March 6, 1956 D. CHARLES 2,737,623

HIGH VOLTAGE ELECTROSTATIC MACHINES

Filed Sept. 30, 1953

Fig. 1

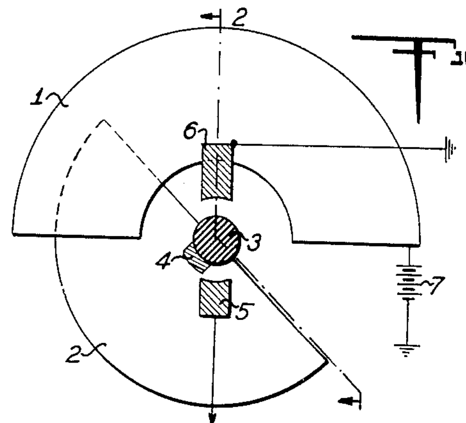
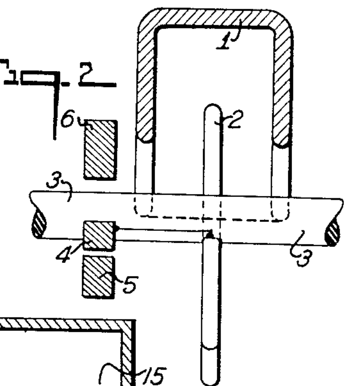


Fig. 2



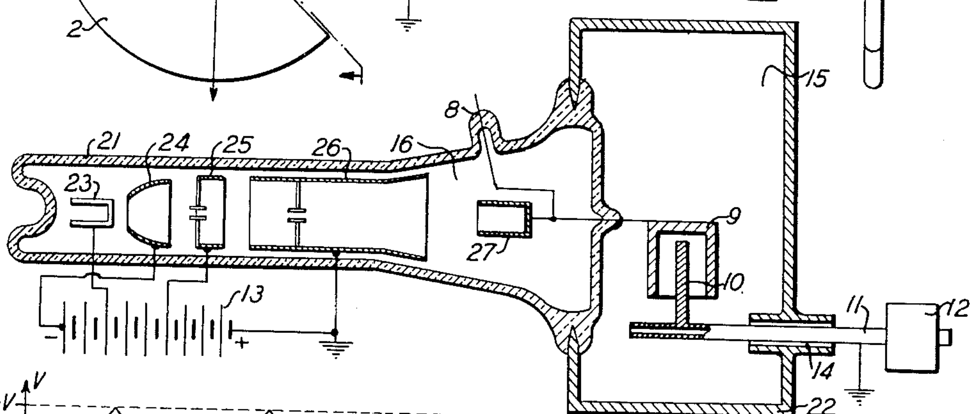


Fig. 3

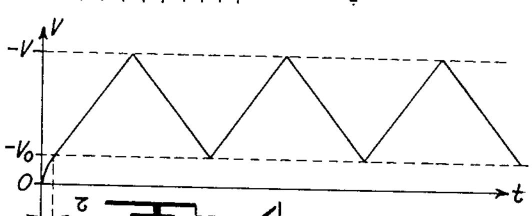


Fig. 4

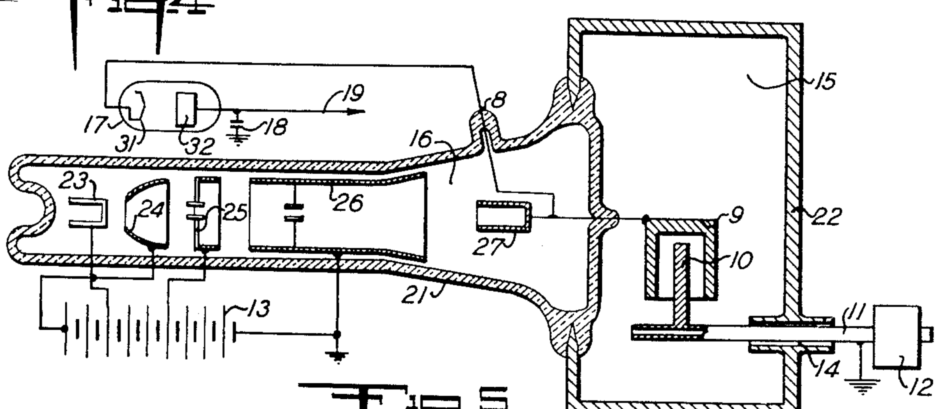


Fig. 5

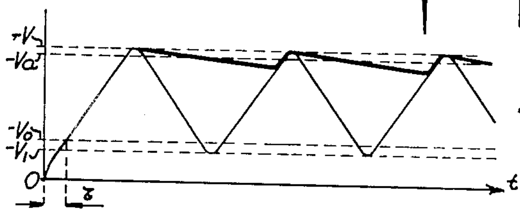


Fig. 6

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HIGH VOLTAGE ELECTROSTATIC MACHINES

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6 Claims. (Cl. 322—2)

The present invention relates to electrostatic machines, and more particularly to machines of this type for producing high voltages.

Modern electrostatic machines are known for the generation of high voltages which are based upon the principle of the electrophorus involving the transfer of electrical charges. Machines of this nature have certain drawbacks, however, which are similar to those of direct current electromagnetic machines. One of the drawbacks results from the use of brush contacts which are difficult to maintain in good working condition and require constant servicing. A further drawback is the inability to vary the excitation current as a result of which it is difficult to control the voltage obtained from the machine. A still further drawback is due to the fact that the shaft upon which is mounted the movable armature of the machine is generally made of insulating material, and most of these materials are fragile.

The present invention relates to an electrostatic machine which comprises no brush contacts and no shaft of insulating material, and with which it is possible to adjust the output voltage with great facility.

In an electrostatic machine having two armatures, one of which is fixed and the other is mounted for rotation, the rotatable armature is electrically connected to the mass while the fixed armature is charged by the impact of charged particles upon an electrode which is in direct electrical contact with said fixed armature. The charged particles may be of ionic or electronic origin carrying a charge of either sign.

The invention will be more readily understood from the following description, reference being had to the accompanying drawings in which:

Figure 1 is a diagrammatic representation of a known electrophoric machine in an end view;

Figure 2 shows a section on line 2—2 of Figure 1;

Figure 3 is a diagrammatic axial section through one form of electrostatic machine in accordance with the present invention;

Figure 4 is a graph of the voltages obtained as a function of time with a generator according to Figure 3, the movable armature of which is presumed to be rotated at uniform speed;

Figure 5 is a view similar to Figure 3 but with the addition thereto of a utilization circuit, and

Figure 6 is a graph similar to Figure 4 but applicable to the generator of Figure 5.

In Figures 1 and 2 illustrating a known electrostatic or electrophoric machine the fixed metal armature **1** is for example in the shape of one half of a body of revolution generated by the rotation of a U-shaped member about an axis perpendicular to the straight legs of the U and on the concave side thereof. This fixed armature **1** is permanently connected to a source of voltage **7**. The movable armature **2** is mounted on a shaft **3** of insulating material the axis of which coincides with the axis of the body of revolution constituting the armature **1**. The movable armature **2** rotates with the insulating shaft and remains within the plane of symmetry of the fixed armature **1**. The movable armature is generally in the form of a one half disc. The shaft **3** of insulating material is provided with a metallic contact piece **4** electrically connected to the armature **2** and rotatable therewith on the shaft **3**. A first brush **5** which is in intermittent contact with the contact piece **4** has an output connection thereto and a second brush **6** diametrically opposed to the brush **5** and which is also in intermittent contact with the contact piece **4** has a connection to ground. It is obvious that the brush **6** is in contact with the contact piece **4** when the half disc **2** is positioned entirely within the armature **1**.

In operation, when the armature **2** has its maximum surface facing the surface of the armature **1** and the contact piece **4** is in contact with the brush **6**, the apparatus constitutes a condenser having a maximum capacity C_{max} which is charged at the voltage V_o of the source **7**. The charge on the armature **2** is then $Q = C_{max}\ V_o$. Upon rotation from that position, the armature **2** is no longer electrically connected to the brush **6** but it carries its charge Q, and when it becomes electrically connected to the brush **5** its capacity has decreased to a minimum value C_{min}. The voltage of the movable armature relatively to V_o is then given by the following calculation:

$$Q = C_{min} \quad U = C_{max} \quad V_o$$

$$U = V_o \frac{C_{max}}{C_{min}}$$

and the voltage of the movable armature relatively to the mass is

$$U - V_o = V = V_o \frac{C_{max} - C_{min}}{C_{min}}$$

The stored energy is

$$\frac{\epsilon E^2}{8\pi}$$

wherein E is the field within the condenser and ϵ is the dielectric constant of the medium separating the plates or armatures of the condenser. In order that the stored energy may be as high as possible, it is clear that the field must be as high as possible and in the neighborhood of the breakdown voltage. In order to increase this voltage, the metallic parts must be of suitable profile and separated by a dielectric medium of suitable nature such as a vacuum or a pressurized gas. Modern machines generally use nitrogen at a pressure of 30 kg./cm.^{2}. The source **7** may comprise another electrostatic machine of the same type which obtains its charge from residual charges and from the frictional charge of the brushes. In this case, it is difficult to apply any control to the value of the excitation voltage thereby constituting one of the drawbacks referred to above.

In contrast to the foregoing description of a known machine, the machine according to the invention illustrated in Figure 3 comprises a gas-tight envelope **21** defining a chamber **16** and a second envelope **22** defining a chamber **15** adjacent to the chamber **16** and also of a gas-tight nature capable of supporting the pressure applied to a gas contained therein such as nitrogen. Within the chamber **16** are provided means for producing a stream of charged particles. Such means may comprise, for example, an electron emissive cathode **23**, a control electrode **24**, a first accelerating anode **25** and a second accelerating anode **26**, these electrodes **23** to **26** constituting an electron gun. The electron gun produces a stream of electrons which are directed into a cylinder **27** of conducting material, the shape of which is such as to prevent the secondary electrons generated by the impact of the beam of primary electrons from escaping from the cylinder 27 and returning to the anode 26. The cylinder or electrode 27 has a first connection therefrom to an output lead 8 extending through the envelope 21 and a second connection therefrom to the fixed armature 9 positioned on the other side of the envelope 21 and inside the envelope 22. The armature 9 is of similar shape to the armature 1 of the known machine and a movable armature 10 of part circular shape cooperates therewith in the same manner as the movable armature 2 of Figure 1. The movable armature 10 is mounted to rotate with the shaft 11 driven by the motor 12.

The armatures 9 and 10 and one end of the shaft 11 are positioned inside the chamber 15 bounded by the envelope 22 which is filled, as is known in the art, with a pressurized inert gas such as nitrogen at a pressure of 30 kg./cm.^{2}. The shaft 11 extends through the wall 22 of the chamber 15 in gas-tight manner through a gland or seal 14. This shaft 11 is made of metal and connected to ground.

The electrodes 23, 24, 25 and 26 are polarized by connections to source of direct current 13 the positive pole of which is connected to earth. The cathode 23 is at a substantial negative potential, the control cylinder 24 is at a weak negative potential relatively to the cathode and the anodes 25 and 26 are at two potentials the first of which for anode 26 is weakly negative and the second of which for anode 26 is ground potential.

As stated above the armatures 9 and 10 correspond in shape to the armatures 1 and 2 of Figures 1 and 2 and they are spaced from each other as is well known, in order to enable the use of a high field at the same time as they constitute a condenser of the highest possible capacity when the two circular sectors are in full overlapping position.

In operation, the beam of electrons striking the electrode 27 imparts a charge thereto until the electrode 27 acquires the same voltage $-V_o$ as the cathode relatively to ground. When this potential is reached, the electrons begin to be reflected and the beam ceases to impart a charge to the electrode 27 which may be considered as isolated in space. If it is assumed that the two armatures 9 and 10 are in full overlapping position during the time necessary for the beam to impart the charge of the cathode 23 to the electrode 27, i. e. if the condenser formed by the two armatures has during that time its maximum capacity C_M, the charge of the condenser will then be $Q=-C_M V_o$.

If the shaft 11 carrying the armature 10 is rotated the capacity of the condenser decreases to a minimum value C_m at which the armature 10 has been rotated 180°. The charge remaining on the electrode 27 and the armature 9, which is then the voltage of the armature 9, will be

$$-V=-\frac{C_M}{C_m}V_o$$

relatively to ground.

During the passage of the charge from $-V_o$ to $-V$, the electrons are continuously reflected by the electrode 27 the charge of which passes from zero to $-V+V_o$ relatively to the cathode. In other words, the electrode 27 becomes increasingly negative relatively to the cathode. The graph of Figure 4 shows the variations of voltage of the armature 9 as a function of the time element assuming that the armature 10 is rotated by the motor 12 at a uniform speed as soon as the charging of the armature 9 has been completed. In the graph, τ is the duration of the charge which obviously depends from the capacity C_M and from the current of the electron beam. It will be seen from Figure 4 that the voltage varies periodically from $-V_o$ to $-V$. The shape of this periodical curve depends obviously from the shape of the armatures 9 and 10. Where these armatures are in the shape of circular sectors, it may be presupposed that this curve is of triangular saw-tooth shape.

In the foregoing description it has been assumed that the electrode 27 is not connected to a load. In practice, a machine according to the invention is particularly useful where it is necessary to apply a very high static voltage to a load which has a very small consumption of energy. An example of this type of load is found in the electrostatic lenses of electron microscopes to which a static voltage of some tens of kilovolts must be applied. A further use for apparatus according to the invention is in connection with the production of ozone, but it can be stated that the present invention relates exclusively to an improvement in electrostatic machines the uses of which are well known to one skilled in the art.

Figure 5 illustrates an apparatus according to the present invention with a load circuit connected to the electrode 27. In that figure the same reference numerals are applied to the same elements as in Figure 3. The output connection 8 connects the electrode 27 to rectifying means such as a diode 17 the cathode 31 of which is connected to the output 8 of the apparatus according to the invention and the anode 32 of which is connected to one plate of a condenser 18 the other plate of which is connected to ground. The anode 32 of the diode 17 is also connected to a load at 19.

In the phase of operation during which the charge on the electrode 27 increases in absolute value, the diode 17 is conductive and the condenser 18 accumulates a charge. In the phase of operation during which the charge decreases, the voltage of the cathode 31 becomes more positive, i. e. weaker in absolute value, than the voltage of the anode 32, and the diode 17 is cut-off. These two phases are repeated cyclicly as the armature 10 rotates. The condenser 18 then discharges through the load circuit during an interval of time which depends from the impedance of the load and from the value of the condenser. The condenser 18 may comprise merely the parasite capacities of the load circuit. Figure 6 is a graph indicating the variations of voltage at the terminals of the load circuit as a function of the time element assuming that the armature 10 is uniformly rotated. In that figure, the heavy line represents the variations of voltage at the terminals of the load circuit while the light lines indicate the variations of voltage at the electrode 27 in the same circumstances. When the apparatus is started up the graph includes the charging period for the electrode 27 the voltage of which passes from zero or ground potential to the cathode potential $-V_o$. This interval of time is greater than the time τ of Figure 4 because the diode 17 is conductive and a certain amount of charges passes through the diode toward the load circuit and the condenser.

The motor 12 is then started and for the first phase of operation of the armature 10 during which the capacity of the condenser of the machine decreases from C_M to C_m, the potential of the electrode 27 decreases again from $-V_o$ to $-V$. During this phase, the electrons issuing from the cathode 23 are reflected by the electrode 27, the diode 17 is conductive, and the condenser 18 accumulates a charge from $-V_o$ up to a peak value of $-V$.

During the second phase of operation of the armature 10, when the capacity of the condenser of the machine increases from C_m to C_M, the diode 17 is no longer conductive and the condenser 18 discharges into the load circuit.

The potential prevailing between the plates of the condenser 18 decreases during this second phase from a value which depends both upon the value of the condenser 18 and upon the impedance inherent to the load circuit. Both these parameters of capacity of the condenser 18 and of impedance of the load circuit are so selected that the potential across the plates of the condenser 18 does not decrease, for example, by more than 10% of its value during a full rotation of the motor 12. The condenser 18 will be recharged to the voltage $-V$ during the next cycle of rotation of the motor. Starting from the instant where the charge on the electrode 27, which is in its phase of increasing absolute value, reaches and exceeds again the potential of the condenser **18**, the diode **17** will once again be conductive and a part of the charges of the electrode **27** will serve to charge once again the condenser **18**, and the cycle will be repeated indefinitely. It should be noted, however, that in this case the aspect of the variation of the charge on the electrode **27** is not exactly the same as in the case of Figure 4.

During the decreasing phase from C_M to C_m when the diode **17** is conductive a part of the charges on the electrode **27** flows toward the lower circuit and is not stored in the condenser **18**. The maximum voltage V is, therefore, necessarily less than in the example of Figure 4. Furthermore, during those phases where the capacity of the condenser of the machine increases from C_m to C_M, the charge on the electrode **27** increases from $-V$ to a value $-V'$ of smaller absolute value than $-V_o$, because the electrode **27** must necessarily receive electrons from the cathode **23** in order to compensate for the charge which it has lost in addition to the part of the charge which the electrode **27** has also lost to the load circuit.

In this case, a voltage is obtained at the terminals of the load circuit which varies only very slightly as a function of the time element and which remains substantially equal to an average voltage V_a provided the charge is small and the condenser **18** has been selected to have a proper value. This condenser **18**, as already stated, may comprise merely the parasite capacities of the load circuit.

Similar results may be obtained if the armatures **9** and **10** comprise a plurality of circular sectors, and in this event, one rotation of the motor involves as many increasing and decreasing phases of the capacity of the condenser of the machine as there are circular sectors constituting the armatures.

The diode **17** included in the connection to the load circuit may be of any known type, for example, a cold cathode tube of particularly easy operation thus avoiding any undue heating of the highly insulated cathode. The diode may also be replaced by rectifying means operating at high voltage.

The static voltage generator according to the present invention always provides high voltage of negative polarity relatively to ground, which is not the case with known machines and which enables a substantial gain in the amplification factor of the voltage.

With the machine according to the present invention it is possible to adjust the value of the peak voltage by adjusting the current of the electron beam, for example, by varying the voltage supplied to the control electrode **24**. Particular reference has been made herein to a cathode **23** emitting an electron beam, but it should be understood that the present invention is not limited to that feature and that it may comprise means for producing and concentrating ions having either a positive or a negative charge which is then transferred to an electrode similar to electrode **27** or otherwise applied to a fixed armature **9** and to a load circuit **8**.

What is claimed is:

1. An electrostatic machine for generating high electrical voltages comprising, in combination, a first fixed conductive armature, a second movable conductive armature, said armatures having substantially parallel portions positioned in partial overlapping relationship, means for uninterruptedly varying the overlapping areas of the surfaces of said first and second armatures, means comprising a conducting shaft connecting said movable armature to a source of fixed potential, a vacuum-tight envelope, means inside said vacuum-tight envelope for producing a stream of electrically charged particles, an electrode inside said envelope positioned to collect said stream of particles, means establishing an electrical connection between said electrode and said fixed armature, and means for collecting the voltage developed on said fixed armature when said stream of particles is produced and when said fixed potential is applied to said movable armature.

2. A machine as in claim 1, wherein said means for producing a stream of particles comprise an electron emissive cathode and means for concentrating the beam of electrons emitted by said cathode.

3. A machine as in claim 2, wherein said concentrating means comprise a control electrode and at least one accelerating anode.

4. A machine as in claim 1 in combination with rectifying means connected to said fixed armature and to said collecting means.

5. A machine as in claim 1 in combination with a diode having a cathode connected to said fixed armature and an anode connected to said collecting means.

6. The combination claimed in claim 5 further comprising a fixed condenser having a first plate connected to the anode of said diode and a second plate connected to said source of fixed potential.

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