219-121 SR
MTR04 XR 3,418,526

COMPACT HIGH VOLTAGE SUPPLY

Filed May 13, 1966 6 Sheets-Sheet 1

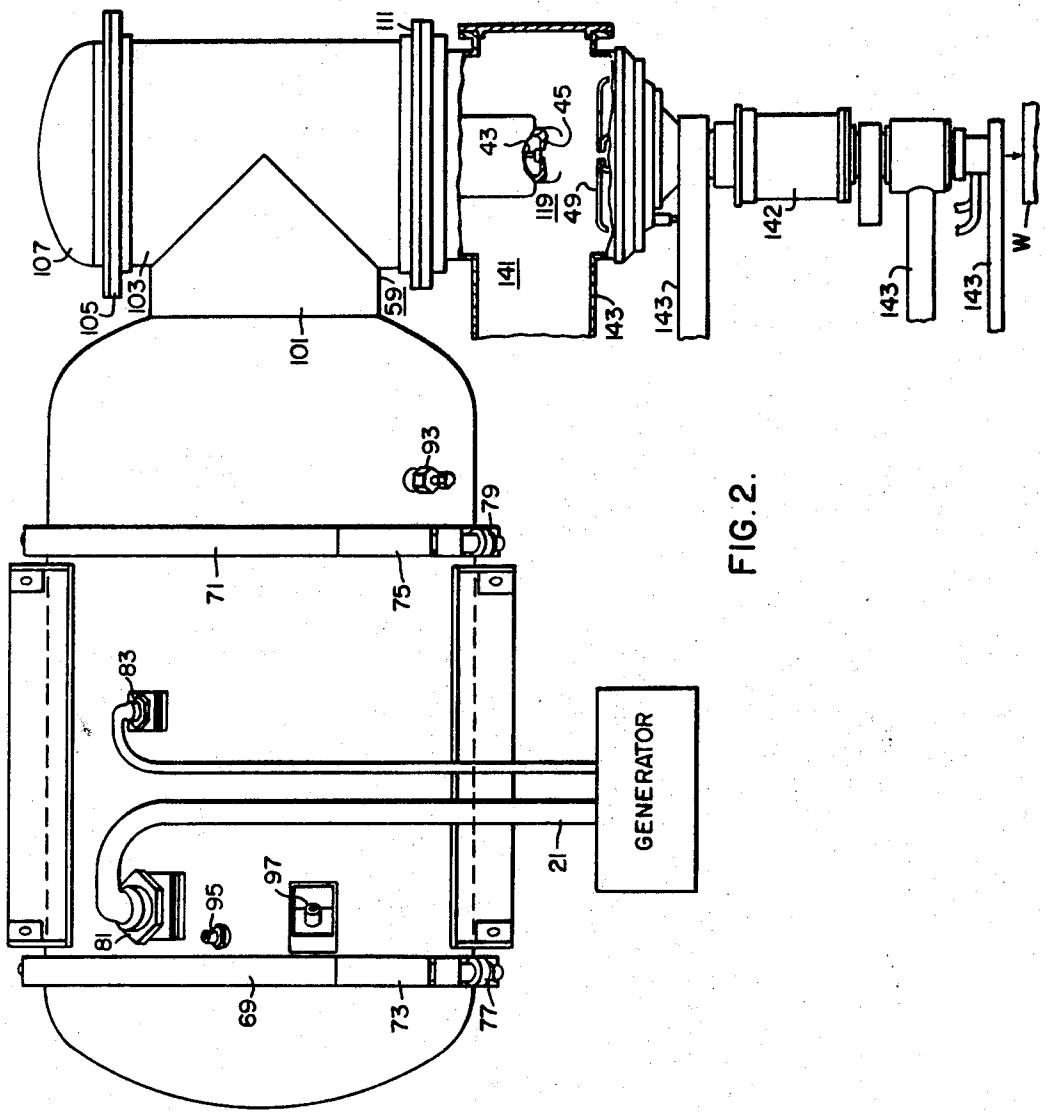


FIG. 2.

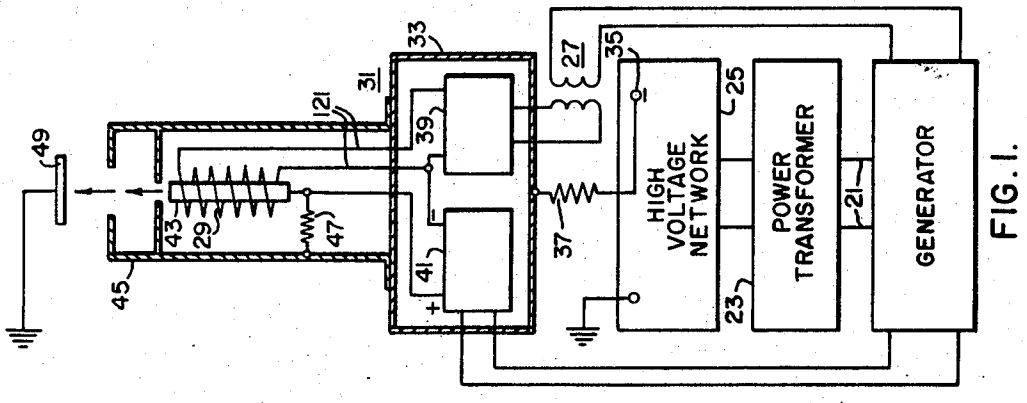


FIG. 1.

COMPACT HIGH VOLTAGE SUPPLY

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FIG.3.

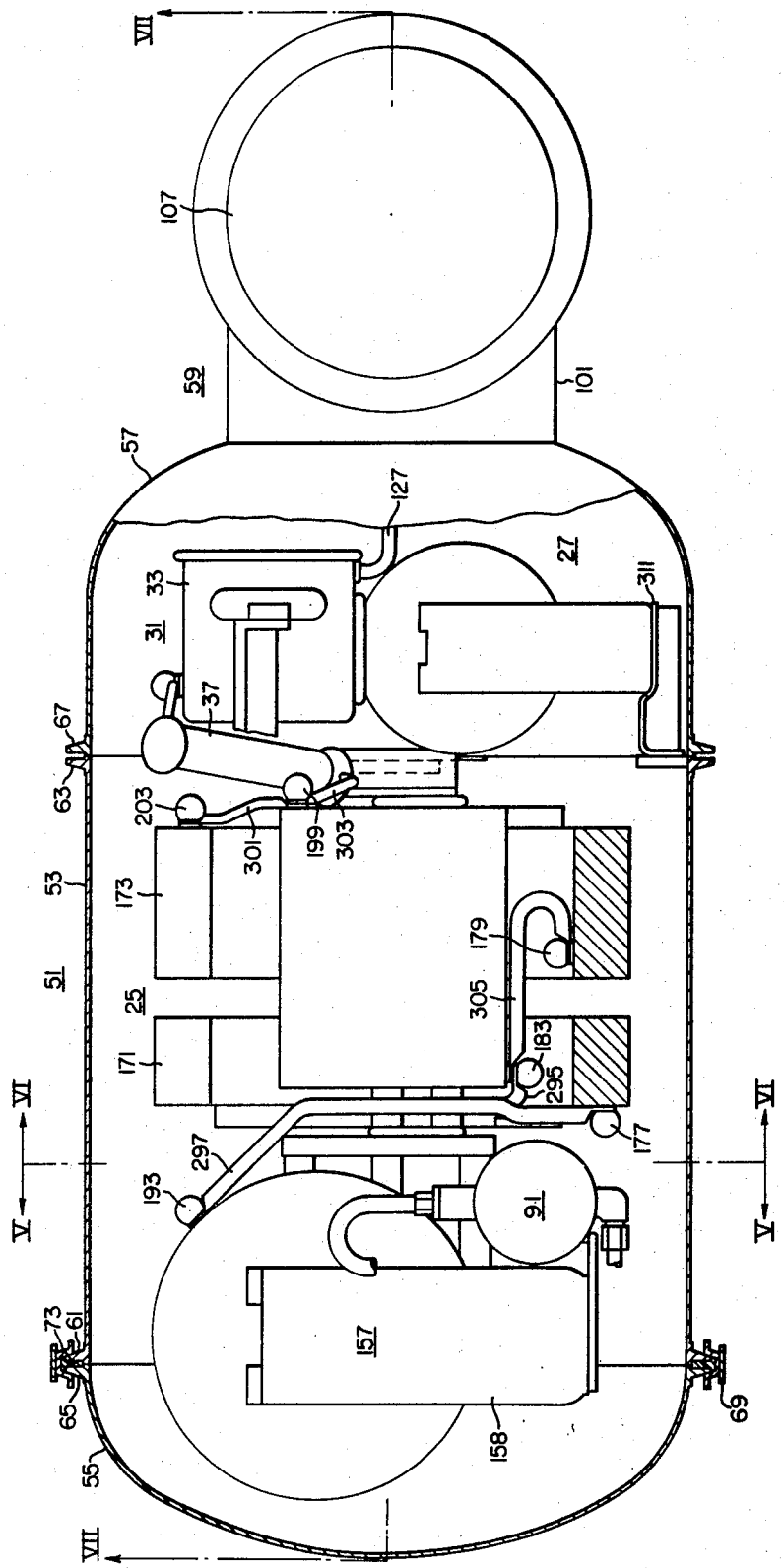


FIG. 4

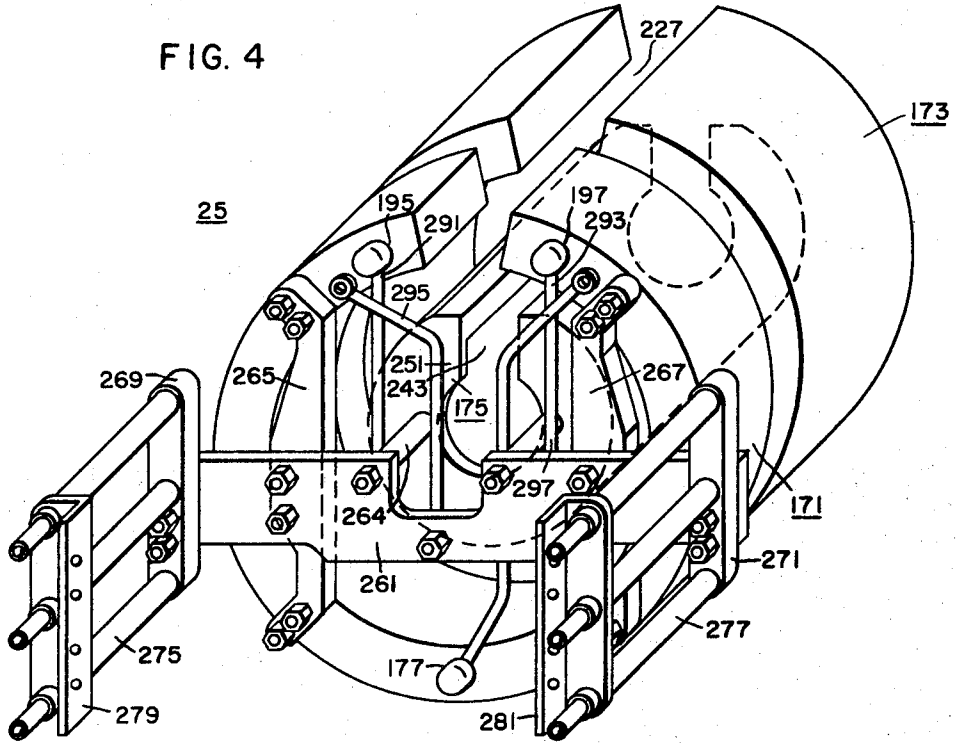


FIG. 8

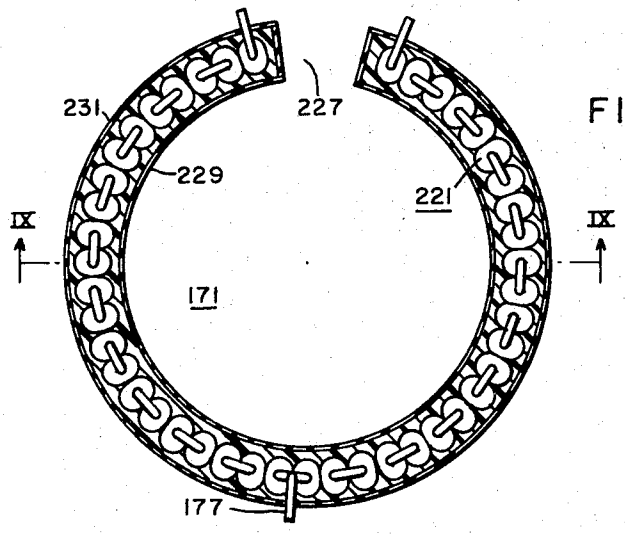


FIG. 10

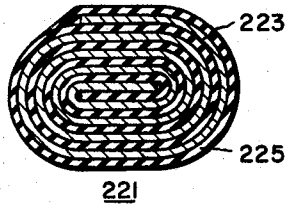
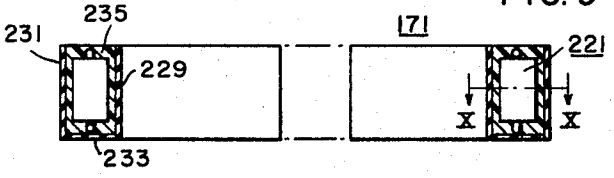


FIG. 9



COMPACT HIGH VOLTAGE SUPPLY

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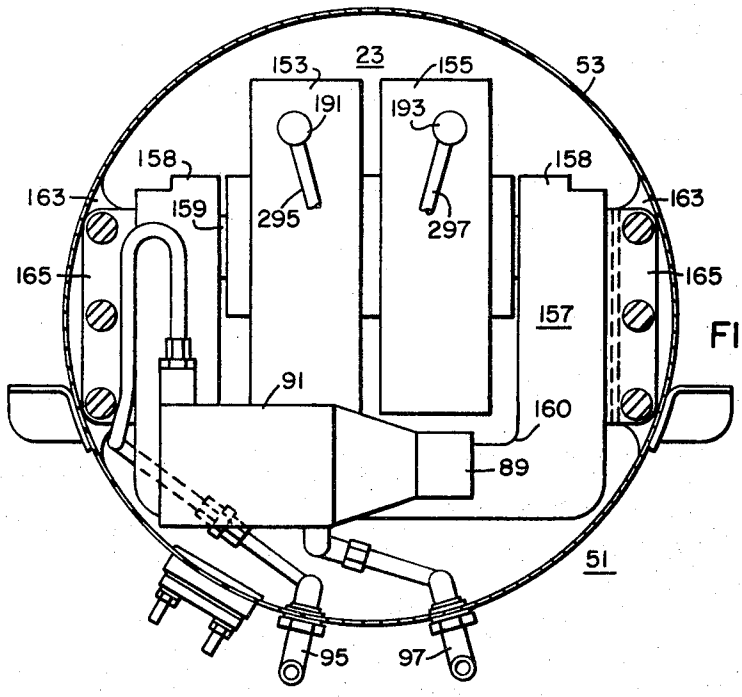


FIG. 5.

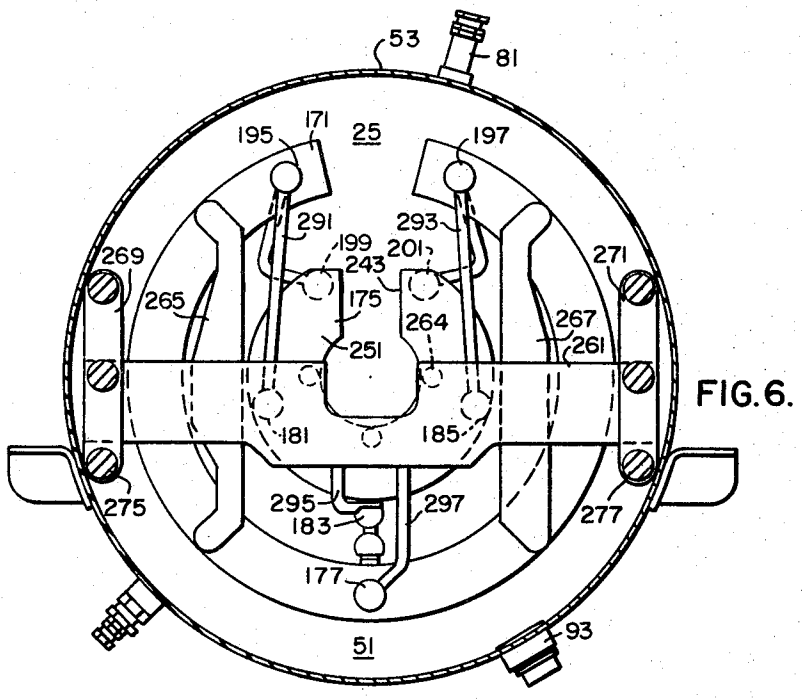


FIG. 6.

COMPACT HIGH VOLTAGE SUPPLY

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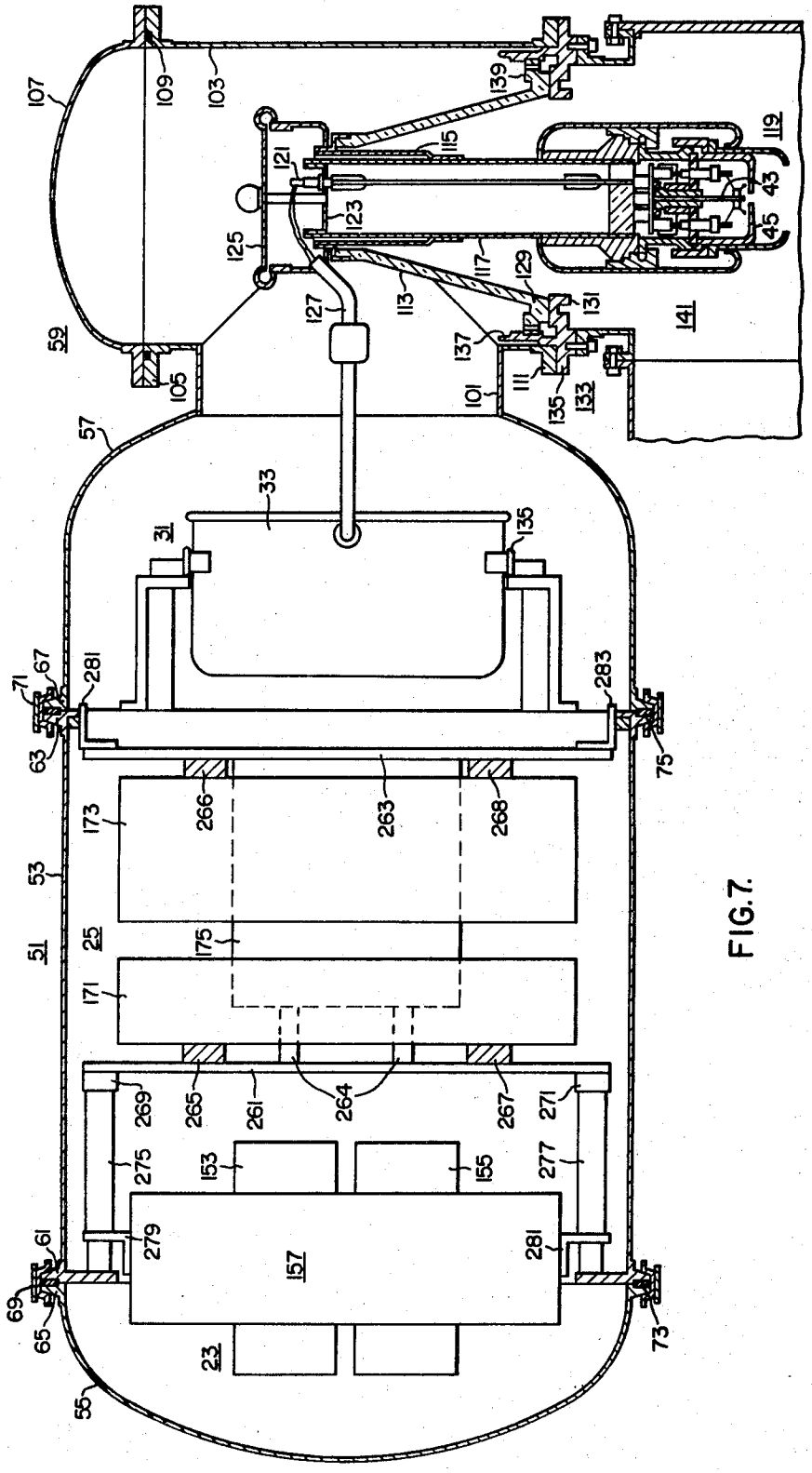


FIG. 7.

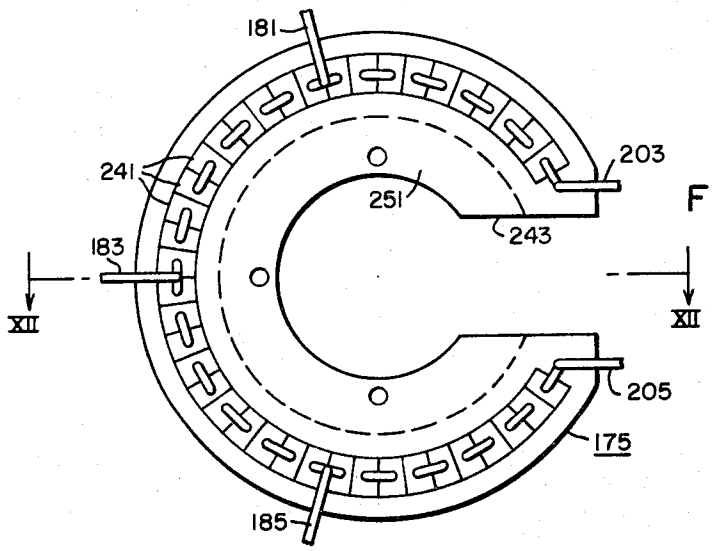


FIG. 11.

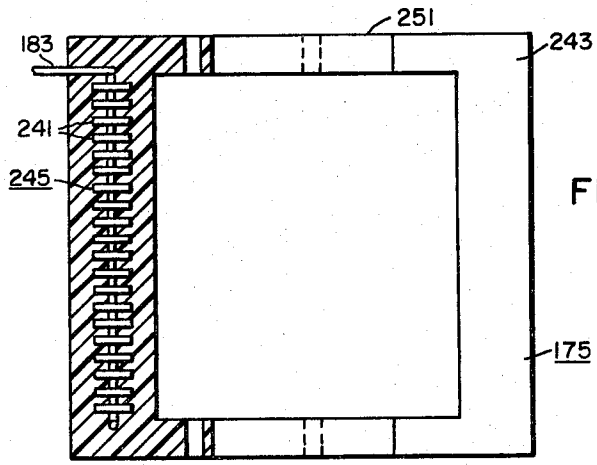


FIG. 12.

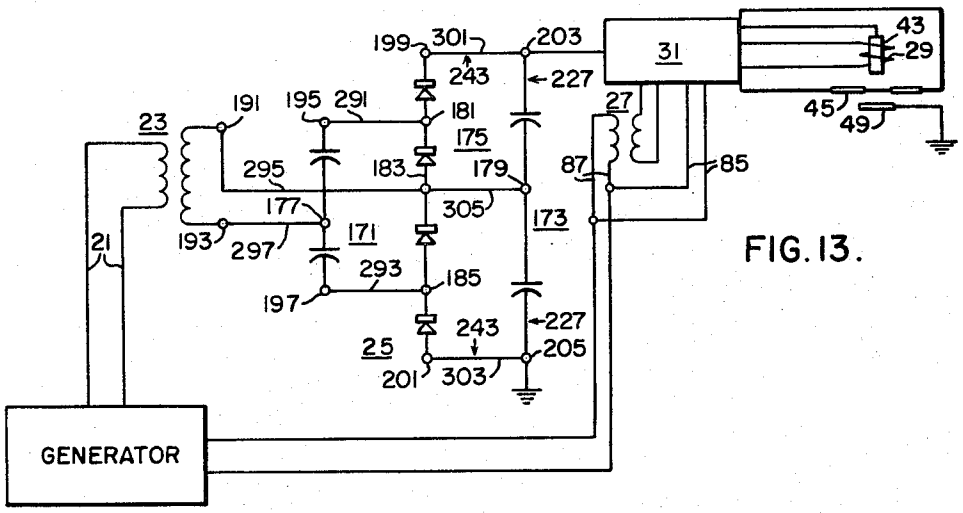


FIG. 13.

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3,418,526

COMPACT HIGH VOLTAGE SUPPLY

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Filed May 13, 1966, Ser. No. 549,863
8 Claims. (Cl. 315—205)

ABSTRACT OF THE DISCLOSURE

A high voltage electrical supply comprising a plurality of split annular rings mounted concentrically about an axis and encased in a container filled with a gaseous dielectric material to permit a reduction in the gap between the high voltage terminal; each of the split rings comprising a plurality of series connected electrical elements arranged with the end terminals of the series connected elements adjacent the gap formed in the ring by the split thereof whereby the voltage gradients in the various split rings are a maximum across the gap thereof and a minimum along the surface thereof; one of the split rings being located concentrically within another of the split rings.

This invention relates to the power-supply art and has particular relationship to high-voltage power-supplies for energizing electron-beam generators for treating materials.

Typically such operations as precision welding and cutting and melting are currently being carried out with electron beams. While this invention has general applicability it is described in this application as applied to electron-beam welding. Electron-beam welding apparatus includes an electron-beam generator which has a cathode, serving as a source of electrons and an accelerating anode in a highly evacuated chamber. A high accelerating potential of the order of 150,000 volts or more is impressed between the cathode and the anode to produce a sharp beam. The generator includes focusing facilities which focus the beam on or in the vicinity of work to be welded and deflecting facilities for moving the beam laterally of its axis.

This invention concerns itself with electron-beam welding apparatus for use with work outside of the vacuum chamber and it is an object of this invention to provide readily portable electron-beam welding apparatus.

In accordance with prior-art practices the electron-beam generator of an electron-beam welder is powered from a fixed high voltage supply. An electron-beam generator so powered is not readily portable because the supply itself is not portable and the connection of the high-voltage output terminals of the supply to the electron-beam generator requires a cable insulated for the high voltage which for movement over any reasonable distance is excessively heavy and cumbersome. It is an object of this invention to overcome this difficulty and to provide a portable electron-beam welder which shall include no heavy cable insulated for high voltage between the supply and the electron-beam generator.

In accordance with this invention electron-beam welding apparatus is provided which includes as a primary supply a generator which may be a motor-generator set or an inverter operating at a frequency substantially higher than commercial frequency, for example at 400 or 520 cycles per second. This generator is fixed and supplies a voltage at a moderate magnitude of the order of 110 or 220 volts. The generator is connected through a cable which is light and flexible and may be as long as desired to a supply or converter which converts the moderate voltage into a high voltage. This supply is light and is

combined as an integrated unit with the electron-beam generator. The supply or converter includes a container having therein the network for converting the voltage received from the fixed generator through the flexible cable to that demanded by the electron-beam generator, which typically is 150,000 volts. The container is filled with a gas of high-dielectric strength usually at the pressure at which the dielectric strength is a maximum. Typical gases providing the high-dielectric strength are sulfur hexafluoride (SF_6), perfluoropropane (C_3F_8) or octofluorocyclobutane (C_4F_8). Typically, a gas such as sulfur hexafluoride is maintained at an absolute pressure of about 60 pounds per square inch or three atmospheres above atmospheric pressure outside the container. In the interest of portability it is desirable that the container be as light as practicable and to achieve this purpose the container has cylindrical walls and has spherical end caps.

The voltage-converting network in accordance with this invention includes a step-up transformer which converts the generator voltage to a voltage of intermediate magnitude for example of the order of 38 kilovolts. The network in addition includes a voltage multiplying network composed of an alternating-current capacitor chain on the input side, a direct-current capacitor chain on the output side and a rectifier chain connected in voltage multiplying relationship with the capacitors. To withstand the high voltage to which the components of the network are subjected each chain includes a large number of capacitors or rectifiers. Typically the voltage may be quadrupled and in this case there are approximately 52 capacitors each in the AC and DC chains and 800 silicon diodes in the rectifier chain.

In accordance with this invention the AC and DC capacitor chains are each mounted in, or formed into, a structure having the general configuration of an open curve which turns back on itself. Specifically, each capacitor chain is mounted in a structure having the form of a generally circular cylinder or ring with a gap having the appearance of a horseshoe. The rectifiers also are mounted in, or formed into, a structure having the general configuration of an open curve which turns back on itself and in this case also the structure is generally circularly cylindrical with a gap in the periphery.

In accordance with this invention the ring-shaped rectifier and capacitor structures are mounted coaxially with one capacitor structure displaced axially with respect to the other and the rectifier structure within the capacitor structures. The gaps of the capacitor structures are substantially radially outwardly from the gap in the rectifier structure and in corresponding positions in the periphery. That is, the gaps in both the rectifier and the capacitor structures are bounded by substantial common radial planes. The high voltage output terminals of the network are straps forming common junctions respectively between the ends of the DC capacitor structures and adjacent ends of the rectifier structure. There are like straps on the AC side between intermediate points in the rectifier structure and the ends of the AC capacitor structure. The straps on each side are then at the terminal voltages. The positioning of the gaps minimizes the lengths of the straps and the possibility of arc over between a strap and the adjacent portion of a rectifier or capacitor structure. The dielectric strength of the high dielectric strength gas across the gap suppresses any tendency to arc over between the terminals. The leakage path between the terminals is along the structures and is relatively long.

For a more complete understanding of this invention, both as to its organization and as to its method of operation, together with additional objects and advantages thereof, reference is made to the following description,

taken in connection with the accompanying drawings, in which:

FIGURE 1 is a block diagram of electron-beam welding apparatus embodying this invention;

FIG. 2 is a view in elevation of a preferred embodiment of this invention showing the power supply as viewed from below and the electron beam generator with which it forms a unit;

FIG. 3 is a plan view of the supply and generator with a part of the wall of the supply broken away and with certain of the components sectioned;

FIG. 4 is a view in perspective of the capacitor-rectifier unit according to this invention;

FIG. 5 is a view in section taken in the direction along line V—V of FIG. 3;

FIG. 6 is a view in section taken along line VI—VI of FIG. 3;

FIG. 7 is a view in section taken along line VII—VII of FIG. 3;

FIG. 8 is a view partly in section and partly in elevation showing the capacitor ring included in apparatus in accordance with this invention;

FIG. 9 is a view in section taken along line IX—IX of FIG. 8;

FIG. 10 is a view in section taken along line X—X of FIG. 9;

FIG. 11 is a view in elevation of the rectifier ring included in apparatus according to this invention;

FIG. 12 is a view taken along lines XII—XII of FIG. 11; and

FIG. 13 is a schematic of the apparatus according to this invention.

The apparatus shown in the drawings comprises a Low Voltage Generator, a power supply and an electron beam generator. The electron-beam generator and the supply are combined into an integrated unit. The Low Voltage Generator is connected to this unit through a long, flexible cable **21**.

The Low Voltage Generator is capable of supplying power at a moderate voltage, such as 220 volts, at a frequency substantially higher than commercial frequency for example 400 cycles. The Power Supply includes a Power Transformer **23** for converting the moderate voltage from the Generator to an intermediate voltage typically 38 kilovolts. The Transformer supplies a High-Voltage net-work **25** which converts the 38 kilovolts to 150,000 volts. The Power Supply also includes a Filament Transformer **27**, for supplying the filament **29** of Electron-Beam Generator, and an Auxiliary Supply **31**. The Auxiliary Supply is enclosed in a conducting casing **33** which is connected to the hot negative terminal **35** of the High-Voltage Network **25** through a surge resistor **37**. The Auxiliary Supply **31** includes a rectifier **39** for rectifying the voltage from the filament transformer **27**. Typically the filament is supplied with about 60 amperes at eight volts. The Auxiliary Supply also includes a rectifier **41** for supplying the volt cathode **43** of the Electron Beam Generator. This rectifier **41** is energized from the Low Voltage Generator. The positive terminal of this rectifier is connected to the volt **43** and the negative terminal is connected to a terminal of the filament. Typically the rectifier **41** impresses a voltage of about 150 volts between the volt **43** and the filament **29**. The volt **43** is connected to the grid **45** of the Electron Beam Generator through a resistor **47** which impresses a bias potential on the beam dependent on the current flowing between the volt **43** and the anode **49** of the Beam Generator.

The apparatus shown in the drawings includes a Low Voltage Generator typically operating at a frequency of 400 cycles per second and supplying voltage at about 220 volts and an electron beam welder. The Power Supply converts the voltage from the Low Voltage Generator into a high voltage typically 150,000 for the electron beam welder.

The Power Transformer **23**, the High-Voltage Network **25**, the Auxiliary Supply **31** and the other components of the Power Supply are included in a pressure-tight container **51**. To suppress arc-over between high voltage and lower voltage parts of this supply, the container is filled with a high-dielectric-strength gas, such as sulfur hexafluoride, at a pressure of about four atmospheres absolute. So that the container **51** may withstand a pressure, it has a circularly cylindrical wall **53** closed at one end by a spherical end cap or bell **55** and at the other by a partly cylindrical and partly spherical end cap **57** from which a projection **59** extends. The Electron Beam Generator is suspended from the projection **59**. The central cylindrical wall **53** of the container **51** has flanges **61** and **63** at each end of the end caps **55** and **57**, cooperative with flanges **65** and **67** respectively and the flanges are secured in pairs pressure tight by couplings **69** and **71**. To assure pressure tightness gaskets **73** and **75** respectively are in each case interposed in the joint. The couplings **73** and **75** are provided with fastening buckles **77** and **79** which are secured to provide an adequate seal at the joints.

The wall **53** of the container **51** has separate connectors **81** and **83** respectively for the main power conductors **21** and for auxiliary conductors **85** and **87** which supply the volt voltage, the filament transformer **27** and a drive **89** for a heat exchanger **91** (FIG. 5). In addition, the wall **53** includes a valve **93** through which the high-dielectric strength gas is injected into the container **51** and connections **95** and **97** for the cooling of fluid, which is usually water, to the heat exchanger **91**. There is in addition a pressure relief valve (not shown).

The projection **59** includes a generally cylindrical tube **101** connected to the end cap **57** at one end and, at the opposite end, to a flanged cylinder **103**, whose axis is at right angles to the axis of the container **51**. The flange **105** on one side is sealed by an end bell **107** with a gasket **109** interposed to assure pressure tightness. The Electron Beam Generator is suspended pressure tight from the other flange **111**. The connection to the Electron Beam Generator is effected through a seal assembly including a generally conical ceramic (porcelain) insulator **113**. An outer flexible tube **115** is brazed vacuum tight to the top of the insulator **113** and to this tube **115** an inner tube **117** is brazed vacuum tight. The cathode **119**, which includes the filament **29** and the bolt **43**, is suspended from the tube **117**. The conductors **121** for the high voltage, for supplying the filament, for the bolt **43** and for the grid **45** are sealed through a cap **123** brazed to the top of tube **117**. The upper end of the ceramic insulator **113** includes the cap **123** and the conductors **121** extend into a tightly closed conducting box **125** which serves as a corona shield. The conductors from the Power Supply for the cathode **119** and the grid **45** extend through a pipe **127** which terminates in the box **125** and in part supports this box. Within the box these conductors are connected to the conductors **121**.

The conical insulator **113** carries a flange **129** at its lower end which engages vacuum tight cooperative outer flange **131** of a joint **133** of the Electron Beam Generator. The joint **133** has an outer flange **135** which is sealed to the flange **111** of the tube **103**, and also has a projection **137** between flanges **131** and **135**. The flange **129** on the insulator **113** is sealed vacuum tight by a ring **139** which is screwed into the projection **137**. The vacuum chamber **141** of the Electron Beam Generator is thus sealed against the gas in container **51**; it is also sealed against penetration by the atmosphere.

The Electron Beam Generator includes the anode **49** for accelerating the electrons from the cathode **119** and an array of apertures (not shown) which serve to guide and to an extent concentrate the beam. The Beam Generator also includes focusing coils **142** which provide a concentrated beam. Pump outlets **143** for maintaining the region **141** through which the electron beam passes highly evacuated are provided along the column through which the electron beam passes. The beam is projected out of the column and impinges on work W outside of the evacuated space.

The Power Transformer includes a primary, a pair of secondaries **153** and **155** and a core **157**. The core **157** has legs **158** joined near their upper ends by a bar **159**. The surfaces **160** of the core **157** of the Power Transformer **23** are rounded to suppress any tendency towards corona. The secondaries **153** and **155** are suspended from the bar **159**. The transformer is suspended from projections **163** extending from the ends of the center wall **53** of the container **51** by plates **165** extending from the legs **158** and secured to these projections. The heat exchanger **91** and its motor **89** are also mounted on the core **157**. Tubes **93** are in communication with the heat exchanger **91** in positions to transmit water through its cooling fins (not shown).

The High-Voltage Network **25** includes an AC capacitor chain **171**, a DC capacitor chain **173** and a rectifier chain **175**. The AC and DC capacitor chains **171** and **173** each have mid-taps **177** and **179** respectively and the rectifiers have a plurality of mid-taps **181, 183,** and **185**. In FIG. 13 the parts of the chains into which the taps divide the chains are shown as separate single capacitors and rectifiers to facilitate understanding of the schematic. Preferably each capacitor chain **171** and **173** are divided into a pair of links of substantially equal capacity (26 capacitors typically) by the taps **177** and **179** and the rectifier chain **175** is divided by the taps **181, 183, 185** into four links each having a substantially equal number of diodes (200 typically).

The output terminals **191** and **193** of the secondary **153–155** of the transformer **23** are connected between the intermediate terminal **177** of the AC capacitor chain **171** and the junction of the intermediate terminal **179** of the DC capacitor chain **173** and the central intermediate terminal **183** of the rectifier chain **175**. The outer intermediate terminals **181** and **185** of the rectifier chain **175** are connected to the terminals **195** and **197** of the AC capacitor chain **171** and the end terminals **199** and **201** of the rectifier chain **175** are connected directly to the end terminals **203** and **205** of the DC capacitor chain. Secondary voltage is quadrupled by this network and is derivable between the junctions of the terminals **203** and **205** and **199** and **201** respectively of the DC capacitors chain and the rectifier chain. One of these terminals **205–201** is grounded. The hot terminal **203–199** is connected to the cathode **119**. The anode **49** of the Electron Beam Generator is grounded.

Each capacitor **221** (FIG. 10) of the capacitor chains **171** and **173** consists of alternate layers **223** and **225** of a conductor, such as aluminum foil, and an insulator, such as paper, wound into a flattened roll of spiral cross section. The capacitor chains **171** and **173** are each formed into a structure of annular cross section having a gap **227** therein (chain **171** shown in FIGS. 8 and 9). This structure consists of a trough formed between inner and outer rings **229** and **231** of insulating material closed on the bottom by a flat ring **233** of insulating material. The capacitors **221** are connected in series and disposed in the trough. The trough is then filled with a potting compound **235** preferably a highly insulating epoxy resin. The intermediate terminal **177** extends out of the annular structure and the structure is provided with facilities for effecting a connection.

The rectifiers are silicon diodes **241** which are also mounted in an annular rings having a gap **243**. For this purpose the rectifiers are assembled in blocks **245** and the blocks are disposed in a circular form (not shown) having a gap. The rectifiers **241** in each block **245** are connected in series and the blocks are so disposed that adjacent blocks conduct in opposite directions. The adjacent blocks are interconnected so that all of the rectifiers form a series chain. The form is then filled with an epoxy resin **249** which after becoming solidified constitutes an annular structure having the gap **243** on one side and having terminals **203** and **205** at the ends and intermediate terminals **181, 183, 185** to provide the connections shown in FIG. 13. The rectifier ring **175** is of substantially smaller diameter than the capacitor rings **171** and **173**. The ring in which the rectifiers **241** are mounted has molded projecting lips **251** which serve for securing the parts by means of which the rectifier ring is suspended in the container **51**.

The capacitor chains or rings **171** and **173** are of greater diameter than the rectifier chain **175**. The capacitor chains **171** and **173** are mounted coaxially, displaced axially and the rectifier chain **175** is mounted within the capacitor chains with the gaps **227** of the capacitor chains extending radially from the gap **243** of the rectifier chain.

The rectifier chain or ring **175** carries a pair of cross insulators **261** and **263** isecured to the opposite lips **251** by studs **264**. The AC capacitor ring **171** is suspended from the cross insulator **261** on one side by a pair of insulating strips **265** and **267** secured to the capacitor chain **171** and also to the cross insulator **261**. The DC capacitor chain **173** is similarly suspended from the rectifier chain **175** by strips **266** and **268**. The cross strip **261** from which the AC capacitor chain **171** is suspended carries at its ends insulating strips **269** and **271** from which a plurality of sets of internally threaded bars **275** and **277** extend. These bars **275** and **277** are screwed to the flanges **61** extending on the adjacent side from the central portion **53** of the container **51**. The bars **275** and **277** engage angle brackets **279** and **281** secured to the transformer core **157** and serve as additional support for the transformer core **157**. On the opposite side the cross insulator **263** is secured to angle brackets **281** and **293** which are in turn secured to the adjacent flange of the center portion **53** of the container **51**.

Connecting straps are provided to effect the connections shown in FIG. 13. A pair of straps **291** and **293** extend between the ends at the gap of the AC capacitor ring **171** and intermediate taps **181** and **185** of the rectifier ring **175**. Another strap **295** extends from the center tap **185** of the rectifier ring **175** and is connected to one terminal **191** of the secondary **155** of the power transformer **23**. A further strap **297** extends from the center tap **177** of the AC capacitor ring **171**, and is connected to the other terminal **193** of the secondary. The straps **291, 293, 295, 297** are securely bolted and connected to the capacitor and to the rectifier rings at each point. Straps **301** and **303** are also connected between the ends at the gap **227** of the DC capacitor ring **173** and the ends at the gap **243** of the rectifier ring **175**. A strap **305** is also connected between the center tap **179** of the DC capacitor ring **173** and the center tap **183** of the rectifier ring **175**.

Within the container **51** there is also the filament transformer **27** suspended from a bracket **311** connected to the end cap **57** from which the projection **59** extends. The auxiliary power supply **31** is suspended from another bracket. The bleeder resistor **37** is on a bracket. Conductors **121** for energizing the Electron-Beam Generator pass through the pipe **127** and the projection **59** extending from the end cap **57** and are connected to the appropriate terminals of the Generator from which the cathode grid assembly **29–43–45** is suspended.

In the use of the apparatus the power supply is mounted in the container **51** and connected as shown and the container is evacuated and filled with the high-dielectric-strength gas. The control and output terminals of the power supply are also connected to the cathode **29–45** of the Electron-Beam Generator as shown. In the use of the apparatus the Beam Generator and power supply may be moved readily over a wide area and welding performed on the work W in the positions where the work is located.

In the practice of this invention a Power Supply is provided which operates satisfactorily to energize an Elec-

tron Beam Generator of electron-beam welding apparatus. This supply has the following characteristics:

Output voltage—150 kilovolts DC supplied with the nega- Input voltage—220 volts AC, 400 cycles per second.
tive pole hot and the positive pole grounded.
Maximum current—80 milliamperes.

The components of the supply including the Power Transformer, the High-Voltage Network and the Auxiliary Supply are mounted in a sealed container **51** filled with sulfur hexafluoride at 60 pounds per square inch absolute pressure (45 lbs. above atmospheric). The container **51** within which the supply is enclosed has a diameter of 15 inches and is 28 inches long. The total weight of this supply is 150 pounds. The High-Voltage Network in this supply has as overall dimensions, a diameter of 12 inches and a length of 6½ inches.

As shown in FIG. 13 the High-Voltage Network escalates the voltage over a wide range from capacitor **221** to capacitor **221** and rectifier bank **245** to rectifier bank **245** and a long continuous circuit path is necessary. To span a 6½ inch dimension with components between which there is a potential difference of 150 kv. would impress an excessive voltage gradient for surface creepage in apparatus in accordance with the prior art. The ring-shaped rectifier and capacitor structures **175, 171, 173** maintains the gradient throughout within safe limits. This structure also has the advantage that it dovetails into the cylindrical shape of the container **51** needed for pressure resistance. The circumferences of the structures avail adequate creepage path. The ring shape also is superior with respect to voltage gradients between components and between components and ground planes. For instance, the capacitors **221** in the chains are concentric within the surrounding wall **53** of the cylindrical pressure vessel. The rectifiers **24** are also concentric and lie within the capacitors **221** and this affords the superior gradients.

The elements in the rectifier-ring structure **175** are silicon diodes encapsulated in epoxy in a configuration to eliminate sharp edges and minimize corona. The rectifier ring structure **175** in the typical supply described above is 6.50 inches long and has a diameter of 6.00 inches and a gap 1.5 inches wide. The capacitor rings **171** and **173** have inside diameters of 9¼ inches and outside diameters of 12 inches and a thickness of about 3¾ inches. They are spaced so that the rectifier ring **175** is wholly within the capacitor ring **171** and **173** with an annular gas space of 1⅜ inches between the rectifier and capacitor rings. The gaps **227** and **243** and the spaces are adequate for insulation purposes. The assembly is mounted in the container **51** by means of strips **261, 263, 265, 267, 269, 271, 275, 277** of glass mica insulation.

The capacitor rings **171** and **173** consist of numerous small tubular capacitors **221** each pressed in an oval shape (FIG. 10). The individual elements are series connected positioned in an epoxy "cake mold" shell and then encapsulated in epoxy.

While preferred embodiments of this invention have been disclosed herein many modifications thereof are feasible. This invention then is not to be restricted except insofar as is necessitated by the spirit of the prior art.

We claim as our invention:

1. A high-voltage power supply for a portable electron-beam work-treating apparatus comprising a container having therein a plurality of rectifiers connected in series, a plurality of capacitors connected in series, input terminals for supplying potential, means connecting said terminals, said rectifiers and said capacitors in a voltage-rectifying network having output terminals between which said high voltage is derivable, the said supply being characterized by the fact that said rectifiers and said capacitors are each individually mounted in an individual structure having a cross section having the general configuration of an open curve which turns back on itself so that its ends are adjacent, the output terminals being near opposite points of said gap, and a high dielectric strength insulating medium bridging the gap to provide a highly insulating medium between said high voltage terminals.

2. The supply of claim **1** wherein the rectifier structure is mounted within the capacitor structure.

3. The supply of claim **2** wherein each structure has the form of a circular cylinder having a gap in its periphery, the cylinders being mounted coaxially with the rectifier cylinder located within the capacitor cylinders, and the gap in the capacitor cylinder extending generally radially from the gap in the rectifier cylinder.

4. The supply of claim **3** wherein the container is of generally cylindrical form generally coaxial with the rectifier and capacitor structures and the high dielectric medium is a high-dielectric-strength gas at an elevated pressure.

5. The supply of claim **1** including a step-up transformer within the container having a low voltage primary and substantially higher voltage secondary, the input terminals being connected in voltage transfer relaitonship with said secondary.

6. The supply of claim **5** wherein the higher output voltage of the secondary is of magnitude intermediate the low voltage of the primary and the high voltage of the supply, and the rectifiers and capacitors are connected in a voltage-multiplying network.

7. The supply of claim **6** wherein the container is of generally circular cylindrical form and the rectifier and capacitor structures are of generally circular cylindrical form generally coaxial with the container with the rectifier structure within the capacitor structure.

8. A high-voltage direct current supply comprising an alternating current capacitor structure including a plurality of capacitors connected in series and mounted in a generally circular cylindrical configuration having a gap therein, a direct-current capacitor structure including a plurality of capacitors connected in series and mounted in a generally circular cylindrical configuration having a gap therein generally coaxial with the alternating-current capacitor structure and axially displaced from said alternating current structure, a rectifier structure including a plurality of rectifiers mounted in a circular cylindrical configuration having a gap therein generally coaxial with said capacitor structures and within said capacitor structures, the gaps in said capacitor structures being bound by substantially the same radial planes, alternating-current terminals, and means connecting said capacitors, rectifiers and terminals in a voltage-multiplier network.

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