combination set forth in claim **4** further including a second spiral generator in line with said spiral generator and electrically connected to said X-ray tube; and
a second cylindrical layer of a material having a high magnetic permability disposed within said second spiral generator, said first and second layers of material having a high magnetic permeability being electrically insulated from each other.

6. The combination set forth in claim **5** in which the material having a high magnetic permeability forming said second cylindrical layer is separated along the entire length of said second cylindrical layer by an electrically non-conductive material, said material having a high magnetic permeability thereby forming an open surface.

7. The combination set forth in claim **1** in which said material having a high magnetic permeability supports a large magnetic field and thereby increases the voltage output of said spiral generator.

8. An X-ray generating machine comprising:
an X-ray tube having an anode electrode and a cathode electrode;
a first spiral generator encircling a portion of said X-ray tube an electrically connected to one of said electrodes;
a second spiral generator in line with said first spiral generator and electrically connected to the other of said electrodes, each of said first and second spiral generators comprising wound inner and outer conductive foils separated by a layer of electrically insulating material; and
means electrically connecting the inner foil of each spiral generator with the outer foil of the other, said electrical connecting means causing a single charging voltage supplied to one foil of one spiral generator and to the foil of the other spiral generator electrically connected to said one foil to charge said generators to produce output voltages of opposite polarity and thus provide a potential drop between said anode and said cathode larger than the output of either one generator.

9. The combination set forth in claim **8** in which
a first conductive element contacting the inner foil of one of said generators and the outer foil of the other said generators, the inner foil and insulating layer of said other generator being folded over said first conductive element; and
a second conductive element contacting the outer conductive foil of said one spiral generator and said folded over portion of said inner conductive foil of said other spiral generator.

10. The combination set forth in claim **9** further including triggering means in line with said first and second spiral generators for shorting said first and second conductive elements at one position to cause transmission waves to propagate from said one position between the foils of each spiral generator and provide an output voltage pulse from each spiral generator at substantially the same instant.

11. An X-ray generating machine comprising:
an X-ray tube;
a spiral generator power source for said X-ray tube connected to said tube; and
means comprising a layer of a material having a high magnetic permeability at least partially containing said spiral generator for reducing electric coupling between said generator and any conductive element in the vicinity of said generator and for increasing the generator output by supporting a large magnetic field about said generator during operation.

12. The combination set forth in claim **11** in which:
said material having a high magnetic permeability comprises a ferrite material having a high electrical resistance.

13. The combination set forth in claim **11** in which:
said spiral generator has an inner diameter larger than the outer diameter of said X-ray tube;
said spiral generator encircles said X-ray tube; and
a second layer of a material having a high magnetic permeability is disposed between said generator and said X-ray tube.

14. The combination set forth in claim **11** in which said layer of material having a high magnetic permeability comprises a cylinder that completely encircles said spiral generator.

15. The combination set forth in claim **14** in which:
the combination includes a second spiral generator in line with said spiral generator; and
said layer of material having a high magnetic permeability also encircles said second spiral generator.

* * * * *