Dec. 24, 1968 N. J. FELICI ET AL 3,418,501

HIGH VOLTAGE ELECTROSTATIC MACHINERY

Filed April 26, 1966 2 Sheets-Sheet 1

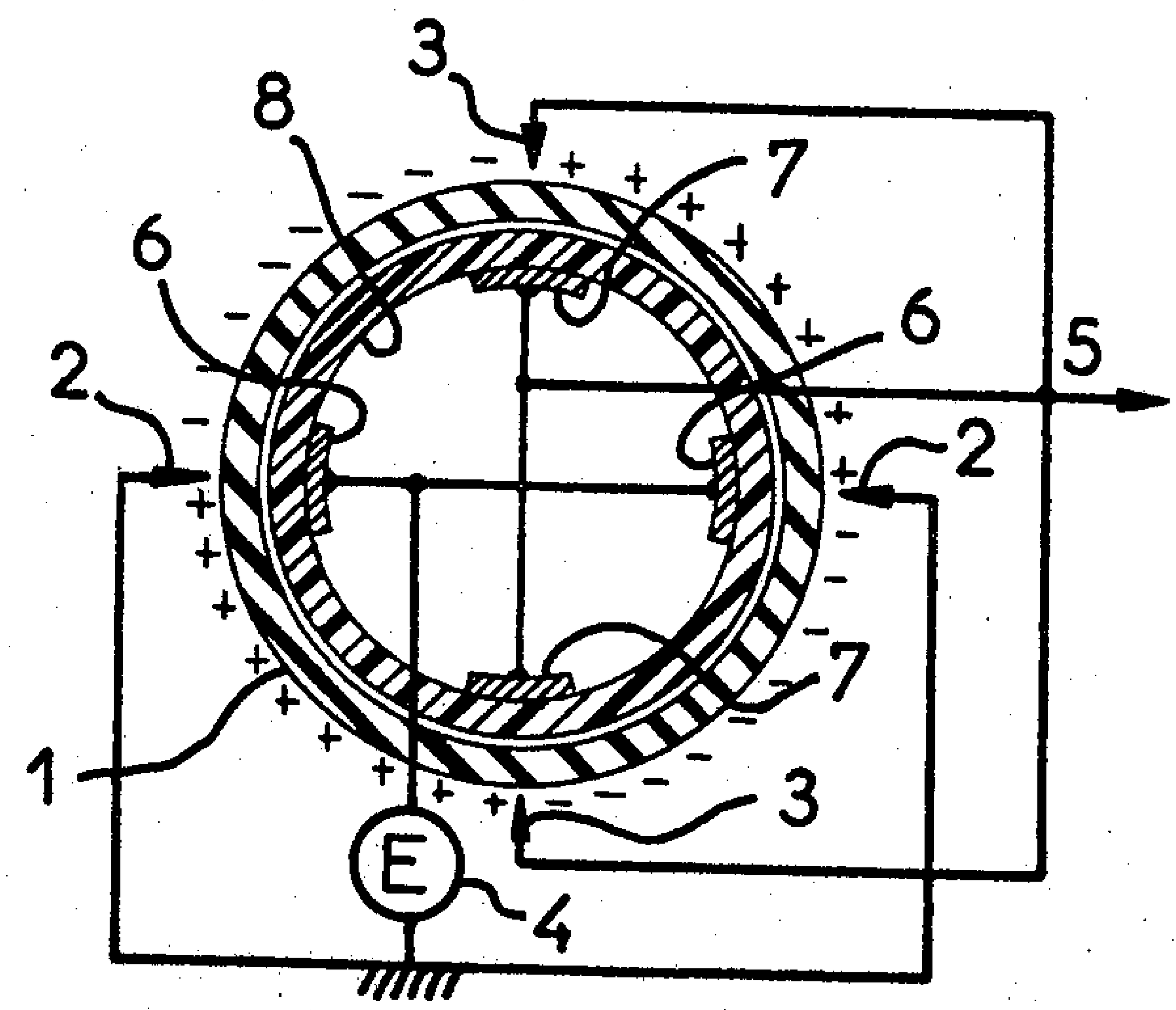


Fig.1

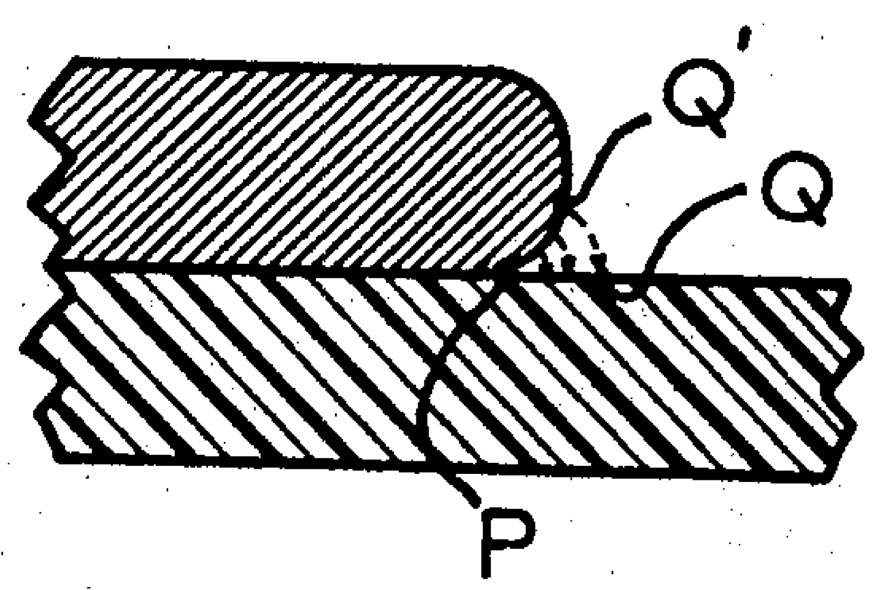


Fig.2

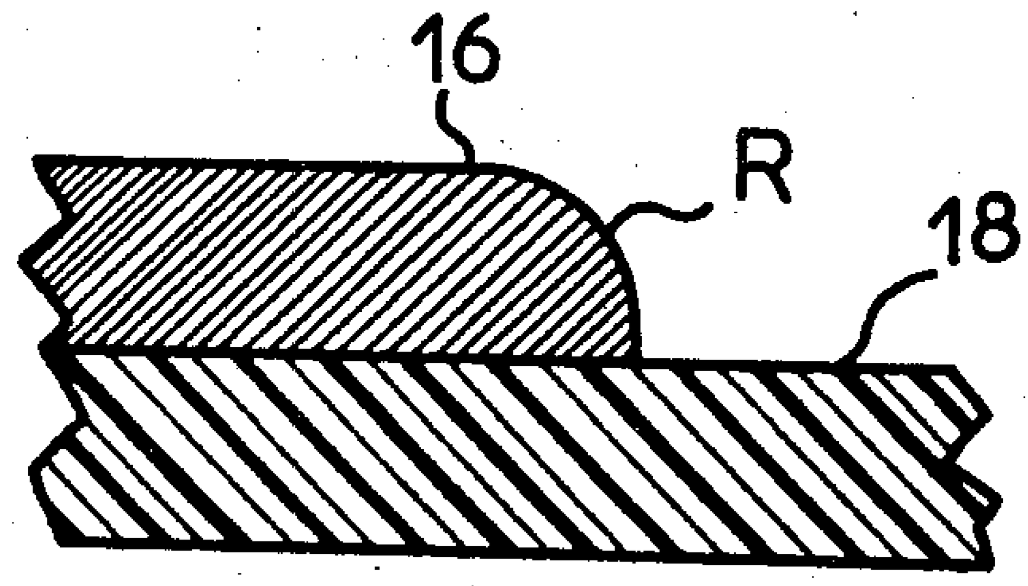


Fig.3

Dec. 24, 1968 N. J. FELICI ET AL 3,418,501

HIGH VOLTAGE ELECTROSTATIC MACHINERY

Filed April 26, 1966 2 Sheets-Sheet 2

Fig.4

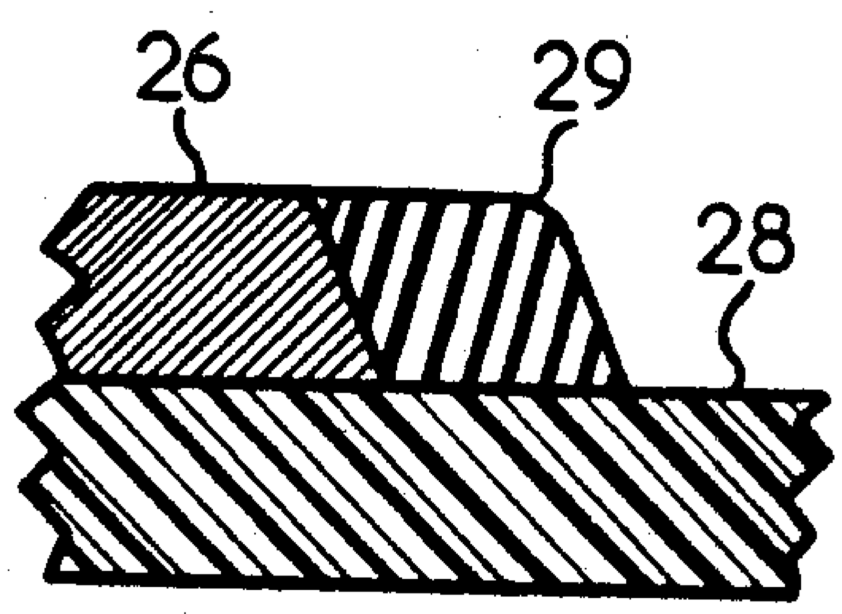


Fig.5

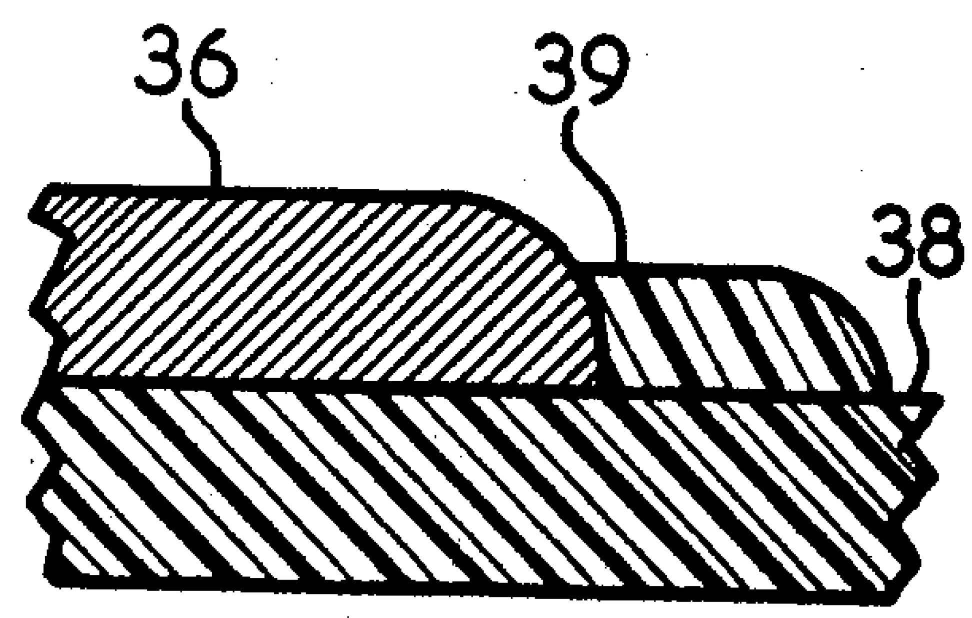


Fig.6

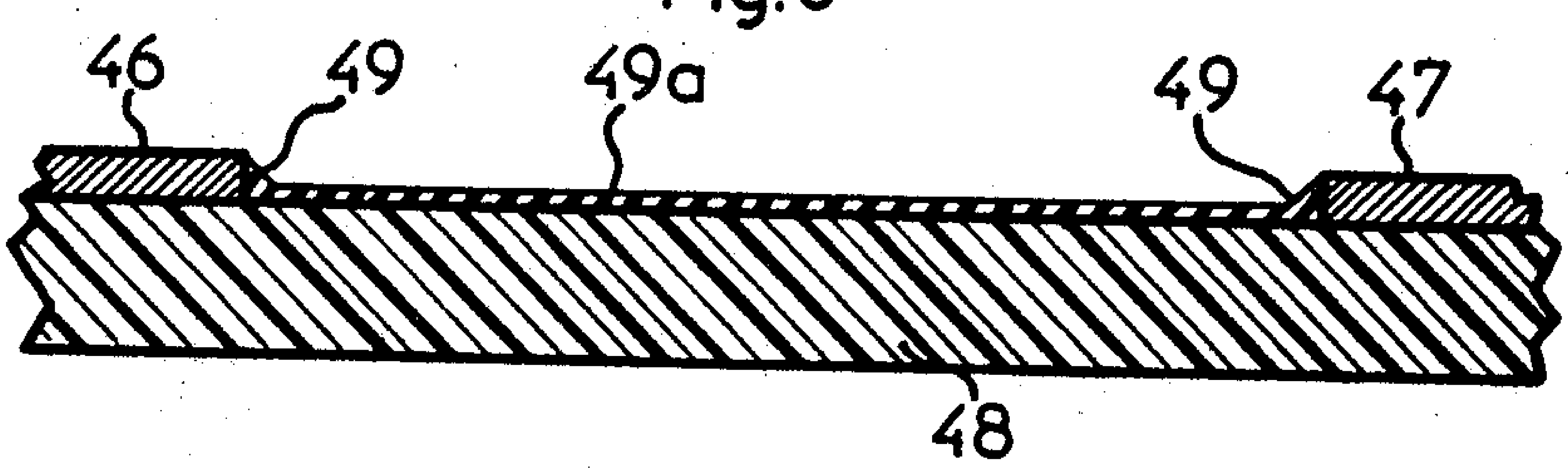


Fig.7

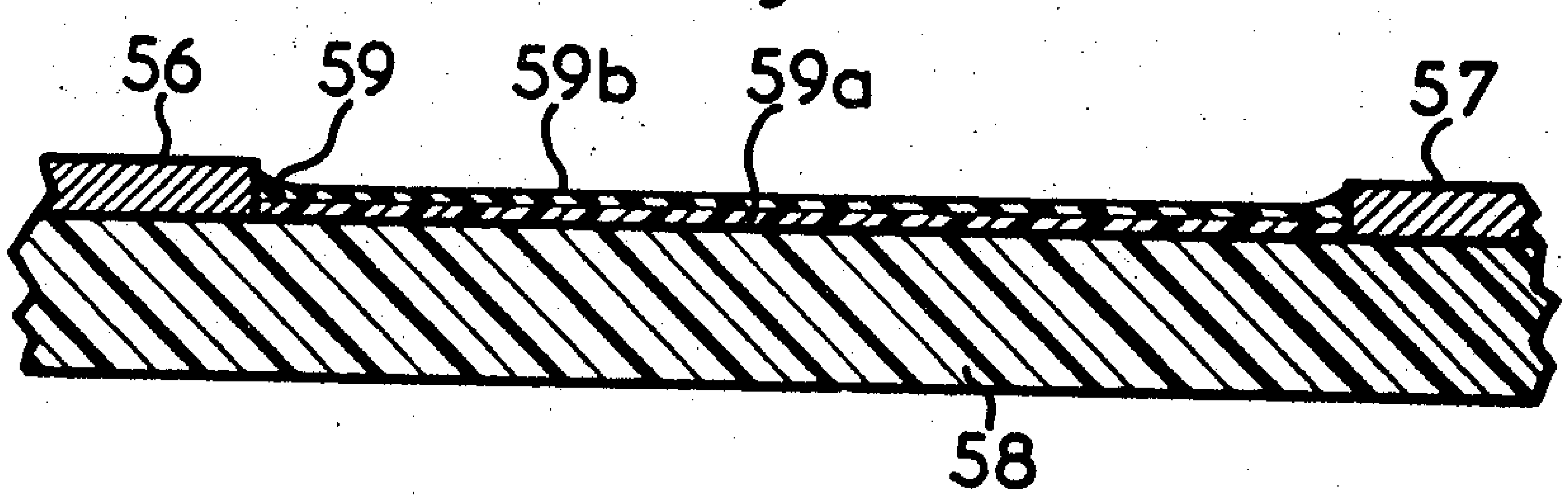
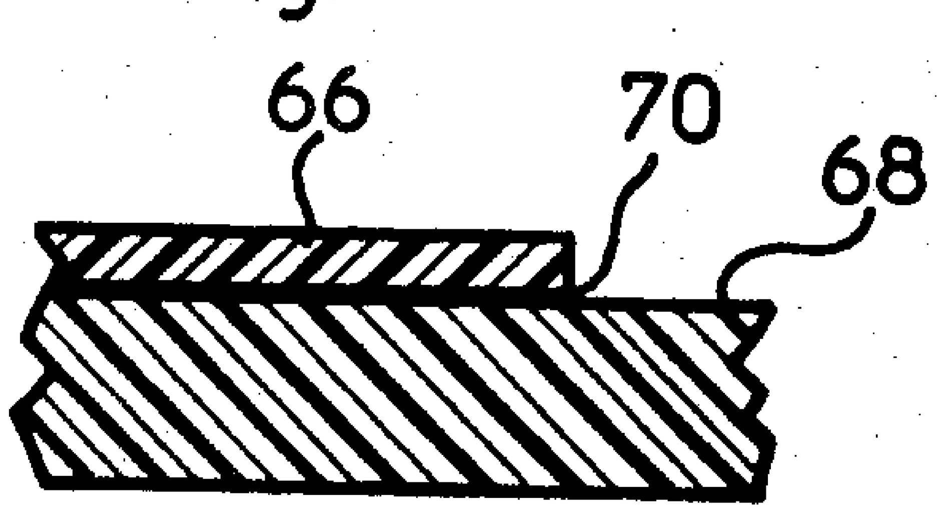


Fig.8



United States Patent Office

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HIGH VOLTAGE ELECTROSTATIC MACHINERY

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16 Claims. (Cl. 310—6)

This invention relates to high voltage electrostatic machinery and more particularly to such machinery in which one or more electrodes are subjected to a high electrical potential.

The present invention, while of general application, is particularly well suited for use in electrostatic generators or other electrostatic machinery of the rotating type. It is customary, in many types of machines of this class, to provide a voltage-distributing member of high, uniform resistivity which serves as a support for one or more pairs of electrode plates bonded to spaced areas thereof. The voltage-distributing member serves to facilitate the creation of a continuous, uniform, electrostatic field or voltage drop between each pair of electrodes. The electric field or voltage gradient thus produced is considerably more uniform than what has been obtainable in the absence of the voltage-distributing member, and the use of a member of this character has greatly contributed to the commercial success, in recent years, of compact electrostatic generators of high power rating, delivering output voltages of many hundred kilovolts.

Heretofore, the presence of the voltage-distributing member, together with the particular configuration of the electrodes with which it is used, has introduced serious difficulties. As an illustration, it previously has been considered desirable, if not essential, to employ electrodes in the form of plates having rounded edges and corners on the voltage-distributing members in order to avoid unwanted discharges and ionization which might result from the use of points, sharp edges and similar electrode configurations. However, when the rounded edges of the electrodes are placed immediately adjacent the voltage-distributing member, which serves to physically interconnect the electrodes by a continuous dielectric surface, there is a tendency for an unwanted sparking to take place across the electrodes along the dielectric surface. Such sparking occurs at voltages which are considerably lower than the theoretical sparking voltage as indicated by Paschen's law for the gaseous medium surrounding the electrodes, which medium customarily comprises pressurized hydrogen in many types of electrostatic generators and related equipment. These difficulties have seriously limited the performance of prior electrostatic machines and the voltages attainable therein.

Previous attempts to overcome the foregoing difficulties for the most part have involved the filling of substantially the entire space adjacent the inner surface of the stator of an electrostatic generator, for example, with a mass of paste-like material having high electrical rigidity. The filling material customarily was in the form of an asphalt base composition or similar potting compound and resulted in further disadvantages, including the difficulty of providing adequate maintenance for the machine and the additional problems in the fabrication and operation of the machine which arose because of the unnecessarily complicated structure.

One general object of this invention is to provide new and improved high voltage electrostatic machinery of the type in which one or more electrodes are supported by a voltage-distributing member.

More specifically, it is an object of the invention to provide such machinery in which the incidence of inter-electrode sparking is substantially reduced.

Another object of the invention is to provide electrostatic machinery of the character indicated having voltage and power ratings which are considerably in excess of the ratings for prior machines of this class.

A further object of the invention is to provide an electrostatic rotating machine in which the electrostatic field over the surface of the voltage distributing member is of improved uniformity.

A still further object of the invention is to provide an electrostatic machine which may be readily dismantled for maintenance purposes.

Still another object of the invention is to provide high voltage electrostatic machinery which is economical to manufacture and thoroughly reliable in operation.

In accordance with one advantageous embodiment of the invention, there is provided an electrostatic machine which includes a voltage-distributing member and voltage means including at least one electrode overlying the voltage-distributing member. The electrode is provided with a surface in immediate proximity with the voltage-distributing member and is of a configuration such that any point on the contour of the surface projects outwardly at least as far as any corresponding point on the electrode's periphery. The arrangement is such that the presence of narrow gaps or fissures between the peripheral edge portions of the electrode and the underlying surface of the voltage-distributing member is eliminated, with the result that any deleterious sparking effects are substantially reduced.

In several preferred embodiments of the invention, the voltage means includes resistive means adjacent at least a portion of the periphery of the electrodes. For some applications, the resistive means comprises a bead or strip of insulating material extending around the electrode, while in other cases the electrode itself is fabricated from resistive material. The use of such resistive means further reduces the incidence of sparking along the surface of the voltage-distributing member and enables the provision of a machine having substantially increased voltage and power ratings.

In accordance with certain good embodiments of the invention, a pair of electrodes are arranged in spaced relationship with each other along the surface of the voltage-distributing member, and a thin film having particular resistivity characteristics is bonded to the surface between the electrodes. The resistive film is arranged such that it extends continuously from the periphery of one electrode to the periphery of the other. The film not only provides a substantial reduction in any inter-electrode sparking but also is effective to improve the uniformity of the voltage drop therealong.

The present invention, as well as further objects and advantages thereof, will become more fully apparent from the following description of certain preferred embodiments, when read with reference to the accompanying drawings, in which:

FIGURE 1 is a schematc representation of an electrostatic generator of the rotating, insulating charge-carrier type, which constitutes one illustrative but important application of the invention;

FIGURE 2 is a generally diagrammatic, enlarged cross sectional view of a peripheral portion of a plate electrode and the underlying part of a voltage-distributing member, illustrating the presence of a narrow gap or interstice therebetween as was frequently the case in prior-art constructions;

FIGURE 3 is a view similar to FIGURE 2 but illustrating a plate electrode and a voltage-distributing member constructed in accordance with one illustrative embodiment of the present invention;

FIGURE 4 is a view similar to FIGURE 2 but illustrating the provision of an insulating marginal strip or bead according to another illustrative embodiment of the invention;

FIGURE 5 is a view similar to FIGURE 2 but illustrating still another embodiment of the invention wherein the plate electrode is in the form of a thin resistive sheet, e.g., of conductive rubber;

FIGURE 6 is a generally diagrammatic, enlarged cross sectional view showing a dielectric film extending between two neighboring plate electrodes spaced along a surface of a voltage-distributing member according to a further embodiment of the invention;

FIGURE 7 is a view similar to FIGURE 6 but showing an additional film of intermediate resistivity between the electrodes in accordance with another embodiment; and

FIGURE 8 is a generally diagrammatic, enlarged cross sectional view of portions of a plate electrode and a voltage-distributing member according to a still further embodiment.

In the drawings, corresponding parts have been designated in the different views by means of reference numbers wherein the last digits are the same. Although in FIGURES 2–8 the parts have been shown flat for convenience, it is understood that they would usually be of arcuate configuration, as illustrated in FIGURE 1, for example.

Schematically shown in FIGURE 1 is a high-voltage electrostatic generator of the revolving insulating charge-carrier type, which constitutes a preferred application of the invention. The general mode of operation of generators of this type is well-known and will be only briefly summarized herein.

The electrostatic generator comprises a hollow cylindrical rotor **1** of insulating material which is driven at high speed through conventional means (not shown). The rotor **1** rotates about a voltage-distributing member in the form of a stator **8** which defines a narrow annular clearance gap with the rotor. The stator **8** is fabricated from highly resistive or semiconductive material, such as a suitable doped glass or plastic, for example, and advantageously has a resistivity within the range of from about 10^{10} to 10^{14} ohm-centimeters, for purposes that will become more fully apparent hereinafter.

Two pairs of ionizers **2** and **3** are stationarily mounted in equiangular relation around the rotor **1** and project into close proximity with its outer surface. These ionizers are in the form of metallic strips which extend parallel to generatrices of the rotor. A first pair of diametrically opposed ionizers, designated **2**, is connected to ground and serves to deposit electrostatic charges on the outer surface of the rotor during its rotation. The other pair of diametrically opposed ionizers **3** is connected to the insulated output terminal **5** of the generator and is effective to collect the charges from the outer rotor surface.

Opposite the two pairs of ionizers **2** and **3** are respective pairs of inductor electrodes **6** and **7**. The electrodes **6** and **7** are in the form of conductive segmental plates or flat strips which overlie the inner surface of the rotor **8**. The electrodes comprising the pair **6** are connected with each other and with the output terminal of a low-voltage D.C. exciter generator **4** having its other terminal grounded. The electrodes which form the pair **7** likewise are connected with each other, and these latter electrodes lead to the common output terminal **5**.

The slightly-conductive voltage-distributing member or stator **8** maintains a continuous uniform tangential electric field or voltage gradient around the inner surface of rotor **1** between the consecutive poles of the machine. With the rotor **1** revolving in a clockwise direction, as viewed in FIGURE 1, the grounded ionizing electrodes **2** coacting with the associated inductors **6** can be regarded as depositing, say, negative charges on the outer rotor surface. As these charges are carried with the revolving rotor to the next following ionizing region between an ionizer **3** and its inductor **7**, their potential is greatly increased in traversing the intervening electrostatic field. The negative charges are collected by the ionizers **3**, and positive charges are deposited thereby on the surface of the rotor. The ionizers **3** are carried to, and in the steady state maintained at, a high negative voltage which is incomparably greater than the voltage delivered by the exciter **4**.

It will be understood that the above outlined theory of operation, while sufficient for an understanding of the present disclosure, is highly simplified. In practice, the operation of an electrostatic generator of the type referred to is considerably more complex, and a detailed discussion thereof can be found in various works of reference. It should also be understood that the machine shown in FIGURE 1 is but one example of high-voltage electrostatic apparatus to which the invention is applicable. Another example is that of a generally similar machine in which the charge-carrying rotor **1** is conductive rather than insulating.

The present invention, as applied to an electrostatic machine of the general type shown in FIGURE 1, is concerned with the construction of the inductor electrodes **6** and **7**. In the past, the configuration of such electrodes has given rise to considerable difficulties because of a propensity toward sparking between neighbouring electrodes along the inner surface of the voltage distributing stator **8**. This sparking has occurred heretofore at relatively low potentials which are considerably lower than the potential at which the spark would fire in the absence of the stator surface. As a result, the maximum potential differences that could be safely maintained in the generator, and hence the generator output, have been limited to two-thirds or even one-third of the power rating that otherwise could be expected in the absence of the sparking effects.

In recent years, this limitation has been partially overcome but only at the cost of considerable complications in the construction of the generator. An expedient that has been widely used in the past included the filling of the interior of the stator from the inner surface to the level of the inner faces of the inductor electrodes with an insulating mass of high dielectric rigidity. For mechanical reasons, the mass or filling had to be firmly adherent to the underlying surface of the stator and was deformable to avert the creation of mechanical strains which were liable to distort or crack the stator. There are not many substances filling these diverse requirements. Those that were most frequently used were asphaltic and tarry compounds. Among other disadvantages, the use of such materials limited the maximum operating temperature of the generator to a relatively low value, above which the material exhibited a tendency to flow. Furthermore, the materials tended to absorb considerable quantities of the pressurized gas (usually hydrogen) filling the generator, and in the case of an accidental drop in pressure because of a leak, for example, the absorbed gas was violently released, fracturing the stator. This property also made it difficult to construct electrostatic machines of the type referred to that could be dismantled for serving.

In accordance with the present invention, low-voltage sparking between the inductor electrodes of a high voltage electrostatic machine is prevented without having to resort to insulating filling masses, with their attendant disadvantages.

In understanding the various embodiments of the invention illustrated in the drawings, it will be helpful to consider some of the causes of such sparking in a typical electrostatic machine of the type used heretofore. FIGURE 2 is illustrative of a typical electrode configuration in a conventional electrostatic generator in common usage. This configuration exhibits a tendency to initiate sparking between the edge of the illustrated plate electrode and the edge of another plate electrode (not shown in FIGURE 2) spaced therefrom at comparatively low voltages. The sparking phenomenon, which may be termed "crack effect," may be explained by the following considerations. The point P in FIGURE 2 indicates a point on the contact contour between the metallic plate electrode and the underlying high-resistance or semi-conductive stator surface. At this point P, the stator surface is obviously at the same potential as the metallic plate electrode, and the potential varies continuously from the point P outwardly to the other electrode. However, progressing from point P outwardly toward the periphery of the illustrated electrode, the potential variation along the surface of the stator is not the same as that along the curved surface of the electrode. In the first case, the potential drops off rapidly because of the high resistance of the stator surface and the potential gradient present therealong. In the second case, the potential remains constant because of the conductive character of the electrode. Consequently, considering two facing points such as Q and Q′ respectively located on opposite sides of the crack or interstice between the stator and the electrode and therefore positioned very close to each other, the point Q is at a considerably lower potential than point Q′, and a comparatively high voltage drop exists between the two points. Accordingly, an electrostatic field of substantial strength is present across the sides of the interstice in the region which extends outwardly from the common contact contour of the electrode and the stator surface. Moreover, because of the relatively great extent or depth of the interstice (in a direction perpendicular to the plane of FIGURE 2), this field and the attendant high potential differences obtain over a correspondingly long distance and encompass a large number of electrostatic flux lines, three of which are indicated by the arrows. Although sparking generally will not take place in cases where a strong electrical field momentarily exceeds the breakdown field strength (as indicated by Paschen's law) in the surrounding gas medium, a crack or interstice of the type shown in FIGURE 2 in most cases is deep enough to initiate a severe spark even at moderate electrode voltages.

An interstice or fissure of the kind depicted in FIGURE 2 is a typical characteristic of plate electrodes of the prior art as used in electrostatic generators and similar equipment. The reason for this construction lies partly in the time-honored custom of using plates having rounded edges in high voltage equipment in an effort to avoid discharges and ionization which might be created by points, sharp edges and similar electrode configurations having small radii of curvature. The necessity of avoiding such discharges is, of course, justified, and the rounding-off of the upper corner of the plate electrode, as indicated at R in FIGURE 3, is desirable, although it is not believed to be essential. However, in prior machines the lower edge of the plate electrode, that is, the edge immediately adjacent the stator surface, also was generally rounded off in an effort to avert further sources of ionization at the inner surface of the stator. Such rounding off contributed to the unwanted sparking effect in a manner which far outweighed any reduction in ionization.

It is important in this connection to not that even in those constructions where the rounding off of the lower edge of the plate electrode was less pronounced than indicated in FIGURE 2, the objectionable spark-inducing conditions were still usually present. One reason for this is that the crack effect, to a certain extent, can be regarded as cumulative. The presence of a strong electrical field over even a short distance created distortional forces and strains which produced a deepening of the crack already present. Erosion due to incipient sparking also contributed to this condition.

Referring to the embodiment of the invention shown in FIGURE 3, the voltage member comprising the inductor electrode plate **16** is so constructed and mounted as to

eliminate the presence of any cracks or fissures between the edge of the plate and the voltage-distributing surface **18**. This involves forming the peripheral edge of the electrode **16** such that all points of its contact contour wtih the underlying surface **18** project outwardly at least as far as any corresponding point on the periphery of the electrode. In addition, the electrode is firmly bonded to the stator surface along the contact contour, thereby averting any tendency toward separation therebetween as a result of electrical or other forces.

The unwanted sparking effect also is inhibited by the provision of a bead or strip of resistive material adjacent the periphery of the electrode. This bead or strip preferably is used with an electrode of the type described in the preceding paragraph, and should have a resistivity of at least 1000 ohm-centimeters. Thus, as best shown in FIGURE 4, there is provided a bead **29** of silicone rubber which is firmly bonded to the underlying surface **28** of the stator or other voltage-distributing member. The bead **29** is a marginal extension of the voltage member comprising the plate electrode **26**. This electrode includes a bevelled peripheral edge. The orientation of the bead **29** in the critical marginal region where high voltage fields are apt to arise further increases the permissible inter-electrode potential above which sparking takes place. At the same time, the bead exerts a beneficial mechanical action in opposing any incipient separation between the electrode and the underlying surface.

In the modified embodiment shown in FIGURE 5, a strip **39** is bonded to the periphery of a metallic plate electrode **36** and to the underlying voltage-distributing member **38**. The strip **39** is fabricated from a material having a resistivity which is intermediate that of the conductive electrode **36** and the highly resistive member **38**, and preferably a material having a resistivity of 10 to 1000 times lower than that of the member **38**. Such material advantageously comprises an epoxy resin or other substances having a resistivity of from about 10^7 to about 10^{13} ohm-centimeters. The strip damps any sparks that might tend to form at the edge of the electrode **36** in that it increases the time constant of the RC circuit including that electrode and the adjacent electrode.

In certain important embodiments of the invention, means is provided for reducing the influence of unavoidable irregularities in the conductivity of the voltage- distributing member or stator. Such members commonly are made of special conductive glass or plastic compositions. Dut to the minor variations in the initial chemical composition, and also as a result of variations subsequently introduced into the surface of the member during operation as a result of vapor adsorption and other factors, the voltage-distributing member frequently presents uncontrollable irregularities in its surface conductivity. These irregularities lead to the creation of considerable local concentrations of the electric field which have been an additional cause of sparking and other disturbances in the operation of the machine and have limited the permissible maximum voltage and power ratings. In accordance with these latter embodiments, the effects of irregular surface conductivity of the voltage-distributing member are reduced by providing a thin film coating or layer which extends continuously over the entire inter-electrode area of the voltage-distributing member from the periphery of one electrode to the periphery of the other.

As an illustration, in FIGURE 6 there are shown two spaced-apart plate electrodes **46** and **47** having beads or strips **49** of insulating material firmly bonded to their peripheral edges. Integral with the strips **49** is a continuous thin film **49a** which is bonded to the intervening surface of stator **48** and extends unbroken throughout the space between the electrodes **46** and **47**. In this embodiment, the beads **49** serve to oppose incipient separation and cracks between the marginal portions of the electrodes and the stator surface, and the beads also provide a further reduction in sparking through an increase in the potential at which sparking is likely to take place. In addition, the continuous film coating **49*a***, which is made of silicone rubber or other material having a resistivity in excess of 1000-ohm-centimeters, improves the uniformity of the voltage drop along the surface of the stator **48** during the operation of the machine. This latter improvement is apparently due at least in part to the protection imparted to the surface of the stator against adsorption of water vapor and the like, which otherwise tends to increase the conductivity of the stator surface in an irregular and unpredictable way. The long-term operation of the machine is thereby substantially improved.

In an advantageous modification of the construction shown in FIGURE 6, the film **49*a*** is fabricated from a semiconductive material having a resistivity intermediate that of the electrodes **46** and **47** and that of the voltage-distributing member **48**. The provision of such a thin film of relatively high conductivity, when compared to the voltage-distributing member, provides a parallel electrical connection between the electrodes. The film greatly reduces the influence of any local variations in conductivity of the voltage-distributing member on the distribution of the electric field along its surface and prevents the setting up of local concentrations of the field. The performance of the machine is thus further improved, and its manufacture is facilitated because the electrical characteristics of the voltage-distributing member no longer need to be as precisely controlled.

In the modification shown in FIGURE 7, the surface of the high-resistance stator **58** is coated with a thin film **59*a*** of semi-conductive material, that is, a material having a resistivity which is intermediate the resistivity of the stator and that of the plate electrodes **56** and **57**. The film **59*a*** extends continuously from the edge of one electrode to that of the other. Coated over the surface of the film **59*a*** is another film **59*b*** which is of high-rigidity insulating material and which is arranged at its ends to form beads **59**. These beads are firmly bonded to the edge surfaces of the electrodes **56** and **57**. The beads serve to oppose the formation of cracks between the electrodes and the stator surface, and they also increase the sparking potential in the critical area adjacent the edges of the electrodes.

The semi-conductive base layer **59*a*** introduces a damping resistance in the inter-electrode circuit and simultaneously acts to improve the uniformity of the electric field between the electrodes. The film **59*b***, which advantageously has a resistivity substantially higher than that of the voltage-distributing stator member **58**, provides a uniform insulating surface and assists in the prevention of vapor adsorption by the surface of the stator member **58**.

In accordance with another highly desirable embodiment of the invention, the spark-inhibiting or damping resistance is incorporated in the material of the plate electrodes themselves. That is, the plate electrodes are made from generally resistive materials, rather than the conductive metals used heretofore. The resistivity of the plate electrodes in such an embodiment should be one or more orders of magnitude less than that of the high-resistance material used for the voltage-distributing member. A suitable range of resistivities for the plate electrode material is from about 10^3 to about 10^8 ohm-centimeters, and the preferred range extends from about 10^6 to about 10^7 ohm-centimeters. The incorporation of resistance in the plate electrodes inhibits sparning at the peripheral edges thereof because of a damping action similar to that described above. The resistance increases the discharge time constant of the RC circuit comprising the electrodes and the capacitance therebetween. Incipient inter-electrode sparks are thus damped, and the potential at which sparking occurs is again increased.

When electrodes are used according to these embodiments of the invention, in a preferred form of construction, the plate electrodes are made from thin sheets of rubber-like material which is suitably doped with carbon

or other electrically conductive particles to impart the requisite resistivity thereto. The conductive rubber sheets may have a thickness of from about 0.5 millimeter to about 3.0 millimeters and are firmly bonded to the high-resistance surface of the stator by means of a suitable electrically conductive adhesive, thereby preventing the separation of the sheets and the consequent formation of cracks as earlier explained.

One such embodiment of the invention is schematically illustrated in FIGURE 8. In this figure, the voltage member comprising the plate electrode is indicated at **66** and is in the form of a resistive or semi-conductive rubber sheet. The underlying voltage-distributing member is shown at **68**. A thin intermediate layer of strong, electrically conductive adhesive is indicated at **70**.

Inductor electrodes having a resistivity in the above indicated ranges operate in a manner which is generally similar to the conventional metallic electrodes used heretofore under steady-state conditions of operation. In addition, the resistive electrodes eliminate the incidence of sparking due to high-voltage transients during normal operation.

Some practical examples of the improved electrode assemblies will now be described.

EXAMPLES

The ensuing examples relate to a four-pole insulated-carrier electrostatic generator of the type generally shown in FIGURE 1. The generator had a power output of 0.5 kilovolt at a velocity of 3000 r.p.m., a voltage difference of 180,000 volts between adjacent inductor electrodes **6** and **7** and an output current of 3 milliamps. The sealed casing of the machine was filled with hydrogen at a pressure of 15 atmospheres. The voltage-distributing stator **8** was molded from an epoxy resin sold under the trade name "Araldite" which had a resistivity of 10^{13} ohm-centimeters.

Example I

The inductor electrodes **6** and **7** were made of highly conductive aluminum and were about 2.0 millimeters thick. The bonding of the electrodes to the "Araldite" stator was effected by an electrically conductive paste, and great care was exercised to prevent the formation of incipient separation and cracks between the electrodes and the stator surface throughout the bonded area and especially in the peripheral regions.

In a general arrangement similar to that shown in FIGURE 7, the surface of the stator between the electrodes was coated with a firmly-adherent semi-conductive film **59*a***. This film was made from a rubber sheet having a resistivity of 10^{11} ohm-centimeters and a thickness of 0.5 millimeter. The film was applied by a resistive paste at a temperature of 25° C. and was allowed to dry. Thereafter, there was applied an insulating film **59*b*** of silicone rubber which had a resistivity of 10^{14} ohm-centimeters and also was 0.5 millimeter thick. The marginal portions of this latter film were further thickened and were firmly bonded to the edge surfaces of the plate electrodes to provide marginal strips or beads **59**.

Example II

In a form of construction similar to that described with reference to FIGURE 8, the inductor electrodes were made from a conductive rubber sheet containing a graphite disperson, the resistivity of the sheet being 10^6 ohm-centimeters. The electrodes were 2 millimeters thick and were bonded to the "Araldite" stator by means of an electrically conductive paste having the same resistivity as the rubber sheet. The bonding was performed at a temperature of 25° C. and under a pressure of 5 atmospheres in a suitable jig to eliminate as completely as possible the occurrence of minute cracks and incipient separation between the sheet and the stator surface throughout the bonded area thereof.

Respective stator members constructed in accordance with Examples I and II were mounted in the electrostatic generator of the type specified above, and the machine was operated under test conditions which included voltage transients of about 200,000 volts. Even after 1,000 hours of operation, no sparking was observed in either case.

In addition, because of the absence of any asphalt-base, tarry or equivalent filling mass in the stator, and since the plate electrodes were not imbedded therein as was customary in conventional machines, the construction of the stator was greatly simplified. The machine was easily dismantled to replace one stator with the other without any danger of a violent release of absorbed gas. During the test runs, the ambient temperature was increased to attain internal operating temperatures of about 80° C. within the stator, and no adverse effect on the improved stator structures was observed. For comparison, in previous machines of comparable class the internal stator temperature was limited to about 50° C. in order to prevent undue softening of the asphalty mass.

The invention may be embodied in a variety of ways other than those specifically shown and described. For example, while in FIGURES 6 and 7 the electrode plates are shown as having straight edges, the edges may be bevelled as in FIGURE 4 or rounded as in FIGURE 5. In each of the embodiments of FIGURES 4 to 7, the electrodes may be made from a material having marked resistivity within the range indicated in connection with the embodiment of FIGURE 8.

The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed.

What is claimed is:

1. In an electrostatic machine, in combination, a voltage-distributing member of high uniform resistivity, voltage means including at least one electrode overlying said voltage-distributing member, said electrode having a surface in immediate proximity with said voltage-distributing member and being of a configuration such that any point on the contour of said surface projects outwardly at least as far as any corresponding point on the periphery of said electrode, said voltage means including resistive means having a resistivity of at least 1000 ohm-centimeters adjacent at least a portion of periphery of said electrode, and means for mounting said voltage means on said voltage-distributing member.

2. A machine of the character set forth in claim **1**, in which said resistive means has a resistivity substantially lower than that of said voltage-distributing member but at least as high as the resistivity of said electrode.

3. A machine of the character set forth in claim **1**, in which said resistive means has a resistivity higher than that of said voltage-distributing member.

4. In an electrostatic machine, in combination, a voltage-distributing member of high uniform resistivity, means including at least one electrode overlying said voltage-distributing member, said electrode having a surface in immediate proximity with said voltage-distributing member and being of a configuration such that any point on the contour of said surface projects outwardly at least as far as any corresponding point on the periphery of said electrode, resistive means including a strip of material having a resistivity of at least 1000 ohm-centimeters adjacent at least a portion of the periphery of said electrode, and means for bonding said resistive means to said voltage-distributing member and to the peripheral portion of said electrode.

5. In an electrostatic machine, in combination, a voltage-distributing member of high uniform resistivity, and voltage means including a pair of spaced-apart electrodes overlying said voltage-distributing member, each of said

electrodes having a surface in immediate proximity with said voltage-distributing member and being of a configuration such that any point on the portion of the contour of said surface facing the other electrode projects outwardly at least as far as any corresponding point on the periphery of said electrode, said voltage means including a thin film of resistive material extending from the periphery of one of said electrodes to the periphery of the other electrode.

6. In an electrostatic machine, in combination, a voltage-distributing member of high uniform resistivity, voltage means including at least one electrode overlying said voltage-distributing member, said electrode having a surface in immediate proximity with said voltage-distributing member and being of a configuration such that any point on the contour of said surface projects outwardly at least as far as any corresponding point on the periphery of said electrode, said electrode comprising resistive means having a resistivity of at least 1000 ohm-centimeters adjacent at least a portion of the periphery of said electrode, and means for mounting said voltage means on said voltage-distributing member.

7. In an electrostatic machine, in combination, a voltage-distributing member of high uniform resistivity, voltage means including at least one electrode overlying said voltage-distributing member, said electrode being formed of a thin sheet of flexible material having a resistivity within the range of from about 10^3 to about 10^8 ohm-centimeters, the resistivity of said voltage-distributing member being substantially in excess of the resistivity of said electrode, and means for mounting said electrode on said voltage-distributing member.

8. A machine of the character set forth in claim **7**, in which said sheet electrode is fabricated from a rubber-like composition containing electrically conductive particles.

9. In an electrostatic machine, in combination, a voltage-distributing member of high uniform resistivity, voltage means including at least one electrode overlying said voltage-distributing member, said electrode being formed of a thin sheet of flexible material having a resistivity within the range of from about 10^3 to about 10^8 ohm-centimeters, the resistivity of said voltage-distributing member being substantially in excess of the resistivity of said electrode, and an electrically conductive adhesive for firmly bonding said electrode to said voltage-distributing member.

10. A machine of the character set forth in claim **9**, wherein the resistivity of said electrode is within the range of from about 10^6 to about 10^7 ohm-centimeters.

11. In an electrostatic machine, in combination, a voltage-distributing member of high uniform resistivity, means including a pair of electrodes arranged in spaced relationship with each other along a surface of said voltage-distributing member and having a high voltage difference therebetween during the operation of said machine, each of said electrodes including a surface in immediate proximity with the said surface of said voltage-distributing member and being of a configuration such that any point on the contour of the electrode surface projects laterally toward the other electrode at least as far as any corresponding point on the periphery of the electrode, and resistive means having a resistivity of at least 1000 ohm-centimeters bonded to the surface of said voltage-distributing member adjacent at least the facing portions of said electrodes.

12. In an electrostatic machine, in combination, a voltage-distributing member of high uniform resistivity, means including a pair of electrodes arranged in spaced relationship with each other along a surface of said voltage-distributing member and having a high voltage difference therebetween during the operation of said machine, each of said electrodes including a surface in immediate proximity with the said surface of said voltage-distributing member and being of a configuration such that any point on the contour of the electrode surface projects laterally toward the other electrode at least as far as any corresponding point on the periphery of the electrode, and resistive means comprising a film of material having a resistivity of at least 1000 ohm-centimeters bonded to the surface of said voltage-distributing member between the electrodes and extending from the periphery of one electrode to the periphery of the other.

13. A machine of the character set forth in claim **12**, in which said film comprises a silicone rubber composition.

14. In an electrostatic machine, in combination, a voltage-distributing member of high uniform resistivity, means including a pair of plate electrodes arranged in spaced relationship with each other along a surface of said voltage-distributing member and having a high voltage difference therebetween during the operation of said machine, each of said electrodes including a surface in immediate proximity with the said surface of said voltage-distributing member and being of a configuration such that any point on the contour of the electrode surface projects laterally toward the other electrode at least as far as any corresponding point on the periphery of the electrode, and a plurality of sheets of resistive material having different resistive properties disposed along the surface of said voltage-distributing member between the electrodes and etxending from the periphery of one electrode to the periphery of the other.

15. In an electrostatic machine, in combination, a voltage-distributing member of high uniform resistivity, means including a pair of plate electrodes arranged in spaced relationship with each other along a surface of said voltage-distributing member and having a high voltage difference therebetween during the operation of said machine, each of said electrodes including a surface in immediate proximity with the said surface of said voltage-dirtributing member and being of a configuration such that any point on the contour of the electrode surface projects laterally toward the other electrode at least as far as any corresponding point on the periphery of the electrode, a first film of material having a resistivity lower than that of said voltage-distributing member but higher than that of said electrodes bonded to the surface of said member between the electrodes, and a second film of material having a resistivity higher than that of said first film bonded thereto, each of said films extending from the periphery of one electrode to the periphery of the other.

16. A machine of the character set forth in claim **15**, in which the portions of said second film adjacent said electrodes form beads along the facing edges thereof.

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