Oct. 24, 1950 E. P. MILLER 2,526,763

ELECTROSTATIC COATING APPARATUS

Filed May 20, 1946 4 Sheets-Sheet 1

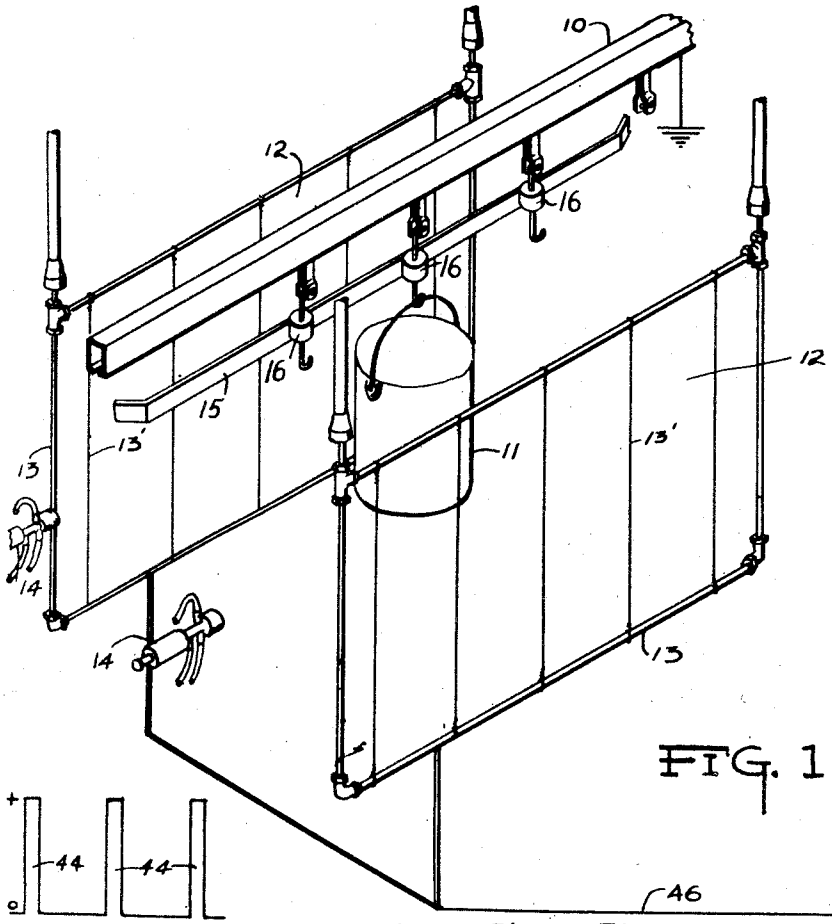
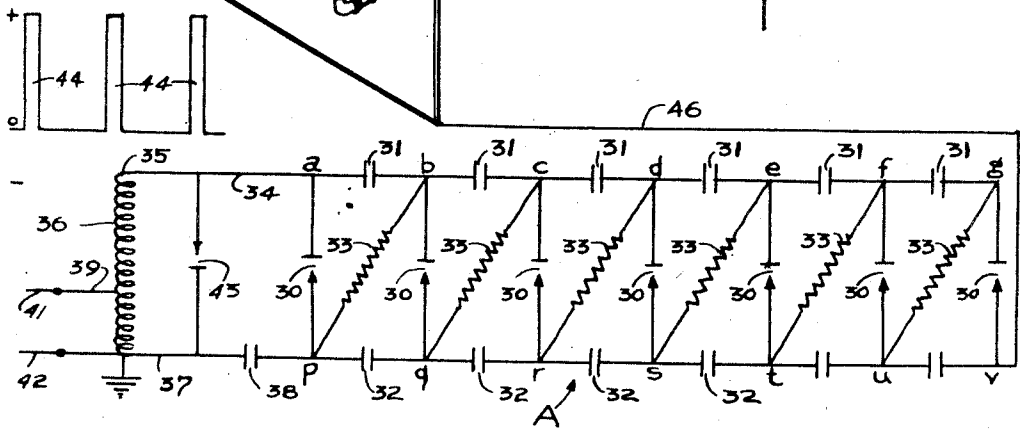


FIG. 1



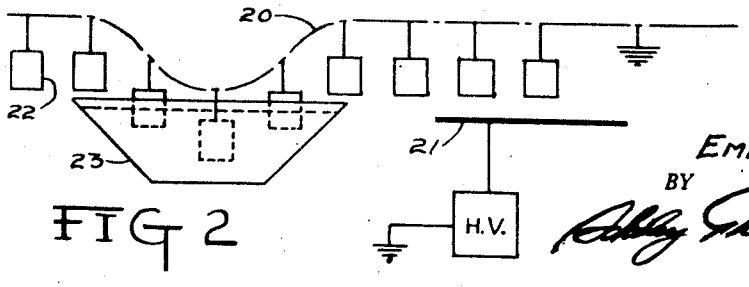


FIG 2

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ELECTROSTATIC COATING APPARATUS

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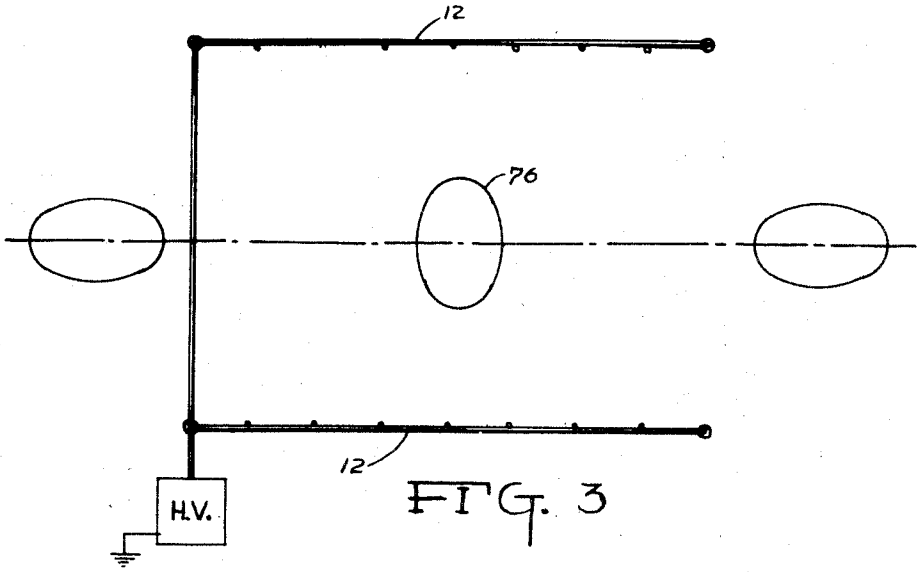


FIG. 3

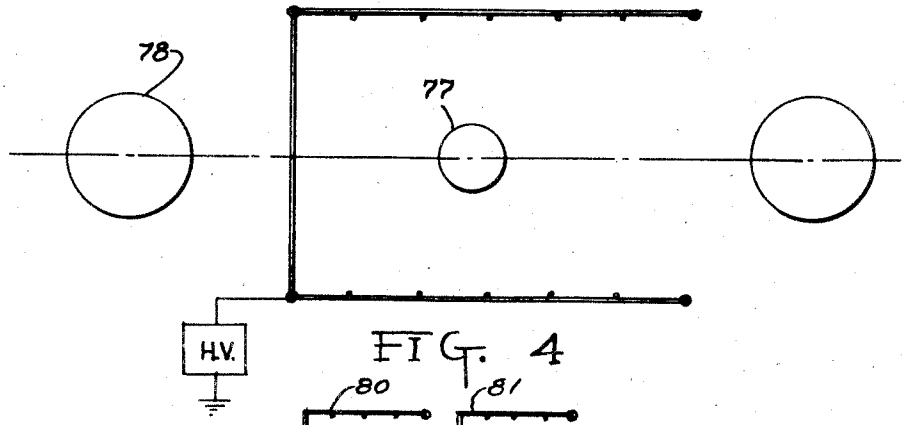


FIG. 4

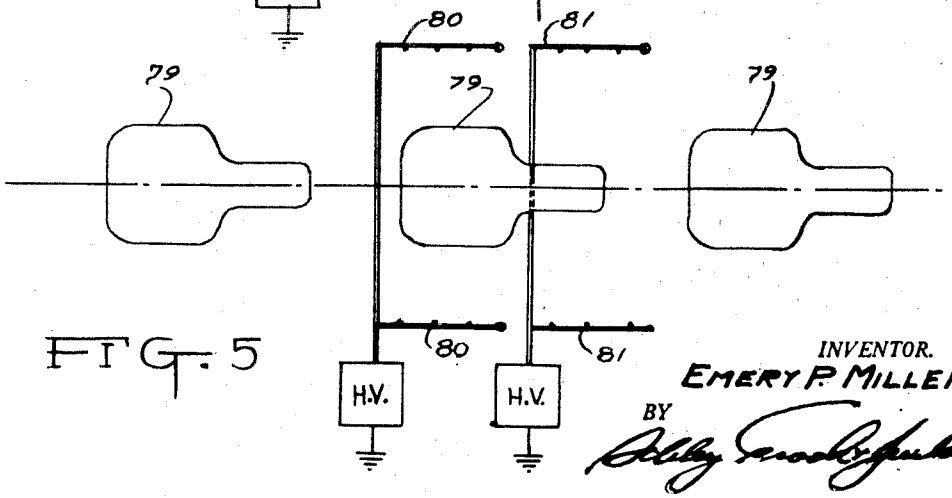


FIG. 5

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ELECTROSTATIC COATING APPARATUS

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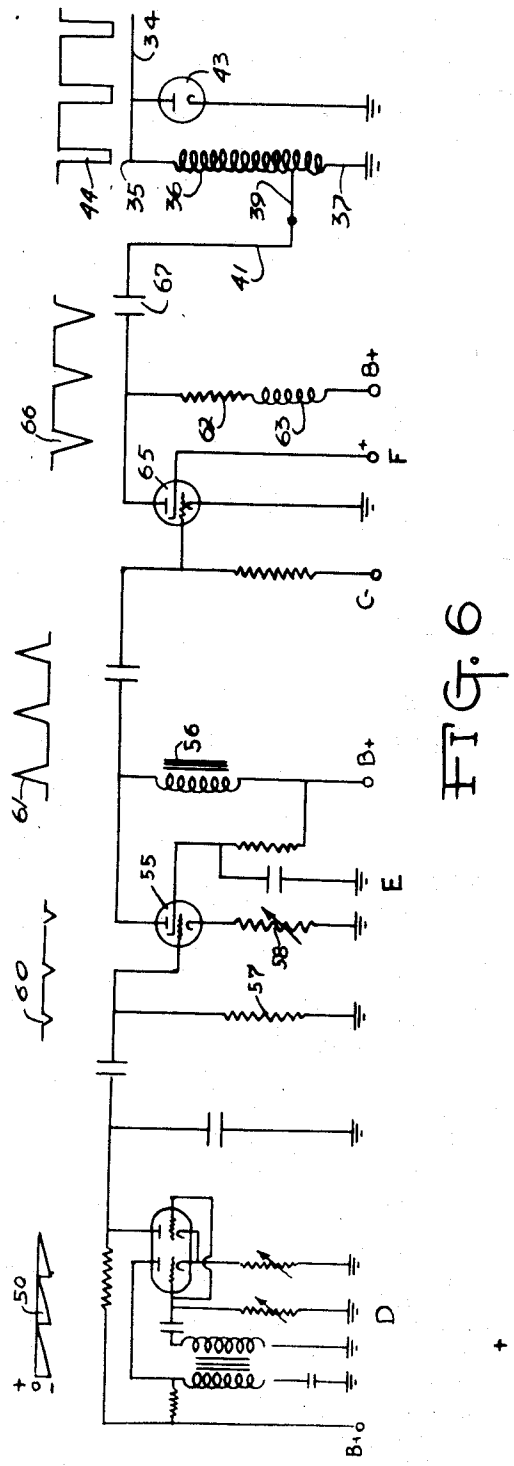


FIG. 6

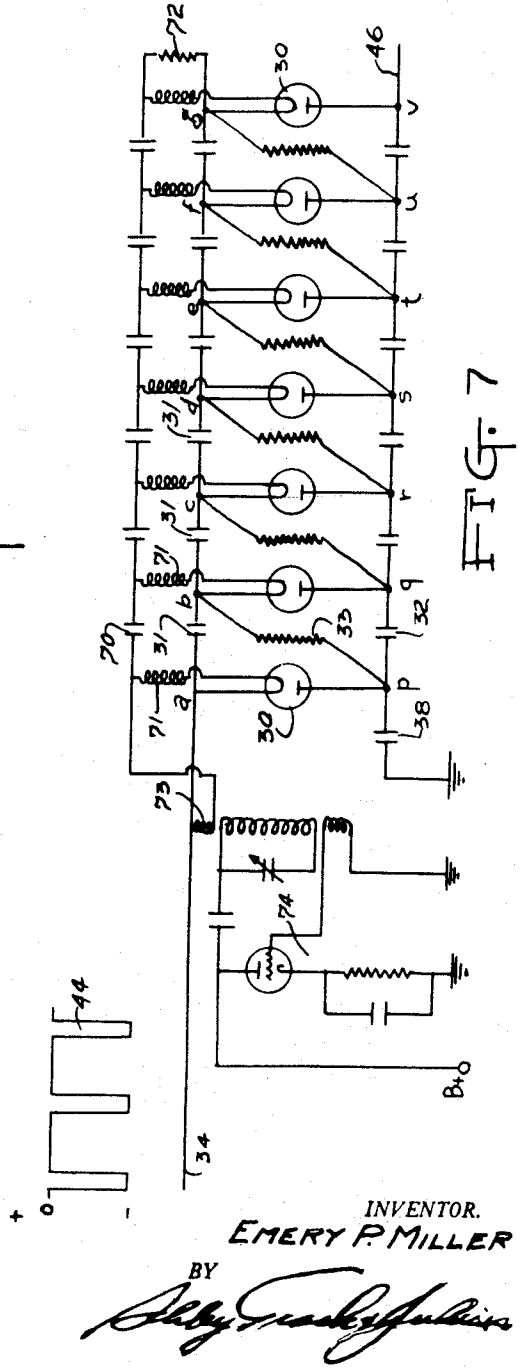


FIG. 7

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ELECTROSTATIC COATING APPARATUS

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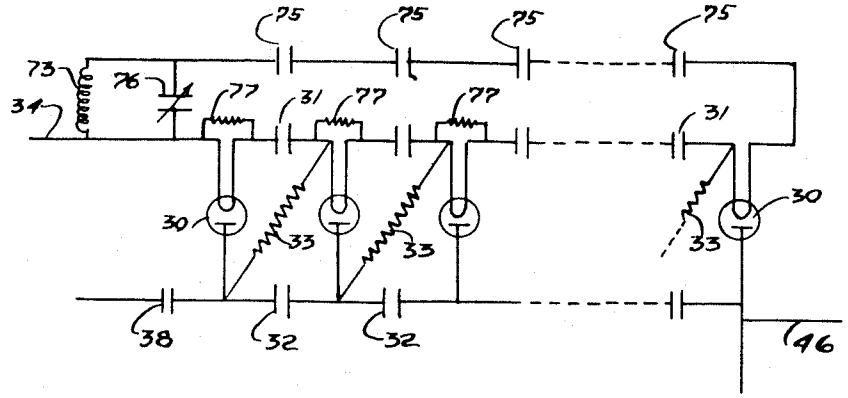


FIG. 8

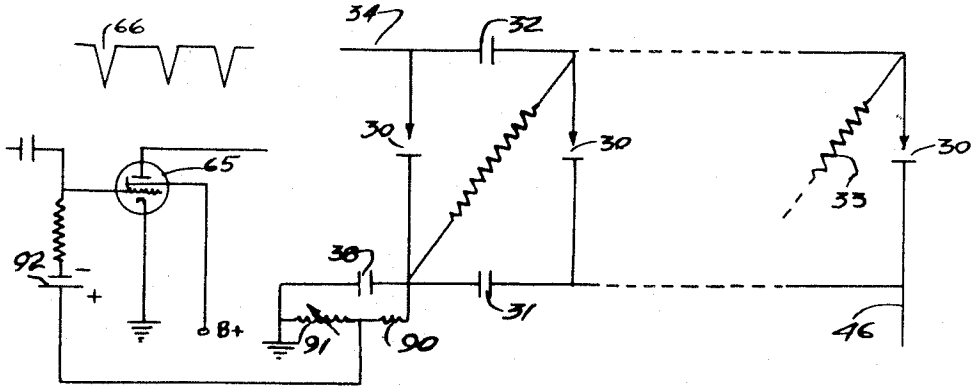


FIG. 9

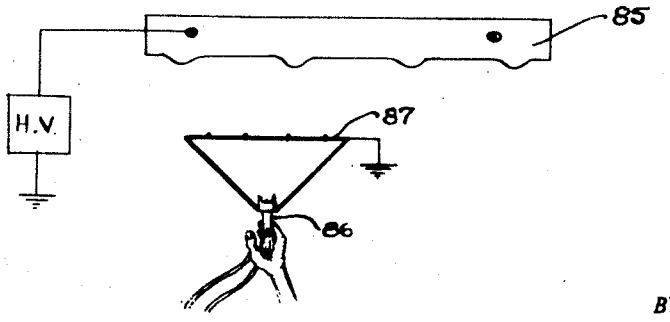


FIG. 10

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UNITED STATES PATENT OFFICE

2,526,763

ELECTROSTATIC COATING APPARATUS

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Application May 20, 1946, Serial No. 671,037

6 Claims. (Cl. 91—18)

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This invention relates to apparatus by which finely divided particles of matter are moved through space by electrostatic forces, and is generally applicable in any situation in which charged particles of matter suspended in a fluid medium are caused to move away from one and toward another of two bodies between which a high difference of electrical potential is maintained. For the sake of convenience, and not by way of limitation, the invention is herein illustrated and described as embodied in apparatus by which charged particles of a coating material are electrostatically deposited on an article to be coated and by which an article, after being coated with an excess of liquid coating material, is subjected to the action of an electrostatic field to remove the excess.

Such apparatus is not broadly new. In utilizing it, the article is supported in spaced relation to an electrode, and an electrostatic field is created between the article and the electrode to promote the desired movement of coating-material particles. To create the high electrical potential necessary for the establishment and maintenance of the electrostatic field it has been customary to employ a transformer, the output of which is usually rectified in order that the acceleration imparted to charged particles in the field may be unidirectional. In practice, the spacing of the electrode and article, and the potential-difference maintained between them, depends on a number of factors, such as the desired uniformity of field distribution over the surface of the article, the necessity of providing, in processes of electrostatic deposition, adequate space between the article and electrode for the introduction and distribution of the finely divided coating material, reduction in the danger of sparking, etc.

The acceleration imparted to a charged particle of coating material in an electrostatic field varies in the same sense as the potential-gradient of the field, and the potential gradient will in turn vary directly with the potential difference, and oppositely to the distance, between the article and the electrode. For efficiency in promoting the movement of coating-materials a high potential gradient is desirable; but high potential gradients increase the possibilities of a spark between the electrode and article. In most instances, especially where there is some possibility of accidental reduction in the distance between the electrode and article, it is customary to space the article from the electrode by a distance about twice the spark-over distance at the potential difference maintained. For example,

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operating in air with a potential difference of 80,000 to 100,000 volts, the article would usually be spaced about eight to twelve inches from the electrode. Even with such a safety-factor, undesirable accidental sparking may occur as the result of improperly supporting the article, swinging of the article when suspended from an overhead support, or from some other cause. In addition to danger of sparking between the article and electrode, there is also the danger of sparking between the article or the electrode and any object of different potential.

It is an object of this invention to reduce the danger of sparking in an electrostatic field employed to produce movement of electrically charged, macroscopic particles.

Another object of this invention is to provide an apparatus which will function to promote the movement of particles of material by electrostatic forces and to reduce automatically the potential difference maintaining the field whenever the current exceeds a predetermined value. An additional object of the invention is to provide an electrostatic particle-moving apparatus in which the average potential-gradient of the electrostatic field will remain approximately constant in spite of variations, within limits, in the distance between the terminals of such field. Still another object of the invention is to produce apparatus of the kind indicated which will produce the high potential difference necessary to the maintenance of an effective electrostatic field without storing large amounts of energy which might cause serious consequences if quickly liberated. A further object of the invention is to provide an apparatus having the above characteristics which will be simple in construction and durable in use and which can be readily inspected, serviced, and repaired in the field.

In carrying out the invention, as applied to the coating art, the articles to be processed are supported in spaced relation to an electrode. In most instances, the articles are conveyed successively past the electrode by some suitable form of continuously moving conveyor. If the articles are to be electrostatically coated, one or more spray guns are provided to discharge finely divided particles of coating material into the region between the electrode and article. If the articles are to be electrostatically deteared, they are coated with an excess of coating material before being brought into association with the electrode. In both cases an electrostatic field is maintained between the articles and the electrodes, such field acting in the first case to cause electro-

static precipitation of coating material on to the article and in the second case to remove excess coating material from the article.

In the preferred form of apparatus employed to create the potential difference necessary to maintain an electrostatic field between an article and an electrode, there are employed a group of rectifiers which, separated by resistors, are connected in series. The free terminal of the first of such rectifiers is connected to one terminal of a source of voltage pulses and the other terminal of such pulse-source is connected directly to one of the elements between which the electrostatic field is to be maintained. The other of such elements is connected to the free terminal of the last rectifier. The rectifiers are similarly arranged in the series, and the anodes of adjacent rectifiers are interconnected by condensers. In addition, the cathodes of adjacent rectifiers are interconnected by condensers, and an additional condenser is connected between the first resistor and the second named terminal of the pulse source. The system of rectifiers, resistors, and condensers described constitutes a voltage-multiplier in which each condenser, in the absence of any loss or drain, would become charged to the voltage of the voltage pulses, with the result that the voltage between the article and electrode would be the pulse-voltage multiplied by the number of rectifiers.

The accompanying drawings illustrate the invention:

Fig. 1 illustrates isometrically an electrostatic coating apparatus and diagrammatically a high-voltage source employed to create the electrostatic field; Fig. 2 is a diagrammatic illustration of electrostatic detearing apparatus; Figs. 3, 4, and 5 are diagrammatic views illustrating additional uses of the invention; Figs. 6 and 7 are diagrammatic views showing elements of the high-voltage source; Fig. 8 is a diagrammatic illustration of a modified apparatus for heating the filaments of the rectifiers; Fig. 9 is a diagrammatic view of apparatus by which the range of control can be enlarged; and Fig. 10 is a view illustrating a further application of the invention.

In Fig. 1 of the drawings I have illustrated electrostatic coating apparatus comprising a conveyor 10 adapted to convey articles 11 to be coated between two spaced interconnected electrodes 12 each of which preferably comprises an open frame 13 and a plurality of fine wires 13' stretched across such frame. One or more spray guns 14 discharge finely divided coating material into the region between the two electrodes. For the purpose of creating the necessary electrostatic field between the article 11 and the electrodes, a high potential difference is maintained between the electrodes and the conveyor 10, and the articles are electrically connected with the conveyor. The finely divided particles of coating material discharged from the gun 14 acquire an electrical charge and are caused, by the influence of the electrostatic field, to move toward and precipitate upon the article 11 as it moves through the coating zone. In most instances, it is preferable to ground the conveyor 10 and connect the electrode to one terminal of a high-voltage source the other terminal of which is grounded. The use of electrodes embodying fine wires 13' is desirable, as the corona discharge from such wires is very effective in charging the particles of coating material. Suitable means may also be provided for rotating the articles

to be coated which preferably comprise a shoe or friction bar 15 and rollers 16.

Fig. 2 illustrates diagrammatically another apparatus in which electrostatic forces are utilized to produce movement of particles of coating material. Here, a conveyor 20 conveys over an electrode 21 articles 22 which have previously been coated, as by dipping in a dip-tank 23, with an excess of coating material. By maintaining a high electrical potential-difference between the article 22 and the electrode, excess coating material on the article is caused to leave the article and move toward the electrode. Here again, it is contemplated that the conveyor will be grounded and the electrode connected to one terminal of a high-voltage source the other terminal of which is grounded.

The high-voltage source which, in combination with an article support and an electrode, constitutes one feature of this invention, includes a voltage-multiplier, indicated at A in Fig. 1.

Such multiplier comprises a series of rectifiers 30, considered as herein described to be of the vacuum-tube type, equal in number to the voltage-multiplication desired. The anode of each rectifier 30 is connected to the anode of the next rectifier of the series through a condenser 31, while the rectifier-cathodes are similarly interconnected through condensers 32. In the specific arrangement shown in Fig. 1, where it is assumed that the electrode 12 is to be positively charged, the cathode of each rectifier except the last of the series is connected to the anode of the next succeeding rectifier through a resistor 33.

The anode of the first rectifier 30 of the series is connected through a conductor 34 to one terminal 35 of a pulse-transformer 36 the other terminal 37 of which is connected through a condenser 38 with the cathode of the first rectifier. The transformer 36 is provided with an intermediate tap 39 so that it may serve as an auto-transformer to multiply the amplitude of voltage-pulses supplied over conductors 41 and 42 connected respectively to the tap 39 and the transformer-terminal 37. A rectifier 43, having its cathode connected to the transformer-terminal 35 and its anode connected to the terminal 37, serves to suppress or by-pass one-half of each of the alternating-voltage waves created by the transformer 36 leaving the other half-waves to be passed to the anode of the first rectifier 30 in the form of positive pulses 44.

The high voltage generated by the circuit of Fig. 1 exists between the transformer-terminal 37 and the cathode of the last rectifier 30. In most cases, it is preferable to ground the terminal 37 and the conveyor 10 and connect the cathode of the last rectifier to the electrode 12, as by a conductor 46.

For convenience in the following description of operation, one set of corresponding terminals of the successive rectifiers 30 are designated in the drawing by the letters *a*, *b*, *c*, etc. and the other set by the letters *p*, *q*, *r*, etc. The individual condensers 31 and 32 and the individual resistors are distinguished by subscripts designating the rectifier terminals between which they are connected.

The high-voltage multiplier shown in Fig. 1, operates in the following manner: Voltage-pulses transmitted to the transformer 36 over the conductors 41 and 42 are amplified by pulse transformer 36 to cause positive voltage-pulses 44 to be impressed across the first rectifier 30 and the condenser 38. The frequency of the pulses 44

will equal that of the pulses supplied over the conductors 41 and 42, while their amplitude will equal that of the latter pulses multiplied by the step-up ratio which the transformer 36 affords. Assuming for the present that none of the condensers is charged and that there is no drain from the high-voltage generator, for example, through the electrostatic field, the first voltage pulse 44 will cause current to flow through the first rectifier 30_{ap} to charge the condenser 38. This current will continue to flow until either the condenser 38 is charged to a voltage equal to that of the pulse 44 or until the termination of such pulse. During the dead portion of the cycle, the rectifier 30_{ap} prevents the condenser 38 from discharging over the same path by which it was charged. However, as the condenser 38 is connected in a series circuit with the resistor 33_{bp}, the condenser 31_{ab}, and the transformer 36, a portion of the charge initially imparted to the condenser 38 will be displaced during the dead part of the cycle to the condenser 31_{ab}. If the dead part of the cycle is of sufficient duration and if the condensers 38 and 31_{ab} are of equal capacity, the charge initially imparted to the condenser 38 will become divided equally between it and the condenser 31_{ab}, and the points p and b will both be at the same potential relative to ground. Whether or not the dead part of the cycle and the constants of the circuit are such as to permit the points b and p to attain the same potential, the condenser 31_{ab} will acquire a charge during the dead part of the cycle and a potential-difference will exist across it between the points a and b when the next voltage-pulse 44 occurs.

When the second voltage-pulse 44 occurs, the potential at points a and p will be raised to that of the pulse and the charge on the condenser 38 will be replenished. However, the potential difference across the condenser 31_{ab} will be added to the potential at point a, so that a potential-difference will exist across the resistor 33_{bp} and current will flow through the rectifier 30_{bq} to the condenser 32_{pq}. As a result, the condenser 32_{pq} will acquire a charge. During the following dead part of the cycle, a part of the charge on condenser 38 will be transferred to condenser 31_{ab} as before, and a portion of the charge imparted to the condenser 32_{pq} will be transferred to the condenser 31_{bc} over the circuit q—c—b—p. In this manner, as the cycle is repeated, a charge on the condenser 38 and on each of the condensers 32 is built up during the existence of the voltage pulse and shared with a condenser 31 during the dead part of the cycle. This condenser-charging process continues until the terminal condenser 32_{uv}, which has no associated condenser 31 with which to share its charge, becomes charged to a potential equal to the amplitude of the pulses 44. When this occurs, the condensers 31, 32, and 38 will be fully charged and the potential difference across each one will equal the amplitude of the voltage pulses 44. Theoretically, the potential difference between the conductor 46 and ground will equal the amplitude of the voltage pulse 44 multiplied by the number of rectifiers 30; but because of inevitable losses, the voltage actually obtained from the system will never attain this theoretical value.

The rise in potential which occurs during the pulse at the points b, c, d, etc., creates across the resistors 33 potential differences representing energy available to increase the charges on the condensers 31 and 32. During the transient charging process above described, this available energy is employed to build the condenser-charges up to normal; but after each condenser has become fully charged, such available energy is employed to replenish the charge lost by drain from the point v. As the pulses are of fixed frequency and width, the energy available to replenish the charges on the condensers is limited. Under any constant load, the multiplier will maintain at the point v a potential corresponding to the equilibrium condition existing when the charge supplied on pulse equals the charge withdrawn by the load. An increase in load current, therefore, will immediately cause a lowering of the output voltage; while if the load current decreases to some fixed value the output voltage will gradually attain a new equilibrium value.

If the high potential at point v is imposed through the conductor 46 on the electrodes 12, an electrostatic field will be created between such electrodes and the grounded article 11 supported between them. The magnitude of the current traversing this field will depend upon the potential difference between the electrodes and the article and upon their spacing. So long as the energy represented by the current traversing the electrostatic field equals the energy supplied to the system as a result of the voltage pulses 44, the potential of the electrodes 12 will remain substantially constant. However, if for any reason the distance between the articles and the electrode should decrease, the current traversing the electrostatic field would increase. The increase in field current could result only from a decrease in the charges on the condensers 31, 32, and 38, and would inevitably be accompanied by a decrease in the potential of the electrodes 12. By proper selection of the constants of the circuit, the field current can be kept near but always less than the value which must exist before a spark between the electrodes, or any other charged body, and the article, or any other grounded object, can occur. If a direct connection could be instantaneously established between the point v and the transformer-terminal 37, the maximum energy represented by the resultant current would be no more than that stored in the condensers. If the point v and the terminal 37 should be permanently interconnected, the maximum instantaneous current which could flow through the connection would equal the amplitude of the pulses 44 divided by the sum of the resistances of the resistors 33.

Performance characteristics of the voltage supply apparatus will depend upon the resistance of the resistors 33, upon the capacity of the condensers 31, 32, and 38, and upon the amplitude, duration, frequency and form of the pulses 44. There are set forth hereinafter the constants of an apparatus which has been found suitable in producing a specific potential difference between the point v and the terminal 37 of the transformer 36. The following discussion is intended to set forth in a general way the considerations which will influence the design of apparatus to meet any particular situation.

The resistance of the resistors, by controlling the current which flows during the dead part of the cycle, controls the rate at which electrical energy is passed from the condensers 38 and 32 to the condensers 31, and hence affects the duration of the time interval necessary to bring or restore the condensers to a fully charged condition. Resistors 33 of too low resistance are to be

avoided; as any current flowing through them during each pulse reduces the quantity of electrical energy transferred from the condensers 31 to the condensers 32. For example, the relatively high potential which exists at point b during the second pulse referred to above, produces current flow from b to p through the resistor 33_{bp} as well as to the condenser 32_{pq}; and the lower the resistance of the resistor, the greater will be the current flow through it and the smaller will be the quantity of electrical energy advanced to the condenser 32_{pq}.

The desired transference of energy among the condensers is through the low-resistance rectifiers during each pulse and through the high-resistance resistors during the dead part of each cycle. Accordingly the duration of each pulse should be short relative to the length of the remainder of the cycle. Each pulse, however, desirably endures for a length of time great enough to charge the condenser 38 to pulse-voltage.

Since the potential at the point v represents the sum of the voltages across all the condensers 32 and 38, and since all such condensers receive increments of charge only during the voltage pulses 44, any drain from the point v will cause its potential to drop gradually during the dead portion of each cycle between successive voltage pulses. Obviously, the condensers employed in the system should possess adequate capacity to prevent the voltage at point v from dropping to an objectionable extent during the dead portion of each cycle. It may be noted in this connection that inductance which will inevitably be present in the system will tend to reduce intracycle potential-variations at the point v.

As the quantity of energy which must be stored in the condensers to prevent an undesirable potential-drop at the point v during the dead portion of the cycle will depend upon the duration of each such dead portion, the necessary capacities of the condensers can be reduced by increasing the frequency of the pulses 44. As previously noted, condensers of small capacity are desirable in order to decrease the energy stored in the system, and hence it is necessary to use relatively high pulse-frequencies if stored energy is to be reduced to a safe minimum.

It is desirable that the voltage pulses 44 be as nearly square in form as is practicable. To make apparent the reason for such a square form, let it be recalled that at the termination of each pulse the potential at the point a drops to zero and remains at that value (except for the voltage drop across the transformer 36) during the dead part of the cycle. During the next voltage pulse, the voltage across the resistor 33_{bp}, which causes charging of the condenser 32, rises with the potential at point a. The less rapid the rise of potential at point a, the smaller the increment of charge which is transferred from the condenser 31_{ab} to the condenser 32_{pq}. It may be noted further that after the potential at point a has attained that previously existing at point p further increase in the potential at point a is transmitted to the point p through the rectifier 39 and hence does not result in any increase of the voltage across the resistor 33_{bp}. Therefore, the more rapidly the potential at the point a rises at the beginning of each voltage-pulse 44, the greater will be the increment of charge which is transferred from the condenser 31_{ab} to the condenser 32_{pq} during the pulse. It is also desirable that the termination of the pulse be as abrupt as possible; since the transfer of charge from the condenser 38 to the condenser 31_{ab} would be opposed by any potential generated in the transformer 36.

While it was assumed in the above description of operation that the voltage-pulses 44 were positive in sign, it is to be understood that the system will operate in the same way to produce a potential difference between the point v and the transformer-terminal 37 if the voltage pulses 44 are negative in sign. In fact, in coating processes it is preferred that the voltage pulses be negative; as the precipitation of coating material on the article seems to be somewhat more effective when the electrode-wires 13' are charged negatively relative to the article than when they are charged positively relative to the article. As it is generally more convenient to ground the conveyor 18, and through it the article 11, than to ground the electrode 12, the preferred negative charge on the electrode wires is most conveniently secured by employing voltage-pulses 44 which are negative in sign. In the preferred form of the apparatus illustrated in Figs. 6 and 7, the pulses 44 are negative in sign.

That preferred form of apparatus, which is shown in its entirety in Figs. 6 and 7, comprises a saw-tooth wave generator D, an amplifier and pulse-limiter E, and a power pulse generator F. The saw-tooth wave generator D comprises, as will be evident from the drawing, a blocking oscillator capable of producing waves of the form indicated at 59 in its output circuit when there is no drain thereon. Such generators are well known, and consequently need not be described in detail here.

The amplifier and pulse limiter E comprises a vacuum tube 55, here shown as a tetrode, the control grid of which is coupled to the output circuit of the saw-tooth wave generator D. The power supply to the plate circuit of the tube 55 includes an inductance 56, and the effective grid-bias of such tube will be determined by the value of the resistance 58. By appropriate selection of constants the control grid of the tube 55 will be given a negative bias such that when the negative signal from the generator D is added to it the tube will swing beyond cut-off. As a result, the amplitude of variations in plate potential will be controlled by the grid-bias and will to a large extent be independent of the amplitude of the input pulses imposed on the control grid.

Because of the drain from the output circuit of the saw-tooth wave generator D, when such generator is connected to the amplifier and limiter E, the saw-tooth wave 59, which otherwise would exist in the output circuit of the generator D, is distorted toward the more or less idealized pulse-form indicated at 60 in Fig. 6. Such negative pulses imposed on the control grid of the tube 55 cause positive, and amplified, pulses 61 in the output circuit of such tube. The frequency of the pulses 61 will of course correspond with the frequency of the wave generated by the oscillator of the generator D. The amplitude of the pulses 61, which is determined by amplification factors, constants of the generator D and amplifier-limiter E, and the B-voltages supplied to those two elements, will ordinarily be several hundred volts. The width of the pulses 61 will depend upon the value of the plate inductance 56, increasing as the value of such plate inductance increases.

The power pulse generator F embodies a vacuum tube 65, shown as a tetrode, upon the grid of which the positive pulses 61 from the amplifier-limiter E are imposed. The tube 65 has a fixed negative bias sufficiently high to render it non-

conducting during the intervals between successive positive pulses 61.

During these non-conducting intervals the condenser 67 is charged by being connected to the "B" voltage supply through resistor 62, choke 63 and pulse transformer primary 37—39. When the triggering pulse 61 is applied to the grid of tube 65 its grid is driven highly positive for the duration of the pulse. The tube is thus highly conducting during this period and represents a low impedance path to ground for the charge stored on condenser 67. A surge of current thus flows through the circuit 37—39—41—65 and ground. In this way a pulse of voltage is supplied to the primary of the pulse transformer which is equal to the plate supply voltage minus the voltage drop across tube 65.

It is these voltage pulses 66 which are imposed over conductor 41 between the intermediate tap 39 and the grounded terminal 37 of the pulsing transformer 36 previously described.

As in the case of the voltage-supply system illustrated in Fig. 1, the voltage pulses 44 generated in the pulse transformer 36 are transmitted to the voltage multiplier over the conductor 34. Since, in the case of the apparatus illustrated in Figs. 6 and 7, it is desired that the high potential produced be negative relative to ground, the rectifier 43 associated with the transformer 36 is reversed from the position shown in Fig. 1 so that it will permit only negative pulses to pass over the conductor 34. As the pulses supplied to the multiplier shown in Fig. 7 are negative, the rectifiers 30 are likewise shown as reversed from the positions shown in Fig. 1.

The rectifiers 30 shown in Fig. 7 are desirably of the vacuum-tube type. In supplying them with filament-heating current, it is necessary to do so by some means which will not interfere with the existence of high potential differences between successive stages of the multiplier. The means for heating the rectifier-filaments of the tubes 30 comprises what is in effect a high-pass filter network one leg of which includes the serially connected condensers 31 and the other leg of which includes a corresponding number of serially connected condensers 70. The filament of each rectifier 30 is connected, in series with an inductance 71, across the two legs of the filter network, one filament and its associated inductance being connected in each stage of the filter to constitute a transverse leg of the filter network. The filter network terminates at one end in a terminal impedance 72 and is connected at its other end to a load coil 73 inductively coupled to the plate circuit of an oscillator 74, shown as of the conventional tuned plate, magnetic feed-back type.

By way of illustration and not limitation, the constants of a suitable apparatus are as follows: The pulse generating system D—E—F is capable of producing voltage pulses 66 having a frequency of 10,000 cycles per second and an amplitude of 3,000 volts, and the pulse transformer 36 has a step-up ratio of 5-to-1, with the result that the amplitude of the pulses 44 supplied to the voltage-multiplier will be 15,000 volts. The duration of each pulse 66 is so controlled that each pulse 44 will endure for about 5% of each complete cycle. In that high-voltage source, each of the condensers 31, 32, and 38 has a capacity of 0.0005 mfd., while the resistors 33 have a resistance of 1 megohm. In the filament-supply circuit, each of the condensers 70 has a capacity of 0.0005 mfd., each of the inductances 71 has a value of 100 microhenries, and the terminal impedance 72 has a value of 600 ohms. The oscillator 74 has an output in the neighborhood of 25 watts at a frequency of 1.5 mc. Employing seven condensers 38 and 32, as shown in the drawings, such a high-voltage source is capable of maintaining a potential difference in the neighborhood of 100,000 volts between the electrode and the articles being treated under the influence of the electrostatic field.

In addition to its general applicability in other fields, a high-voltage source of the type herein illustrated and described has particular advantages in electrostatic coating and detearing apparatus, because of its inherent ability to reduce the potential difference between the electrode and the article being treated when the distance between such electrode and article decreases or when, for any other reason, an increase in field current occurs. Thus, where articles of non-circular cross-section, such as the articles 76 shown in Fig. 3, are rotated as they pass between discharged electrodes 12 by a mechanism such as that illustrated in Fig. 1, the distance between each electrode and the adjacent surface portion of the article will vary. If a constant potential difference were maintained between the article and electrode, variations in such distance would cause variations in the average potential gradient of the field. However, by maintaining the field through the use of the apparatus above described, the potential difference between the articles and electrode will vary in the same sense as the distance between them and variations in the average potential gradient of the field will be materially reduced in extent. Similarly, where, as in Fig. 4, articles 77 and 78 of different sizes are to be passed between the electrodes, variations in average potential gradient can be materially reduced by the use of the apparatus of Fig. 7. In each of these cases, the electrodes 12 may be set to provide a field of satisfactory strength over the surfaces of the articles when the distance between the article-surface and the electrode is a maximum. When such distance decreases, as by reason of rotation of the article 76 (Fig. 3) or by reason of the entry of a larger article into the field (Fig. 4), the resultant tendency of the field current to increase will cause a decrease in the potential difference responsible for the field. Thus it is possible to maintain satisfactory field-strength over the article-surface at all times while greatly reducing the possibility of sparking.

Another apparatus in which the high-voltage source above described may be used with advantage is shown in Fig. 5. Here, each individual article 79 being treated in the field has varying dimensions transversely of the line of travel, and two independent electrode systems 80 and 81, each having its own high voltage source A, are employed. The voltages and the spacing of the electrodes from the path of article travel are established to provide a field of satisfactory strength over the smaller-dimensioned portion of each article. When such smaller-dimensioned portion is opposite either electrode, the voltage of that electrode will have its normal value; but when the larger dimensioned portion of an article is opposite either electrode, the voltage of such electrode will automatically drop. Thus, it is possible to maintain a reasonably uniform field strength over a surface whose distance from electrodes may vary widely.

Still another form of electrostatic coating apparatus in which the voltage-multiplier above

described can be used to advantage is that illustrated in Fig. 10. In that figure, an article 85 is to be coated with coating material discharged from a manually manipulated spray gun 86 with which a discharge electrode 87 is movable. The high voltage source including the multiplier is connected between the article 85 and the electrode 87 so that the coating-material particles discharged from the gun will enter an electrostatic field, acquire a charge, and be urged toward the article for precipitation thereon. In this case, the electrode 87 rather than the article 85 is shown as grounded. The voltage multiplier, when used as a means to create the electrostatic field between the electrode and article, serves to maintain a field of reasonably uniform potential gradient and to reduce greatly the danger of sparking and of injury to the operator.

Other advantages of the high-voltage source described herein result from the fact that different potentials can be obtained by tapping the high-voltage source at any of the points *p*, *q*, *r*, etc., and the fact that such a source could be approached by any grounded object and as approach took place a corresponding reduction in voltage would occur, so that serious shock or discharge would never be possible.

In the filament-heating arrangement shown in Fig. 8, the filaments of the rectifiers 38 are connected in a series circuit including the condensers 31, the load coil 73 (Fig. 7), and preferably additional capacity which, for convenience in manufacture and maintenance, may be a bank of condensers 75 similar to the condensers 31. The series circuit just referred to is adapted to be tuned to the frequency of the oscillator 74, as by means of a variable condenser 76 connected in parallel with the coil 73. By varying the adjustment of the condenser 76, the current supplied to the rectifier-filaments may be varied as desired. To compensate for radiation losses which might interfere with uniform heating of the filaments, resistors 77 may be connected in shunt with the filaments of those rectifiers nearest the coil 73.

To augment the range of automatic control of potential produced, the apparatus previously described may be arranged so as to cause a reduction in the amplitude of the pulses 44 upon an increase in field current. One arrangement suitable for that purpose is illustrated in Fig. 9. As there shown, a fixed resistor 90 and a variable resistor 91 connected in series with each other are inserted in parallel with the condenser 38, and the intermediate terminal of such resistors is connected to the positive terminal of the source 92 which provides the negative bias for the grid of tube 65. In such an arrangement, an increase in current traversing the electrostatic field, by increasing the voltage-drop across the resistor 91, will cause an increase in the negative bias imposed on the grid of tube 65, thus reducing the amplitude of the pulses 66 and 44. Since the maximum possible voltage across the voltage multiplier is equal to the number of condensers 32 and 38 multiplied by the amplitude of the pulses 44, reduction in such pulse-amplitude will reduce the potential difference between the electrode and ground.

The invention claimed is:

1. In apparatus for coating articles, a conveyor for moving articles over a predetermined path, an electrode mounted in spaced relation to said path, a source of unidirectional voltage pulses and a multiplying means associated with said source and including a plurality of capacitors connected in series and having end terminals which are electrically connected respectively to said electrode and an article to be coated to establish an electric field therebetween, and the intermediate terminals of which are electrically associated with said source whereby the voltage difference maintained between said electrode and an article to be coated is equal to the sum of the voltage differences across each of the capacitors of the series and the electrical charge on each capacitor of the series is adapted to be changed in inverse proportion to the field current flowing between said electrode and an article to be coated.

2. In apparatus for coating articles, a conveyor for moving articles over a predetermined path, an electrode mounted in spaced relation to said path, a source of unidirectional voltage pulses, an outlet terminal electrically connected to said source for maintaining an electrostatic field between said electrode and an article in the predetermined path, means for electrically connecting the article being coated to one terminal of said source a multiplying circuit intermediate the other terminal of said source and said outlet terminal comprising a plurality of stages each including a capacitor, a resistor and a vacuum tube rectifier connected in delta, each stage being connected to two adjacent stages in such a way that its resistor is common to one of the adjacent deltas and its rectifier common to the other adjacent delta, said pulse source replacing the resistor of the initial delta and said outlet terminal being the common connection between the rectifier and the capacitor of the final delta.

3. In apparatus for controlling the movement of macroscopic particles in a gaseous medium, at least two electrodes spaced in the gaseous medium, a source of unidirectional voltage pulses, a multiplying means associated intermediate said source and said electrodes including a plurality of capacitors connected in series and having end terminals which are electrically connected respectively to said electrodes to establish an electric field therebetween, and the intermediate terminals of which are electrically associated with said source whereby the voltage difference maintained between said electrodes is equal to the sum of the voltage differences across each of the capacitors of the series and the electrical charge on each capacitor of the series is adapted to be changed inversely to the field current flowing between said electrodes.

4. In apparatus for controlling the movement of macroscopic particles, at least two electrodes separated in a gaseous medium, means for introducing particles into the medium between said electrodes, a source of unidirectional voltage pulses, a transformer for said pulses, a first rectifier connected between the outlet terminals of said transformer, a series of capacitors one end of which is directly connected to one terminal of said first rectifier and the other end of which is connected through a rectifier to a first of said electrodes, each of said capacitors being shorted by a rectifier and a resistance in series, said rectifier of said series being connected to the terminal of said capacitor closest to said source, a second series of capacitors one end of which is connected directly to the other terminal of said first rectifier and the other end of which is directly connected to said first electrode, the intermediate connections of said second series being in turn connected to the terminal common to

both the rectifier and resistance which shorts the capacitors of said first series.

5. In apparatus for controlling the movement of macroscopic particles, at least two electrodes separated by a gaseous medium, means for introducing particles into the medium between said electrodes, a source of unidirectional voltage pulses, an outlet terminal electrically connected to one of said electrodes, means for electrically connecting the other of said electrodes to one terminal of said source, a multiplying circuit intermediate the other terminal of said source and said outlet terminal comprising stages each including a capacitor, a resistor and a rectifier with a filament connected in delta, each stage being connected to two adjacent stages in such a way that its resistor is common to one of the adjacent deltas and its rectifier common to the other adjacent delta, said pulse source replacing the resistor of the initial delta and said outlet terminal being the common connection between the rectifier and the capacitor of the final delta, and high frequency means for heating filaments of said rectifiers.

6. In apparatus for controlling the movement of macroscopic particles in a gaseous medium, at least two electrodes spaced in the gaseous medium, a source of unidirectional voltage pulses including a vacuum tube with a control grid, a multiplying means associated intermediate said source and said electrodes and including a series of capacitors the end terminals of which are electrically connected to said electrodes to establish an electric field therebetween and the intermediate terminals of which are electrically associated with said source, and resistance means connected across one of said capacitors and to said control grid for controlling the output of said vacuum tube inversely to the field current flowing between said electrodes.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,855,869	Pugh	Apr. 26, 1932
2,042,181	Knowles	May 26, 1936
2,119,588	Lindenblad	June 7, 1938
2,247,963	Ransburg et al.	July 1, 1941
2,359,476	Gravley	Oct. 3, 1944
2,371,605	Carlton	Mar. 20, 1945
2,421,787	Helmuth	June 10, 1947