Sept. 15, 1970 AKIRA ISOYA ET AL 3,529,185

ELECTROSTATIC GENERATOR OF THE VAN DE GRAAFF TYPE

Filed Feb. 4, 1969 2 Sheets-Sheet 1

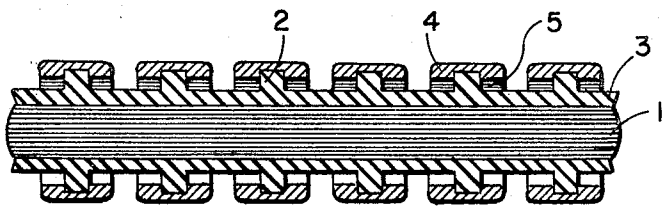


FIG. 1

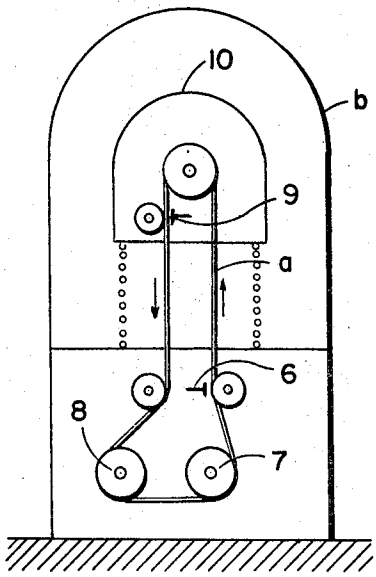


FIG. 2

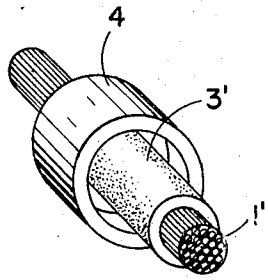


FIG. 3

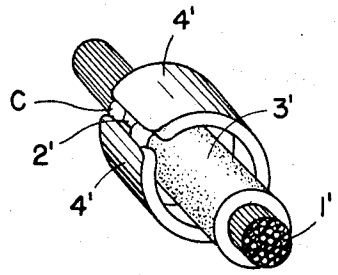


FIG. 5

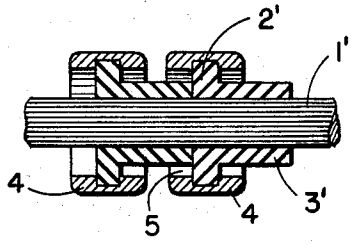


FIG. 4

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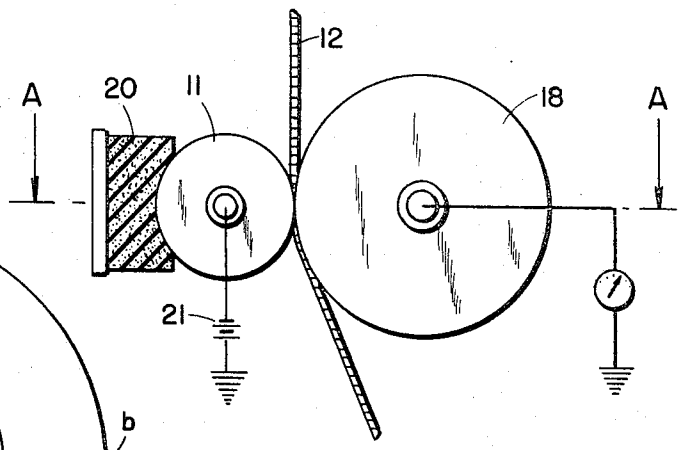


FIG.7

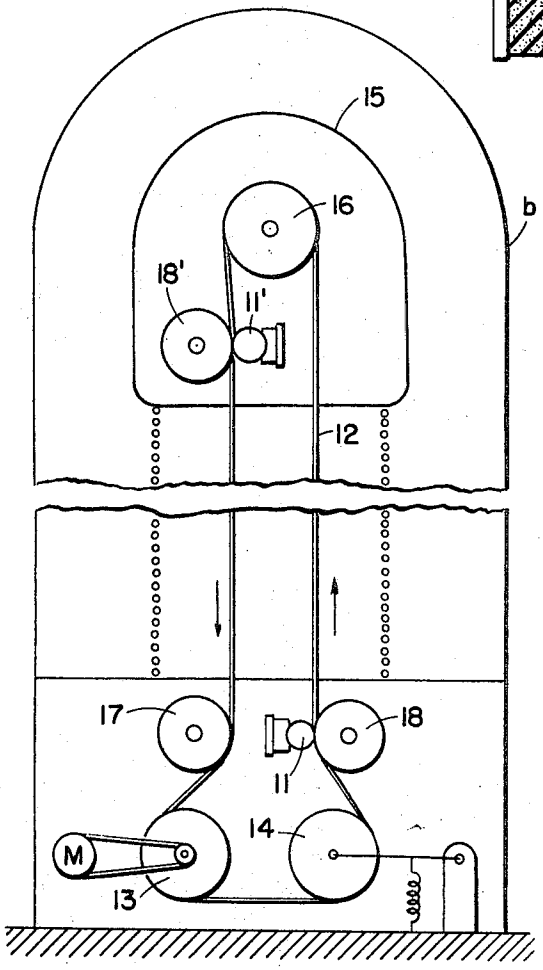


FIG.6

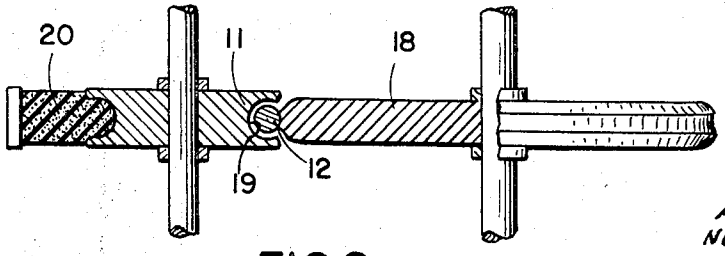


FIG.8

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United States Patent Office 3,529,185 Patented Sept. 15, 1970

3,529,185

ELECTROSTATIC GENERATOR OF THE VAN DE GRAAFF TYPE

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Filed Feb. 4, 1969, Ser. No. 796,438
Claims priority, application Japan, Mar. 21, 1968, 43/18,714; Aug. 2, 1968, 43/55,093
Int. Cl. H02n 1/12
U.S. Cl. 310—6 15 Claims

ABSTRACT OF THE DISCLOSURE

A charge carrying element for a Van de Graaff generator comprises a flexible endless cord of dielectric material, such as synthetic and other fibers having a small elongation and a high resistance to repeated bending, coated or impregnated with rubber, a layer of rubber enclosing the cord and formed with external annular ribs at substantially uniformly spaced intervals along the length of the cord, and a series of electroconductive rings mounted on respective ribs and spaced axially from each other. The radially inner surface of each electrically conductive ring, in conjunction with the rubber layer and the associated rib, defines a pair of annular cavities opening in axially opposite directions from the associated rib. A first rotatable inductor electrode applies charges to the charge carrying element by electrostatic induction, and a second rotatable inductor electrode transfers charges, by electrostatic induction, from the charge carrier to a high voltage electrode. Respective wipers engage the peripheral surfaces of the inductor electrodes to clean the same.

BACKGROUND OF THE INVENTION

The Van de Graaff type electrostatic generator is an apparatus capable of producing high voltages, of the order of several million volts, utilizing an endless belt of dielectric material to carry electric charges from a point of relatively low potential, or ground, to a high voltage electrode. The belt is an endless flat belt made of fiber-reinforced rubber to increase its mechanical strength. Charges are applied to the belt and transferred from the belt utilizing corona discharge of pointed electrodes.

In order to generate a terminal high voltage which has only small variations in magnitude, it is important to use a belt which is uniform in both its mechanical and its electrical properties. Practically, it is not easy to produce such a belt. In addition, when the apparatus is operated with a high voltage, sparks often are induced on the belt surface, producing a carbonized marking on the belt along the track of the spark. This shortens the life of the belt a great deal.

Another disadvantage of the rubber belt normally used in these generators is related to the manner of transferring the electric charge to and from the belt. It is highly desirable to use, in the generator, a dieletcric gas having a large dielectric value or constant, such as "Freon" (dichlorodifluoromethane) or sulphur hexachloride, to insulate the interior of the generator. However, gases of this type, composed of complex gas molecules, are decomposed by the electric discharge, producing harmful components. For this reason, the usual charging method, depending on corona discharge from pointed electrodes, is not suitable for safe operation.

SUMMARY OF THE INVENTION

This invention relates to electrostatic generators and, more particularly, to a Van de Graaff type electrostatic generator including a novel and improved endless charge carrying elements and novel means for applying charges to the charge carrying element and withdrawing charges therefrom.

In accordance with the invention, an electric charge carrying element or chain for an electrostatic generator of the Van de Graaff type comprises a flexible dielectric cord, of synthetic or other fibers, coated or impregnated with rubber. A rubber layer encloses this cord and is formed with external annular ribs at substantially uniformly spaced intervals along the length of the endless cord. A series of electrically conductive rings are provided, and each ring is mounted on a respective rib, the rings being spaced axially from each other. The radially inner surfaces of the electrically conductive rings, in conjunction with the rubber layer and the associated ribs, define pairs of annular cavities opening in axially opposite directions from the associated ribs.

As the charge carrying element or chain comprises a series of electroconductive rings arranged at regular intervals along a dielectric cord of rubber and fiber, the charge carrying element has a satisfactoy mechanical strength. Inasmuch as the mechanical properties of the element are uniform throughout its whole length, it can be operated smoothly by a suitable driving element.

If spark discharges occur along the length of the charging element, due to external electrical surges, the series of metallic electroconductive rings serve as spark gaps to prevent damage of the internal insulator. Furthermore, when using a charge carrying element or chain of this type, corona discharge need not be used to charge the element or to transfer charges therefrom. Charges can be applied to the element and transferred therefrom to the high voltage electrode by electrostatic induction. Consequently, the charge carrying element of the invention is particularly suitable for an electrostatic generator which contains a dielectric gas having a high dielectric constant but easily decomposed by corona discharge.

When an electrostatic induction method of charging and discharging the charge carrier is used, the charge transferred to each electroconductive ring is practically constant, so that variation of the voltage generated at the high voltage terminal or electrode can be controlled to be a minimum.

An additional feature of the invention is that the charge is applied to the charge carrier, and transferred therefrom to the high voltage electrode, by using the principle of electrostatic induction. This feature of the invention has many advantages as compared to the usual arrangement involving an endless belt and corona discharge. For example, the charge carrying chain or element can be operated with only a very small variation of the electric charges on the individual metal rings, and thus the voltage generated at the high voltage electrode can be maintained very constant. Further, the generated voltage bears an accurate linear relation to the inductor electrode voltage used for charging the chain, and hence control of the high voltage is simple and accurate.

Utilizing the principle of electrostatic induction, a dielectric gas with an especially high dielectric constant, such as "Freon" (dichlorodifluoromethane) or sulphur hexachloride can be used, in view of the absence of corona discharge from pointed electrodes. Thus, since the arrangement of the invention does not depend on corona discharge for transfer of charges, there is no trouble or failure due to decomposition of complex gas molecules.

In accordance with the invention, a chain grounding electrode of the inductor charging arrangement is constructed in the form of a pulley having a slight concave depression extending around its otherwise tapered periphery. The chain engages in this depression and the grounding electrode rotates at a speed such that its pe-

ripheral speed is equal to the linear speed of the chain, while maintaining contact with the chain. This limits the friction between the chain grounding electrode and the chain to rolling friction only. A similar chain grounding electrode is provided at the point where the charge is removed from the chain.

Each of the two inductor electrodes is a wheel formed with a deep circumferential groove of a nature such as to surround, with a very small clearance, as much of the chain as possible. The inductor electrodes are rotated at a relatively low speed. One inductor electrode is connected to the ungrounded side of a grounded source of potential, and the other inductor electrode is connected to the high voltage terminal or electrode.

Each inductor electrode has associated therewith a cleaner engaging the inductor electrode at a point opposite the zone of embracing the chain, and these cleaners wipe the hollowed out periphery of the associated inductor electrode to continuously remove dust gathered on the surface of the associated inductor electrode, due to the action of the electric field during operation.

An object of the invention is to provide an improved endless charge carrying element for an electrostatic generator of the Van de Graaff type.

Another object of the invention is to provide improved means for charging and discharging the charge carrying element.

A further object of the invention is to provide an electrostatic generator of the Van de Graaff type in which charging and discharging of the charge carrying element are effected by electrostatic induction.

Still another object of the invention is to provide a charge carrying element including means forming a spark discharge gap protecting the charge carrying element.

A further object of the invention is to provide a charging and discharging system for the charge carrying element of a Van de Graaff type electrostatic generator in which charge and discharge are effected by inductor electrodes with each inductor electrode having associated therewith a cleaning wiper or the like for removing dust therefrom.

For an understanding of the principles of the invention, reference is made to the following description of typical embodiments thereof as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a longitudinal or axial sectional view of one form of charge carrying element embodying the invention;

FIG. 2 is a somewhat schematic illustration of an electrostatic generator embodying the invention;

FIG. 3 is a partial perspective view of another form of charge carrying element embodying the invention;

FIG. 4 is a longitudinal or axial sectional view corresponding to FIG. 3;

FIG. 5 is a partial perspective view of still another form of charge carrying element embodying the invention;

FIG. 6 is a view similar to FIG. 2 illustrating an arrangement for charging and discharging the charge carrying element by electrostatic induction in accordance with the invention;

FIG. 7 is an enlarged side elevation view, with parts shown schematically, of the grounding electrode and inductor electrode for charging the charge carrying elements; and

FIG. 8 is a further enlarged sectional view taken on the line A—A of FIG. 7.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, an electric charge carrying element or chain embodying the invention comprises an endless dielectric cord or belt and a series of rings 4 of electroconductive material, such as stainless steel. The insulating cord or belt **1** has a circular cross section and comprises a bundle of fibers having a small elongation and high resistance to repeated bending. Cord or belt **1** is enclosed within an outer layer **3** of a dielectric or insulating rubber or rubber-like material, such as polyurethane. Layer **3** is molded integrally with cord or belt **1**, and its outer surface carries a series of external annular ribs **2** spaced at uniform intervals therealong.

Each electrically conductive or electroconductive ring **4** is fixed or adhered to a respective rib **2**, and the rings **4** are thus spaced at uniform intervals along the charge carrying element, and are spaced axially from each other. Each electroconductive ring **4** has an axial length greater than that of the associated rib **2**, so as to form, in conjunction with the associated rib **2** and the outer surface of rubber layer **3**, a pair of annular cavities **5** which extend in axially opposite direction from the associated rib **2**. Each ring **4** can be easily fixed or adhered on the associated rib **2** by forming the interior peripheral surface of the ring with an annular groove of the same width as the associated rib **2**, as shown in the drawing, or each ring **4** may be mounted on the charge carrier by inserting the ring **4** into a mold and casting an elastomer in the mold to produce a ring **4** as an integral component of the charge carrier.

FIG. 2 illustrates the essential components of a Van de Graaff type electrostatic generator to which the charge carrying element of the present invention is applicable. As shown in FIG. 2, the generator includes a lower inductor **6** to charge the chain, an adjustable pulley **7** acting to tension the chain, a pulley **8** for driving the chain, an upper inductor **9** and a high voltage electrode **10**. The charge carrying element or chain proper is shown at *a*, and the mentioned components are enclosed in an enclosure indicated at *b*. Enclosure *b* is filled with "Freon" gas at a gauge pressure of 6 atm., and chain *a* is driven at a speed of 10 m./sec.

Referring to the modification of the invention shown in FIGS. 3 and 4, the cord or belt comprises a bundle of fibers which has small elongation, a high Young's modulus, a high resistance to repeated bending and a high resistance to radioactive rays. For example, the bundle of fibers may comprise polyester fiber filaments or high tenacity rayon. Alternatively, a cord formed of loosely knit fiber filaments of these types is impregnated and coated with a rubber having good dielectric properties and a good resistance to "Freon." Such a rubber may be a suitably compounded polychloroprene. The rubber or rubber material is molded and vulcanized, and a flexible, dielectric cord or belt **1'**, as shown in FIGS. 3 and 4, is produced.

A tubiform body **3'** of a high modulus natural or synthetic rubber with good dielectric properties and a good resistance to "Freon," such as suitably compounded polyether polyurethanes, is inserted in a thin electroconductive ring **4** of suitable material such as stainless steel. The tubiform body **3'** has an axial length slightly greater than that of a ring **4**, and the dielectric cord or belt **1'** is passed through the apertures of the tube-like bodies **3'**, and adhered to these bodies, to position the electroconductive rings **4** at uniform intervals along the cord or belt **1'**. The arrangement is such that the rings **4** are out of contact with each other and spaced sufficiently apart longitudinally of the cord or belt so that no discharge occurs between the rings. Additionally, the cavities **5** are formed at the same time due to the provision of a rib **2'** on each body **3'**, as at one end of the latter.

When the axial spacing between adjacent electrocondwuctive rings **4** is 1 mm., the interval between adjacent electroconductive rings along the surface of cavity **5** is 7 mm.. The enclosure, such as the enclosure *b* of FIG. 2, is filled with "Freon" gas at a gauge pressure of 6 atm., and adjacent electroconductive rings **4** can withstand a voltage of 30,000 volts therebetween. Even if a higher potential difference is developed between adjacent electroconductive rings **4**, as by an external electric surge, dis-

charge through the dielectric surface of the charge carrier is prevented by the cavity **5** and thus the dielectric charge carrier is protected. Furthermore, due to the provision of the cavities **5**, the charge carrier is not heavy, is easy to flex, and can be driven smoothly.

When the Van de Graaff generator such as shown in FIG. 2 is surrounded by "Freon" gas at a gauge pressure of 6 atm., and a charge carrier or chain *a* which is 13 meters long with respect to its loop length, is driven at a speed of 10 m./sec., one chain can carry a current of 30 microamperes at most during each circuit. In this case, a high voltage of the order of 9 megavolts has been generated by arranging four chains *a* in one generator. The charge carrier is not at all damaged by surface discharge or by sparks, and the generator always generates a constant high voltage.

The fibers used in the cord **1'** preferably have a small elongation, a high Young's modulus, a high resistance to repeated bending, a high dielectric constant with respect to high voltage, a high resistance to radioactive rays, and no water absorbability. The cord or belt **1'** preferably is made by knitting or weaving to assure small elongation and to prevent elongation during operation. If the cord or belt **1'** is coated with rubber or, rather than being simply surface coated with rubber is coated and impregnated with rubber thoroughly to the center thereof, the conditions as to these various required properties of the fibers can be considerably mitigated.

When polyurethanes are used as the materials for the tubiform bodies **3'** inserted between cord or belt **1'** and the electroconductive rings **4**, such materials have a high modulus, a good electrical insulating property and satisfactory resistance to "Freon" gas. Polyurethanes are especially advantageous from the standpoint of long life because, if they should be perforated by a spark, the perforation is soon closed due to their thermoplasticity. When the resistance to high voltage of polyether-polyurethanes and polyester-polyurethanes are compared, it will be seen that polyether-polyurethanes are more resistant to surface discharge.

The electroconductive rings **4** and tubiform bodies **3'**, shown in FIGS. 3 and 4, are combined by inserting the bodies **3'** into the rings **4**, as mentioned above. However, when natural or synthetic rubbers which can be cast or molded in a liquid state, such as polyurethanes, are used as the material of the bodies **3'**, the charge carrier can be fabricated more precisely.

In this case, each electroconductive ring **4** is inserted into an outer mold which is combined with an inner mold to form a cavity to mold the tubiform body **3'**. A liquid natural or synthetic rubber is cast into the cavity to mold each body **3'** and simultaneously to unite the same to the associated electroconductive ring **4** to form an integral unit. In this method of formation, the length of the tube-like boy **3'** and the position of the same as integrally attached to the associated ring **4**, are very precise. Additionally, internal strain caused by inserting a tubiform body **3'** into a ring **4**, and any very small error in the diameter of the tubiform body, are completely eliminated. Consequently, the distance between two adjacent rings **4** can be maintained strictly constant and thus prevent any accidental electric discharge between adjacent electroconductive rings **4** while the electric charge is being carried.

In the embodiments of the invention shown in FIGS. 1, 3 and 4, the electroconductive ring **4** is illustrated as a ring completely formed into a hollow cylinder. However, fabrication of the electroconductive rings, and interchange thereof, is made simpler and easier by providing the rings in the form of two semi-cylinders **4'**, **4'**, as shown in FIG. 5. The two semi-cylinders are placed around the rib **2'** of a tubiform body **3'** and are then welded to each other, as by spot welding, as indicated at *c*.

The charge carrying element of the present invention, as described above, has many advantages as compared to the usual wide flat belt of plural textile layers and plural rubber layers, as hitherto used. As the chain or charge carrier of the invention can be assembled so as to provide a uniform weight distribution by molding each part, the chain or charge carrier can be driven very smoothly without vibration. When charging and discharging is effected by electrostatic induction, a variation of the voltage generated at the high voltage electrode, when the generated voltage is of the order of 7 megavolts, is limited to about 100 volts. Finally, the central cord or belt cannot be damaged by spark discharge in any manner.

FIGS. 6, 7 and 8 illustrate the arrangement for electrostatic induction charge and discharge of the charge carrier, such as the charge carrier shown in FIGS. 1 through 5. Referring to FIG. 6, a lower inductor electrode, for charging a charge carrying element **12**, such as the charge carrying element *a* of FIG. 2, is illustrated at **11**, and an upper inductor electrode, for discharging the chain **12**, is illustrated at **11'**. Chain **12** is driven by a pulley **13** and is tensioned by an adjustable pulley **14**. A motor M is schematically illustrated as driving the pulley **13**, and the high voltage electrode is indicated at **15**, the entire generator being enclosed within an outer enclosure *b*. Thus, the electric charge carrying chain **12** is driven, while under a suitable tension, by a driving mechanism comprising the series of pulleys **13**, **14**, **16** and **17**, with the pulleys **13**, **14**, and **17** being at the low potential or grounded side of the generator and the pulley **16** at the high voltage portion of the generator. All of the pulleys have wear-resistant rubber rings attached to their peripheries.

Chain grounding electrodes **18**, **18'** are in the form of pulleys arranged opposite the inductor electrodes **11** and **11'**, respectively. Pulleys **18** and **18'** contact chain **12** and rotate at an angular velocity such that their peripheral speed is the same as the longitudinal speed of chain **12**, to minimize friction between these pulleys and the chain.

As clearly shown in FIGS. 7 and 8, inductor electrode **11**, which is identical with inductor electrode **11'**, is a rotatable disk having a semi-circular groove or recess **19** extending around its peripheral surface and embracing chain **12** to the largest extent possible. The inner surface of groove **19** is polished very smoothly, and the gap between groove **19** and chain **12** is maintained at 3 mm. Groove **19** of inductor electrode **11** is sufficiently deep as to surround chain **12** as completely as possible while allowing passage of chain **12** therethrough. The width of the contact between chain grounding pulley **18** and chain **12** is made as narrow as possible. For maintaining the position of the running chain **12** stable, the area of the periphery of electrode **18** in contact with chain **12** has a slight depression of substantially the same curvature, in cross section, as that of the chain **12**. As the lower inductor **11** is identical with the upper inductor **11'**, it is believed not necessary to describe, in detail, the upper inductor **11'**.

With the arrangement of the present invention as described above, when a voltage is impressed on inductor electrode **11**, as by means of a battery **21** having one terminal grounded, an electric charge is induced on the portion of chain **12** facing inductor electrode **11**. When this portion of chain **12** moves away from pulley **18** as chain **12** is driven, the induced electric charge remains on the chain portion. The magnitude of this electric charge is directly proportional to the voltage of inductor electrode **11**, and the polarity of the charge is opposite to that of the voltage impressed on inductor electrode **11**.

The voltage which can be impressed on inductor electrode **11** is limited by spark or corona discharge at the gap between inductor electrode **11** and chain **12**. When the generator is operated over a long period, dust in the generator enclosure is drawn to this gap and adheres to the surface of inductor electrode **11** (or inductor electrode **11'**) to produce a corona. If a corona current is produced, it neutralizes the electric charge generated by

electrostatic induction, and thus the magnitude of the electric charge carried by chain **12** is diminished and is changed in an irregular manner.

To eliminate this difficulty, the inductor electrodes **11** and **11'** are rotated slowly at a speed of about 1 r.p.m., and a cleaner **20**, comprising a sponge-like body, wipes the groove **19** of the inductor electrode at a point diametrically opposite the chain **12** to remove the dust continuously.

The mechanism of transferring the electric charge to chain **12** by inductor electrode **11** has been described above, and a detailed description of the mechanism of transferring the electric charge from chain **12** to upper inductor electrode **11'** by electrostatic induction will not be described as it is the same as mentioned above. Thus, FIG. 6 shows only the upper inductor electrode **11'** and the associated chain grounding electrode **18'**, omitting the connections of the inductor electrode to the high voltage terminal or electrode **15**, as such connections are well known to those skilled in the art.

The magnitude of the electric charge carried by the apparatus of the present invention, as described above, is about 6 microamperes upon the application of a potential of 10 kv. to the inductor electrode with the chain **12** running at a speed of 10 m./sec. When the input potential is increased to 30 kv., with the electrostatic generator filled with "Freon" gas at 7 kg./sq. cm. pressure, and both the ascending and descending parts of the chain are used, a charging current of 36 microamperes per chain can be carried.

What is claimed is:

1. In an electrostatic generator of the type including an endless charge carrying element, means driving the element, a high voltage electrode adjacent one end of the element travel, means applying electric charges to the element at a point spaced from the high voltage electrode and means adjacent such one end of the element travel transferring the electric charges from the element to the high voltage electrode: the improvement in which said charge carrying element comprises, in combination, a flexible endless cord of dielectric material; a layer of natural or synthetic rubber enclosing said cord and formed with external annular ribs at substantially uniformly spaced intervals along the length of said cord; and a series of electrically conductive rings each mounted on and surrounding a respective rib, said rings being spaced axially from each other; the radially inner surface of each ring, in conjunction with said rubber layer and the associated rib, defining a pair of annular cavities opening in axially opposite directions from the associated rib.

2. In an electrostatic generator, the improvement claimed in claim **1**, in which said flexible endless cord comprises dielectric fibers having a small elongation and a high resistance to repeated bending.

3. In an electrostatic generator, the improvement claimed in claim **2**, in which said fibers are impregnated with a natural or synthetic rubber.

4. In an electrostatic generator, the improvement claimed in claim **2**, in which said fibers are coated with a natural or synthetic rubber.

5. In an electrostatic generator, the improvement claimed in claim **1**, in which each ring is mechanically interlocked with its associated rib.

6. In an electrostatic generator, the improvement claimed in claim **1**, in which each ring is integrally united with its associated rib.

7. In an electrostatic generator, the improvement claimed in claim **1**, in which said layer of rubber enclosing said core is in the form of a series of axially abutting identical tubiform bodies each formed with one of said ribs, the axial length of said tubiform bodies being in excess of the axial length of the associated rings.

8. In an electrostatic generator, the improvement claimed in claim **1**, in which each electrically conductive ring comprises a pair of semi-cylindrical ring sections united, in embracing relation with the associated ribs, by welds.

9. In an electrostatic generator, the improvement claimed in claim **1**, in which said means applying electric charges to said element and said means transferring electric charges from said element to the high voltage electrode comprise electrostatic induction means.

10. In an electrostatic generator, the improvement claimed in claim **9**, in which each of said electrostatic induction means comprises a rotatable inductor electrode in charge transferring relation with said charge carrying element.

11. In an electrostatic generator, the improvement claimed in claim **10**, in which each of said rotatable inductor electrodes is formed with a deep groove extending peripherally thereof, each groove extending a substantial distance around said charge carrying element in fixed spaced relation thereof.

12. In an electrostatic generator, the improvement claimed in claim **11**, including cleaning wipers engaging each rotatable inductor electrodes at a point substantially diametrically opposite the point of association of the associated inductor electrode with said charge carrying element.

13. In an electrostatic generator, the improvement claimed in claim **12**, including a respective grounding electrode engaging said charge carrying element at a point directly opposite a respective rotatable inductor electrode.

14. In an electrostatic generator, the improvement claimed in claim **13**, in which each grounding electrode has a radially tapered periphery formed with a peripherally extending concave groove having a curvature substantially equal to the curvature of said charge carrying element.

15. In an electrostatic generator, the improvement claimed in claim **14**, in which each grounding electrode is rotated at an angular velocity such that its peripheral speed is substantially equal to the linear speed of said charge carrying element.

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U.S. Cl. X.R.

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