Feb. 9, 1960 A. P. DAVIS ET AL 2,924,714

ELECTRON ACCELERATOR

Filed Aug. 9, 1956 5 Sheets-Sheet 1

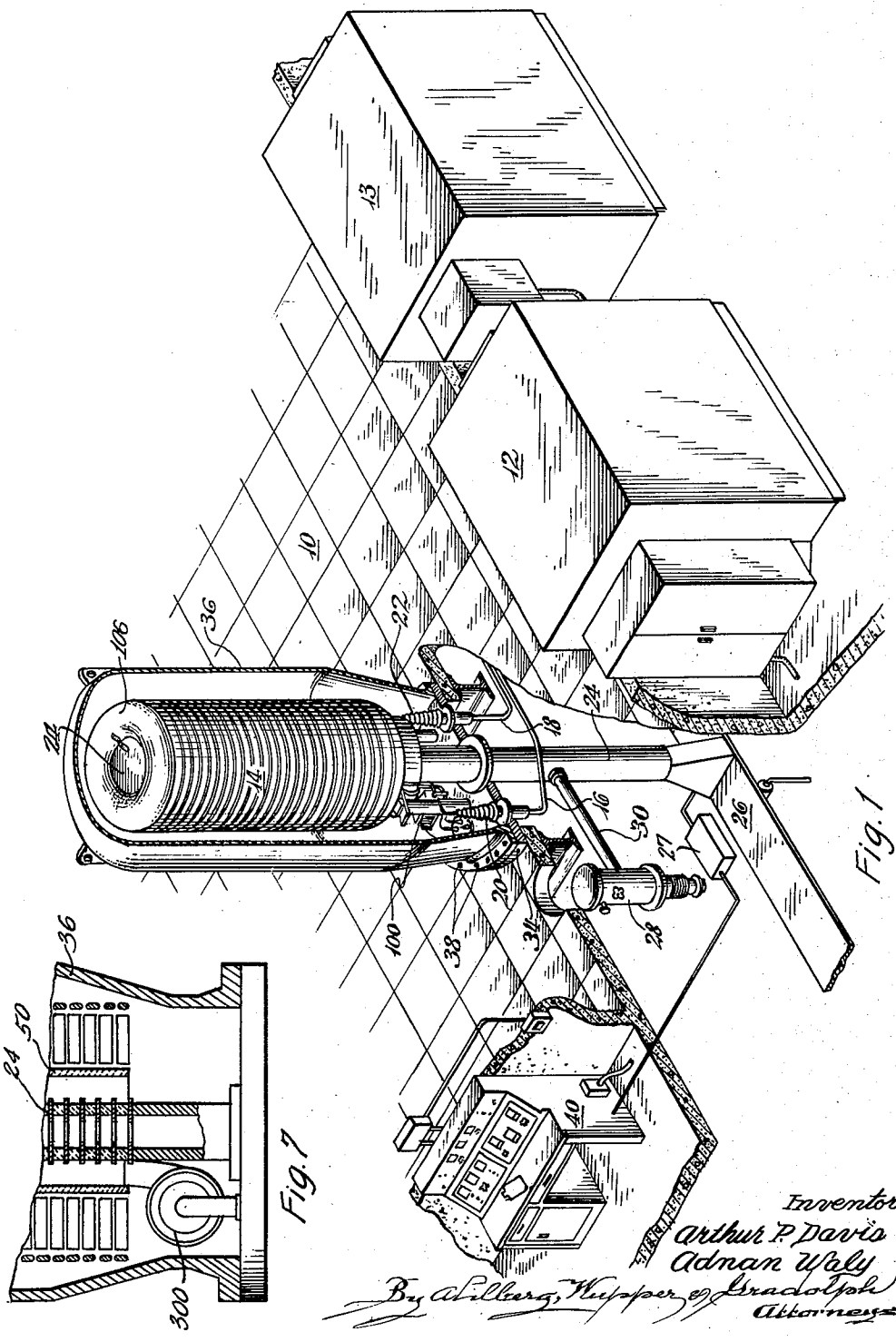


Fig. 1

Fig. 7

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ELECTRON ACCELERATOR

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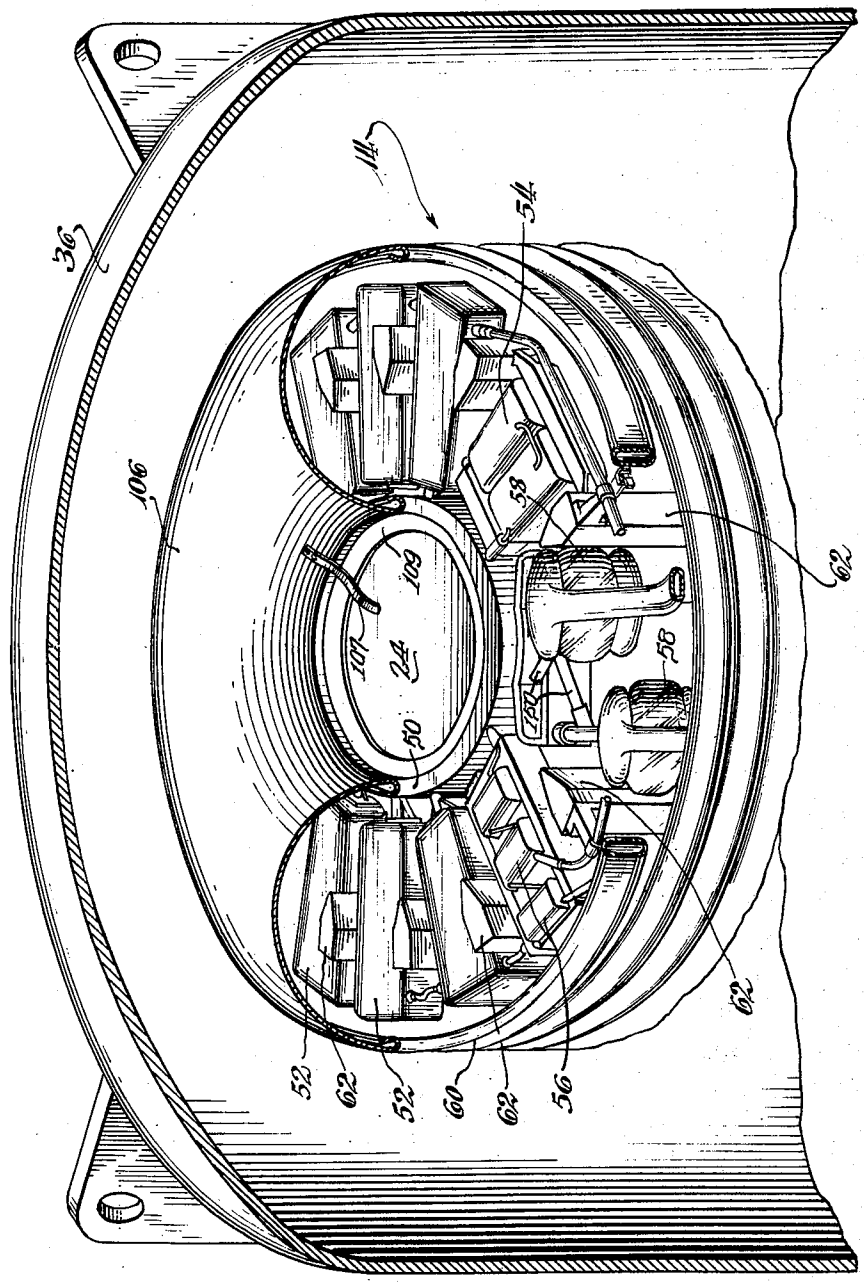


Fig. 2.

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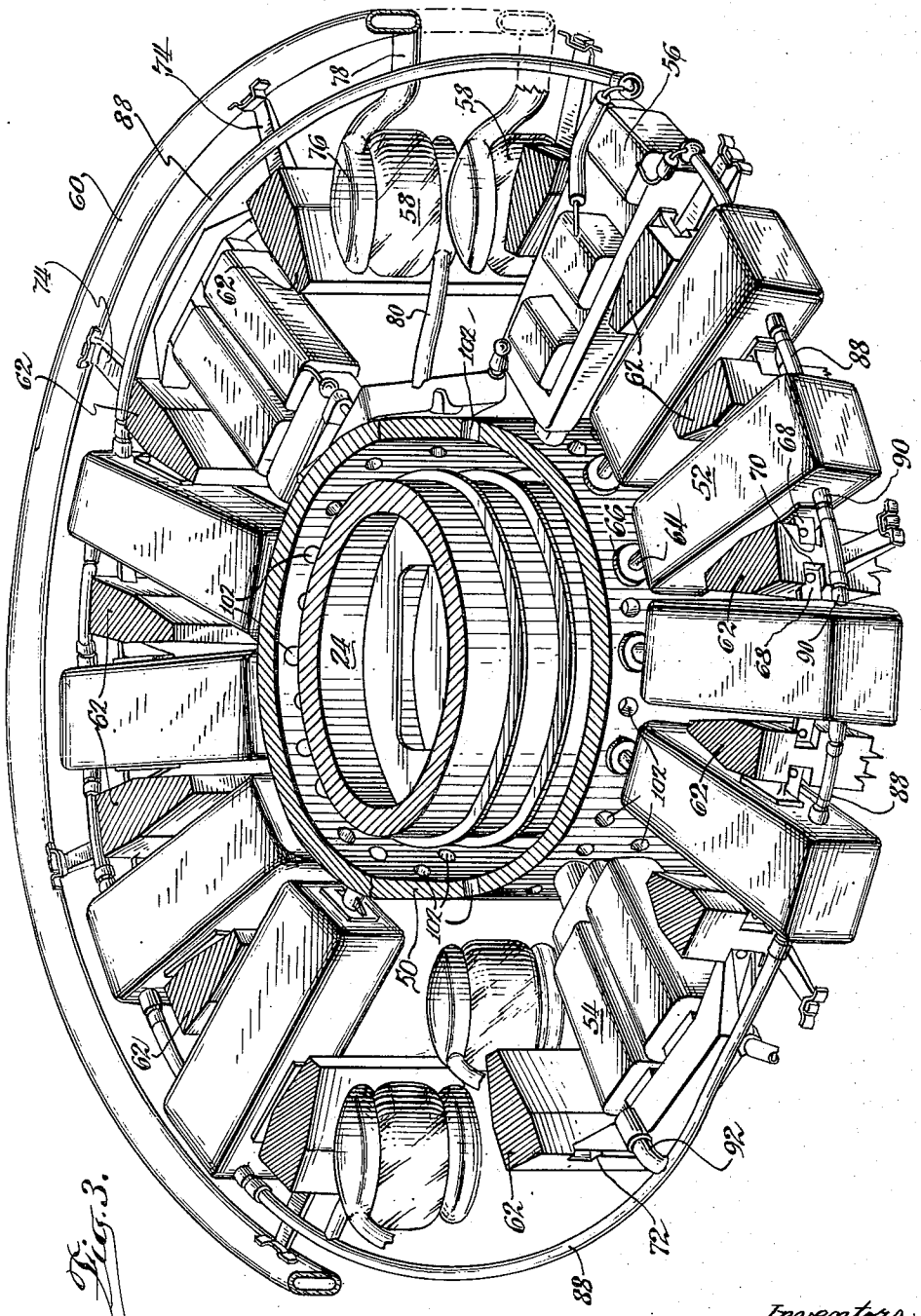


Fig. 3.

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ELECTRON ACCELERATOR

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Fig. 5.

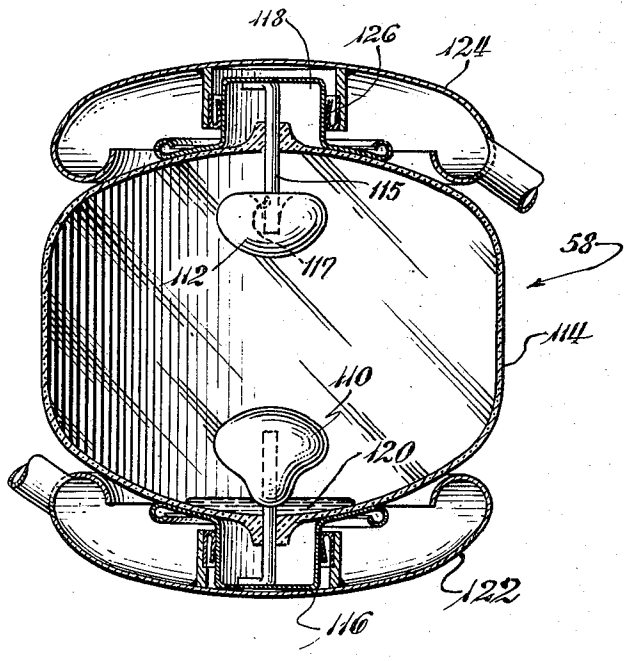
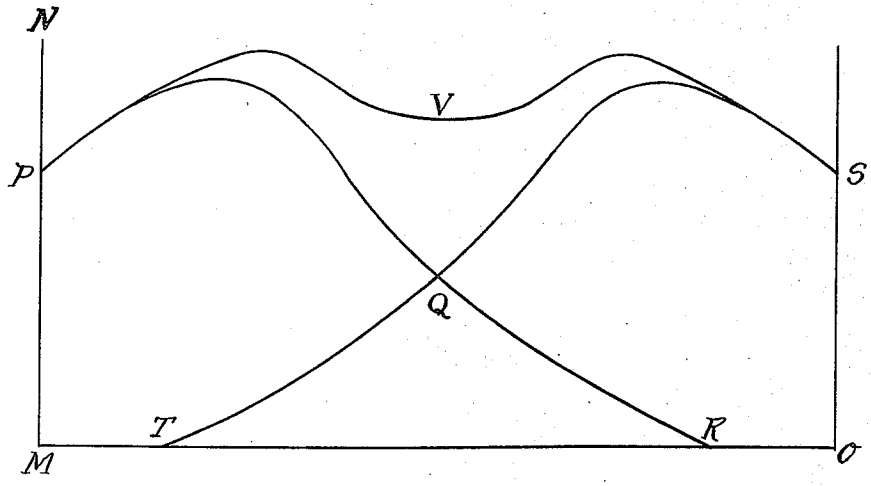


Fig. 6.



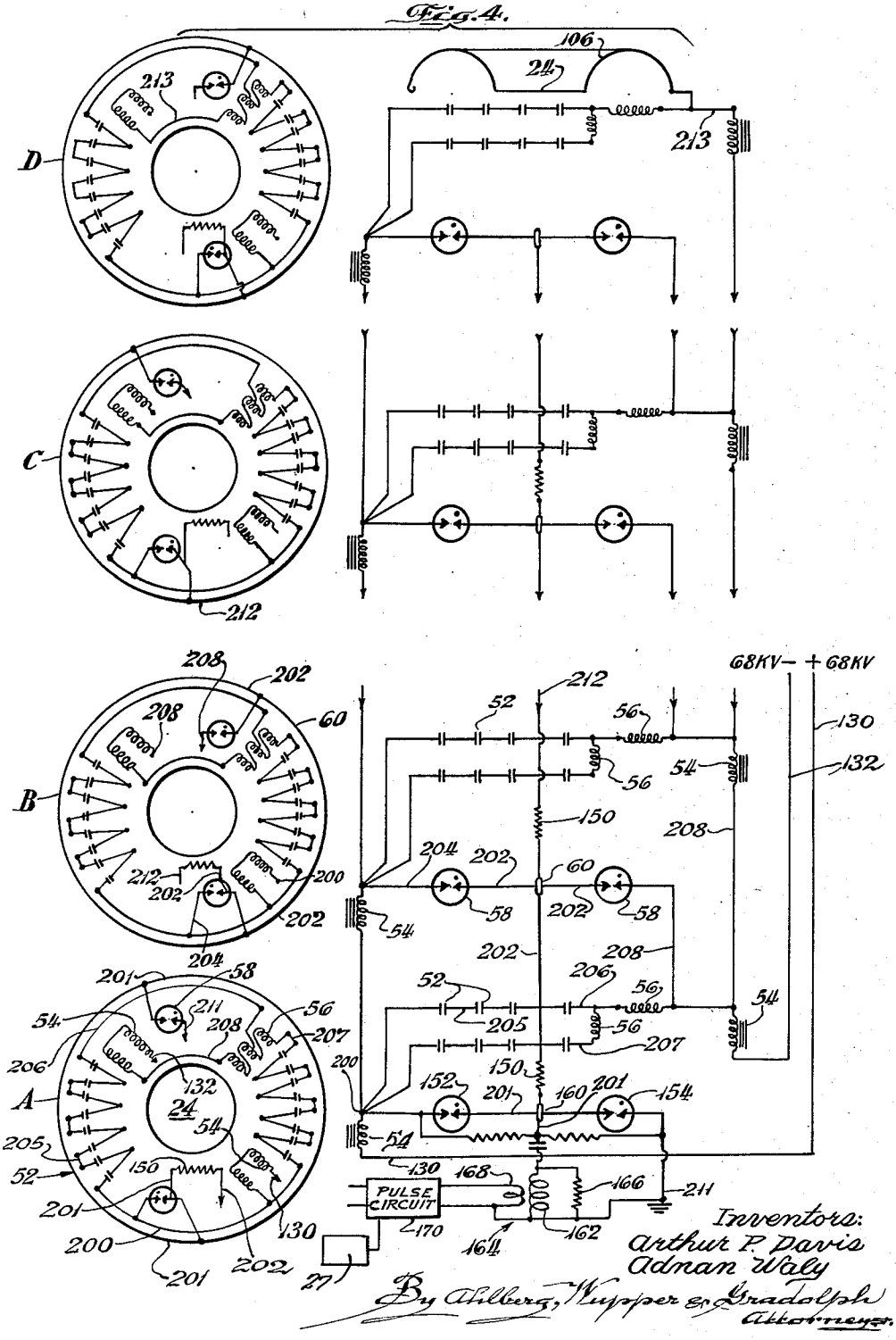
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ELECTRON ACCELERATOR

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Fig. 4.



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United States Patent Office

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2,924,714

ELECTRON ACCELERATOR

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Application August 9, 1956, Serial No. 603,102

10 Claims. (Cl. 250—49.5)

The present invention relates to electron accelerators and more particularly to an electron accelerator having a very high power capacity which supplies high velocity electrons in bursts of extremely short duration and at a high burst repetition rate.

Although an accelerator of the type which forms the subject matter of this invention can be constructed in a rather wide range of power and voltage capacities, the particular embodiment herein illustrated and described, supplies electrons at a velocity of something over two million volts and at a continuous input power capacity of approximately sixty thousand watts. The repetition rate for the electron bursts may be conveniently at a rate of sixty per second although other rates may be desirable as will appear. The burst duration is about five and one-half microseconds. The wattage or electron density during the bursts is therefore seen to be extremely high.

The high voltage circuit for the accelerator which forms the subject matter of the present invention is a variation of the classic Marx impulse circuit which produces high voltages by charging a large number of capacitors in parallel to an intermediate voltage and then, discharging them in series across spark gaps which isolate the individual capacitors prior to the discharge. The ultimate potential realized during the discharge is a function of the charging voltage times the number of capacitor and spark gap groups in the circuit.

One of the objects of the present invention is to provide a practical high density electron accelerator of the above character which can be manufactured in quantity at reasonable cost and in which the circuit elements are largely standardized and easily replaceable.

An additional object is to provide a novel accelerator of the above character in which high voltage fields are rather precisely controlled so as to permit voltages of the order necessary in a relatively low cost, very compact machine.

Still another object is to provide an electron accelerator of the short duration pulse type in which the electron beam from the accelerating tube is almost monochromatic.

Yet another object is to provide an electron accelerator capable of supplying high velocity electrons in bursts of short duration and in which the character of the electron beam is particularly adapted for irradiating substances so that all portions of the substance will receive substantially the same electron dose.

Still another object is to provide improved components for such an accelerator so as to greatly extend the service life and reduce maintenance problems and costs.

Other objects and advantages will become apparent

from the following description of a preferred embodiment of our invention which is illustrated in the accompanying drawings.

In the drawings, in which similar characters of reference refer to similar parts throughout the several views:

Fig. 1 is a diagrammatic perspective view illustrating a typical installed arrangement of the electron accelerating equipment of the present invention;

Fig. 2 is a somewhat diagrammatic perspective view drawn to larger scale of the top of Fig. 1 with portions of the structure broken away so as to reveal underlying details;

Fig. 3 is a somewhat diagrammatic perspective view of a portion of the mechanism with certain of the structure broken away or removed so as to reveal features of the construction.

Fig. 4 comprises a diagrammatic electrical circuit for the principal portion of the apparatus together with an electro-mechanical diagram of the arrangement of the elements providing this circuit;

Fig. 5 is a vertical transverse sectional view through one of the spark gaps used in the present device;

Fig. 6 is a graphic representation of the energy absorption within a substance bombarded by substantially monochromatic high velocity electrons; and

Fig. 7 is a view primarily in vertical central section showing a portion of the electron accelerator of Fig. 1.

Electron accelerating apparatus of the present type is made up of several interconnected circuit and mechanical elements. In general there is an accelerating tube having a cold cathode at one end and an anode and electron permeable window at the other. The space within the tube is quite highly evacuated although some gas remains therein. On a large scale, such as is here required, the low pressure within the tube is preferably continuously maintained by a vacuum pump, in the present instance of the common diffusion type. The tube cathode and anode are energized by the high voltage output of a battery of capacitors discharged in series across spark gaps and these capacitors are recharged in parallel to a lower potential, in the present instance by a direct current charger which operates by stepping up and rectifying the available alternating current power. Means are also provided for periodically firing the tube after the capacitors have been charged.

Referring to Fig. 1 of the drawings, in which a typical installation of an electron accelerator of the type forming the subject matter of this invention is illustrated somewhat diagrammatically, it will be seen that the equipment is housed within a building, a building floor being indicated at **10**. Charging current for the accelerator is supplied by a pair of chargers **12** and **13** which need no particular description since they may be of well known type and consist merely of transformers and rectifiers such that their circuits supply relatively high voltage direct current power. One of these charges is connected so as to supply power at a positive potential of sixty-eight thousand volts with respect to ground, whereas the other charger supplies a negative potential of sixty-eight thousand volts with respect to ground. The potential difference as between the outputs of the two charges is thus, approximately one hundred thirty-six thousand volts, which in this instance is the charging voltage.

The mechanism in this machine which combines the capacitors and spark gaps and some ancillary equipment to be described presently, is indicated at **14** and re-

ceives the output from the chargers **12** and **13** by way of lines **16** and **18** which enter the assembly by way of insulating bushings **20** and **22**.

The electron accelerating tube is arranged at the center and coaxial with the condenser and spark gap mechanism and its lower end or anode **24** is shown as projecting downwardly through the floor **10** so that the exit window of the tube is spaced a short distance above the support for an article or substance to be bombarded. In the present instance this support is illustrated as a moving conveyor belt **26**. The accelerating tube needs no special description, since it may be conventional, for instance of the type described in Patent No. 2,043,733, issued June 9, 1936, to Arno Brasch and Fritz Lange. Accelerating tubes of this character are preferably of a laminated construction. That is, the tube with the cathode at one end and the anode and window at the other, is formed of alternate rings of conducting and insulating material so as to limit the electrical field gradient across individual sections of the insulating material to a relatively low value, thereby preventing the possibility of break-down of the insulating material under the high voltage stress to which electron accelerating tubes are subjected. This principle is explained in the above mentioned patent and is currently a well known construction technique. For further details and variations if interested see the following United States patents: No. 2,099,427 issued to Arno Brasch and Fritz Lange; No. 2,429,417 issued to Arno Brasch; No. 2,449,872 issued to Arno Brasch and Wolfgang Huber.

The vacuum pump for maintaining an appropriate subatmospheric pressure within the electron accelerating tube is indicated at **28**, this pump being connected to the tube by way of a duct **30**. The portion of the equipment which comprises the accelerating tube (excepting the lower or window end), the capacitors, the spark gaps and some additional equipment is enclosed within a pressure vessel consisting of a base plate **34** and bell tank **36** having its open end secured against the plate by bolts **38**. This tank is shown as being made of steel, but some advantage in reducing the stray capacity of the system is obtained if a glass reinforced plastic tank is used. The cost on the basis of present manufacturing methods of such plastic tanks is higher, however.

The controls and monitoring portion of the apparatus are centered in an operator's console at **40**.

By referring to Fig. 2, in which the structure of the top of the tower unit **14** is shown in somewhat greater detail, it will be seen that the accelerating tube **24** at the center of the tower is surrounded by a sleeve **50** of insulating material which extends from top to bottom. Around the sleeve **50** are arranged the capacitors **52**, the charging chokes **54**, wave shaping inductances **56** and the spark gaps **58**. These elements, which extend generally radially outwardly of the sleeve **50** in layers are surrounded by corona rings **60** at each layer. Each of the tiers or layers represents a potential difference with respect to the adjacent layers, as will appear more clearly presently, of about 68,000 volts. These layers are substantially identical and a description of the top unit will therefore serve to clarify the entire structure.

Vertical support pillars **62** extend from top to bottom of the tower and in general are spaced so as to provide room therebetween for the individual electrical circuit components. These pillars are formed of insulating material and act to support the individual capacitors, charging chokes, discharge inductances, spark gaps, corona rings and resistors as will appear.

The pillars and sleeve **50** may conveniently be formed of interlocked relatively short sections which are molded to appropriate shape and they may if desired be of laminated construction by interspersing thin metal plates at intervals between adjacent insulating sections. By referring particularly to Fig. 3 it will be seen that each of the capacitor units, **52** for instance, is enclosed within a metal

case having well rounded corners and edges. The avoidance of any sharp edges or projections is important. Note that each case on its inner end, that is, the end closest to the sleeve **50**, is provided with a cylindrical projection or peg **64** formed of insulating material. This peg slides into a socket **66** formed in the wall of the insulating sleeve **50**. Near their opposite ends, the cans for the capacitors **52** are provided on their sides with fingers **68** formed of insulating material, which slide into notches **70** formed in the adjacent vertical pillars **62**.

Thus a condenser pack **52** can be removed from the assembled mechanism by simply pulling outwardly upon the can so as to slide the fingers **68** out of the notches **70** and the peg **64** from the socket **66**. This plug-in arrangement greatly facilitates assembly and disassembly of the electron accelerator and subsequent servicing thereof. The chokes are similarly provided with pegs at their inner ends for insertion into complementary sockets in the insulating sleeve **50** and with fingers such as at **72** for insertion into notches formed in the sides of the pillars **62**.

Insulating brackets **74** secured to the outer faces of the pillars extend outwardly and are turned upwardly at their free ends to form hooks upon which the metal corona rings **60** are hung as is best seen in Fig. 3.

The spark gaps **58** are manufactured as separate enclosed units, as will be explained presently, and are plugged in at their ends to sockets **76** which are carried in some instances by conducting brackets **78** attached to the corona rings and in other instances by brackets **80** which are secured to the sleeve **50**. These brackets **78** and **80** form a portion of the electrical circuit as well as structural supports for the spark gaps.

Other electrical connections between the individual circuit components are provided by lengths of tubing as at **88** which snap into place. For instance, each of the capacitor packs is provided with contact balls **90** at each side outwardly of the fingers **68** which are connected internally of the cans to the capacitors. Each piece of tubing **88** has cup-shaped ends which are spring loaded outwardly and snap over the appropriate balls thereby connecting together a set of two adjacent capacitor packs. Substantially this same arrangement is used for interconnecting the other circuit elements although it will be appreciated that some of these tubes **88** will be longer and have different conformation than others, as for instance the one to the left of Fig. 3 which interconnects two capacitors a considerable distance apart and has an intermediate plug-in support **92** to the bracket which supports the choke **54** from the adjacent pillars.

The space within the tank **36** is pressurized with a relatively inert gas which helps to prevent electrical breakdown as between the various elements maintained at a high relative potential. For this purpose a mixture of nitrogen and carbon dioxide at a pressure of about 25 to 30 atmospheres is satisfactory. Lower pressures and other gases may be used, depending upon individual design variations. This gas also acts as a coolant and is circulated by the mechanism indicated generally at **100**. This circulating and cooling mechanism needs no particular description since it consists merely of one or more electrically driven blowers (such as shown at **300** in Fig. 7) which take the gas from a low point within the tank and pass it through a water cooled heat exchanger and thence by way of any suitable duct to the bottom of the annular space between the insulating sleeve **50** and the discharge tube **24**. The cool gas passes upwardly toward the top of the tower and outwardly through a plurality of holes in the sleeve **50** so arranged as to cause the cool gas to flow over the capacitors, chokes, and spark gaps arranged around the sleeve. After cooling these circuit components the gas passes outwardly into the space between the tower and the tank wall **36** and thence downwardly so as to be recycled by the circulating and cooling unit.

A few of the cooling holes through the wall of the sleeve **50** are indicated at **102**, their size and position being best determined by the amount of heat rejected by the various circuit components. In general, the charging chokes will need the most cooling.

At the top of the tower the various circuit components are enclosed beneath a cover **106** formed of sheet metal which is shaped as half a torus. The outer periphery of this cover has the same diameter and is in alignment with the top corona ring **60**, while the portion at the inner diameter thereof rests upon the upper end of the accelerating tube **24** and serves as the conductor between the tube cathode and the output of the circuit components just described. Optionally, the inner portion of the torus may rest upon the top edge of the sleeve **50** in which case a jumper **107** is used to connect the tube top or cathode to the cover. To prevent cooling air from being blown out of the annular space at the top, a simple cover **109** may be used to close this opening.

Ordinarily at the top of a high voltage structure of the general nature of that just described, a hemispherical cover is conventional for controlling and limiting the electrical field. Customarily, therefore, the diameter of the sphere of which such a dome is a portion is determined by the diameter of the cylindrical structure to be covered. The height of the cover, therefore, is equal to approximately half the diameter of the tower structure. We have found, however, that the radius of curvature of a cover of this character from the electrical standpoint can be much less than that determined simply by the physical diameter of the tower structure. The torus arrangement shown has a radius of curvature which is more than electrically adequate and has a considerable advantage in that it reduces the overall height of the cover structure by about one-half. It is also beneficial in that it reduces the stray capacitance between the cover and tank **36**.

The spark gaps are shown in Fig. 5 where it will be seen that the cathode at **110** and the anode **112** are sealed within an envelope **114** in the present instance glass, and are connected therethrough by supports **115** to terminal caps **116** and **118**, respectively. Spark gap cathodes in the type of service to which these are subjected ordinarily have a relatively short life. In the present instance this problem has been largely solved. The cathode at **110** is formed of sintered powdered substantially pure iron and the lower end thereof dips into a small pool of mercury at **120**. The mercury wets the iron and forms a thin coating thereover. The result is that the electrical discharge vaporizes the mercury rather than the iron and the mercury vapor thus produced in turn condenses upon the cooler surface of the envelope and returns to the pool at **120**, additional mercury being continuously absorbed from the pool to replace that vaporized.

So as to reduce the physical size of these spark gaps and extend their life, they are carefully heated, evacuated and washed with helium and hydrogen to remove the enclosed air and finally are refilled with hydrogen to a pressure of approximately two to three and one-half atmospheres.

This is accomplished by a connection to the outer end of the tubular anode support **115** which has an opening **117** in the wall thereof close to the back reentrant surface of the anode. The anode may be made of any of several materials, but molybdenum has proved to be highly satisfactory for this purpose.

The sockets for accepting the spark gaps have convexly curved shields as indicated at **122** and **124** to aid in controlling the electrical field and internally these shields are provided with rings **126** which form a spring loaded slip fit with the cylindrical terminal caps **116** and **118**.

In Fig. 4 the principal circuit for the device is illustrated in electrical circuit diagram form at the right hand side, with the general physical arrangement of the circuit elements being indicated directly to the left for purposes of easy comparison. In this diagram the positive 68,000 volt lead from the power supply is shown at **130**, while the similar negative lead appears at **132**.

For convenience in comparison, the numbers used to indicate the circuit components where possible are the same as those used in Figs. 2 and 3, excepting that the individual layers of the tower have been indicated generally by the letters A, B, C and D. In this diagram, A indicates the layer at the bottom of the tube, B the layer next thereabove, D the top layer, and C the layer next below the top. Between layers B and C there are a multiplicity of additional layers which are substantially identical to either B or C. In this connection it should be noted that the circuit arrangements of layers B and C are substantially identical excepting for the alternate arrangement of the spark gaps which is merely for convenience in positioning these elements and making the connections. These minor differences alternate from layer to layer so that successive layers have their mechanical placement and electrical connections in the order B—C—B—C—B—C, and so on.

By tracing the charging current it will be evident that there is a connection from the charging positive lead **130** through a choke **54** to one side of the capacitor banks at **52** in the layer A. Similarly, the negative charging lead **132** is connected through a choke **54** and discharge inductances **56** to the other side of these condenser banks. The positive potential is also applied through a charging choke **54** in the layer B to the condensers **52** in that layer, whereas the negative potential is applied to the opposite side of these capacitors by way of layer A charging choke **54**, and layer B charging choke **54** and the wave shaping inductances **56** in layer B. The positive side, that is, the left hand side of the capacitors in layer B is connected through two spark gaps **58** in series to the negative side of the capacitors in the next lower bank by way of the wave shaping inductances **56** in this lower bank.

The two spark gaps **58** in series, since they are connected across the leads **130** and **132**, support a potential difference of about 136,000 volts. The center point between these two spark gaps is connected to the corona ring of the particular layer. The corona ring, therefore, is essentially at ground potential during charging, but would probably have some tendency to float one side or the other of ground, depending upon how closely the individual circuit components are matched to each other.

To avoid any problem from this source, the corona rings are connected together by high value resistors which are indicated at **150**. These resistors, like the spark gaps, are not electrically strictly speaking in any particular layer, but rather serve as elements which interconnect adjacent layers. Physically the resistors may be arranged between the spark gap support brackets that are secured to the insulating column **50**. They are conveniently connected into the circuit in this embodiment by means of ball and socket fittings as are the other elements.

The bottom layer A differs from the others somewhat in that the two spark gaps **152** and **154** in series, are connected between the positive charging line **130** and ground and therefore each of these supports half the positive potential of 68 kv. Each of these gaps, therefore, is designed to support 34 kv. and to break down at considerably less than twice this value. All other spark gaps support 68 kv. and break down at less than 136 kv.

The central point between the two 34 kv. spark gaps **152** and **154** is indicated at **160** and this point is connected to ground through the secondary **162** of a trigger transformer **164**. This secondary is also shunted by a high value resistor **166** similar to the resistors **150**. The primary **168** of the trigger transformer **164** is connected to the output of a pulse circuit **170**. This pulse circuit needs no special description since it periodically merely provides a short duration pulse in a well known manner. For this purpose we prefer to use a substantially conventional thyratron type circuit which conveniently may

cycle at a rate of 60 times per second, since the power supply will ordinarily cycle at this rate, thereby simplifying the control arrangement. If desired, the conveyor **26** may operate a simple control mechanism **27** which is connected to fire the pulse circuit in synchronism with the conveyor, so that objects or material on the conveyor will receive a predetermined dose regardless of conveyor speed up to the maximum cycling rate of the circuit.

The layer at C is electrically a duplication of that of B and needs no special description. The top layer at D is also similar to those in the intermediate layers excepting that the negative potential side of this subcircuit is connected to the field control cap **106** and thence to the cathode of the tube **24**.

This circuit operates in the following fashion:

The capacitor banks in the several layers are isolated from each other by the several spark gaps and are charged so that in each bank there are two charged parallel branches or groups of capacitors with each of these branches consisting of several capacitors in series (in the present instance, each branch provides four capacitor packs **52** with two capacitors in series in a can comprising each pack)

After all capacitors have been charged so that each series branch supports a potential of about 136 kv., the pulse circuit **170** energizes the trigger transformer primary **168**. This energizes the transformer secondary **162** and momentarily raises the potential across the spark gap **154** sufficiently above 34,000 volts to cause this spark gap to break down. Discharge of this spark gap results in a potential difference across the spark gap **152** of about 68,000 volts, with the result that this spark gap in turn breaks down, and so on throughout the system. This discharge cycle takes place in a matter of only a few microseconds and in older type circuits results in a sharp rise and then a sharp drop in the potential difference between the tube cathode and the grounded anode. The maximum potential difference between the cathode and anode in a typical system might therefore be 2,000,000 volts, but the entire voltage range up to 2,000,000 would also be present in such quantity as to make the 2,000,000 volt portion represent only a small fraction of the discharge energy. This conventional type discharge thus produces electrons at a velocity of 2,000,000 volts mixed with a large quantity of electrons at low and intermediate voltages. Such activity results in a great loss in efficiency and excessive radiation at the surface and at shallow depths as compared to the deep interior of the substance being treated.

Monochromatic radiation (radiation at a single voltage) gives an energy absorption substantially as indicated by the curves of Fig. 6. If it is assumed, for instance that the radiation comes from the left and that the surface is at M—N and that the deepest energy absorption is at R, the area lying beneath the curve P—Q—R represents the energy absorption at various depths. From this it is apparent that the greatest energy absorption is not at the surface, but at a level about one-third or so of the distance into the interior. By similarly radiating the substance from the opposite side, the energy absorption will be as represented by the curve S—Q—T. The effect of radiating from both sides, therefore, is to given an absorbed energy distribution as represented by the composite curve P—V—S. This curve is of course one of a family, since by using a thicker or thinner layer of the substance being radiated, the degree of overlap of the curves P—Q—R and S—Q—T can be changed. In any event, from these curves it will be apparent that almost, but not quite monochromatic radiation is desirable. Some but not much lower voltage radiation is desirable to raise the points P and S approximately to the level of V.

Monochromatic radiation requires that the high voltage pulse applied to the accelerating tube have the form of a square wave. We have found that excellent efficiency can be achieved with a substantially square wave having a short rise time so that the total discharge covers a period of about 5.5 microseconds with the comparatively flat top of the wave occupying a period of about 4 microseconds. This is accomplished by the interaction of the capacitors and the wave shaping inductances **56** previously mentioned.

In the circuit given and those of a related nature various values may of course be used and will depend to some extent upon the power capacity and upon the distributed capacity and inductance of the system.

In the interest of completeness, however, the following values have been found to be satisfactory and may be considered typical in the embodiment described.

The storage capacity of the capacitor packs **52** is about 4 watt seconds per pack at the voltage used. The wave shaping inductances **56** have a value of about 2 millihenrys with about 15% of this value as mutual inductance. The resistors **150** have a value of about 3.5 megohms, and a suitable value for the isolation chokes **54** is about 300 millihenrys. Although it is not essential, we prefer to provide the inductances **56** as separate coils which can be shifted slightly with respect to each other so as to vary the mutual inductance, thereby providing a means for tuning or aligning the system. Note also that each of these inductance units **56** consists of one coil of about 1 millihenry in series with one of the condenser banks **52** and this coil plus another, also of about 1 millihenry is in series with the other condenser bank in the same layer so that the discharge time of one of the capacitor banks is shaded slightly with respect to the other, thereby filling out or broadening the flat top of the discharge wave.

In order to facilitate reference between the right and left portions of Fig. 4, numbers from **200** to **213** have been used to indicate points of equal potential, thus making it easier to trace the leads from one layer to the next.

In Figures 2 and 3 which are somewhat diagrammatic, the charging chokes **54** and the wane shaping inductances **56** have been shown as open coils in order to distinguish them from the capacitors. This is satisfactory, but preferably they should be potted in cans as are the capacitors. By enclosing the capacitors and the inductances of both types in cans which are smooth and have well rounded corners and edges the field between the cans is so well controlled that the layers may be brought extremely close together without difficulty. Furthermore, this closeness of the cans concentrates the fields into the region between the cans and subjects the insulating material to much less field stress.

Previously it was mentioned that stray capacity between the corona cap **106** and the tank **36** is reduced by using the arrangement shown. This situation can be improved further by using a larger tank, a pear-shaped tank which is larger at the top or a glass reinforced plastics tank. The importance of stray capacity is that it reduces the efficiency somewhat by giving a lower voltage back wave to the discharge. More important, this back wave may cause a reverse discharge of the spark gaps, which has a tendency over a period of time to erode the anodes. The embodiment shown is believed by us to be an excellent compromise of these several factors which affect the cost of the equipment and its size.

From the above description of a preferred embodiment of our invention shown as incorporated in a specific structure, it will be apparent that modifications and variations may be made without departing from the scope or spirit of the invention and that therefore the scope of the invention is to be measured by the scope of the following claims.

Having described our invention, what we claim as new and useful and desire to secure by Letters Patent of the United States is:

1. In an electron accelerator, means forming a tower, said tower comprising a centrally disposed electron discharge tube, means forming an insulating supporting structure surrounding said tube, a multiplicity of capacitors, charging chokes and spark gaps supported by said structure in a plurality of substantially circular layers, said layers being substantially similar to each other, circuit means interconnecting said capacitors, chokes and spark gaps in a Marx type circuit so that the maximum potential difference between adjacent layers during discharge is substantially constant from layer to layer, means forming a pressure vessel enclosing said tower, charging means outside said vessel for supplying a charging current at a desired charging voltage, and circuit means connecting said charging means to the first said circuit means.

2. In an electron accelerator, means forming a tower, said tower comprising a centrally disposed electron discharge tube, means forming an insulating supporting structure surrounding said tube, a multiplicity of capacitors, charging chokes and spark gaps supported by said structure in plug in relationship thereto in a plurality of substantially circular layers, said layers being substantially similar to each other, circuit means interconnecting said capacitors, chokes and spark gaps in a Marx type circuit so that the maximum potential difference between adjacent layers during discharge is substantially constant from layer to layer, means forming a pressure vessel enclosing said tower, charging means outside said vessel for supplying a charging current at a desired charging voltage, and circuit means connecting said charging means to the first said circuit means.

3. In an electron accelerator, means forming a tower, said tower comprising a centrally disposed electron discharge tube, means forming an insulating supporting structure surrounding said tube, a multiplicity of capacitors, charging chokes and spark gaps supported by said structure in a plurality of substantially circular layers, said layers being substantially similar to each other, circuit means interconnecting said capacitors, chokes and spark gaps in a Marx type circuit so that the maximum potential difference between adjacent layers during discharge is substantially the maximum discharge potential divided by the number of layers, means forming a pressure vessel enclosing said tower, charging means outside said vessel for supplying a charging current at a desired charging voltage, and circuit means connecting said charging means to the first said circuit means.

4. In an electron accelerator, means forming a tower, said tower comprising a centrally disposed electron discharge tube, means forming an insulating supporting structure surrounding said tube, a multiplicity of capacitors, charging chokes and spark gaps supported by said structure in a plurality of substantially circular layers, said layers being substantially similar to each other, means interconnecting said capacitors, chokes and spark gaps in a Marx type circuit so that the maximum potential difference between adjacent layers during discharge is substantially constant from layer to layer, said marx type circuit providing a charging circuit by way of said chokes for said capacitors in parallel and a discharge circuit by way of said spark gaps for said capacitors in series, said discharge circuit including inductance means for giving the output of said discharge circuit a substantially square wave impulse characteristic, means forming a pressure vessel enclosing said tower, said vessel being filled with an inert fluid, an intermediate voltage circuit outside said vessel for supplying a desired charging voltage, and circuit means connecting said intermediate voltage circuit to said charging circuit.

5. In an electron accelerator, means forming a tower, said tower comprising a centrally disposed electron discharge tube, means forming an insulating supporting structure surrounding said tube, a multiplicity of capacitors, charging chokes and spark gaps supported by

said structure in a plurality of substantially circular layers, said layers being substantially similar to each other, circuit means interconnecting said capacitors, chokes and spark gaps in a Marx type circuit so that the maximum potential difference between adjacent layers during discharge is substantially constant from layer to layer, means forming a corona ring surrounding each of said layers, a high potential field controlling cap shaped as substantially half a torus having a major diameter substantially equal to that of the corona rings at one end of said tower, means forming a pressure vessel enclosing said tower, charging means outside said vessel for supplying a charging current at a desired charging voltage, and circuit means connecting said charging means to the first said circuit means.

6. In an electron accelerator, means forming a tower, said tower comprising a centrally disposed discharge tube, means forming an insulating sleeve surrounding said tube, a supporting structure surrounding said sleeve, a multiplicity of capacitors, charging chokes and spark gaps supported by said sleeve and structure in a plurality of substantially circular layers, said layers being substantially similar to each other, circuit means interconnecting said capacitors, chokes and spark gaps in a Marx type circuit so that the maximum potential difference between adjacent layers during discharge is substantially constant from layer to layer, means forming a pressure vessel enclosing said tower, said vessel being filled with an inert gas to a pressure of several atmospheres, a heat exchanger, blower means for circulating gas through said heat exchanger, through said sleeve and outwardly thereof over said chokes, spark gaps and capacitors, charging means outside said vessel for supplying a charging current at a desired charging voltage, and circuit means connecting said charging means to the first said circuit means.

7. A high voltage spark gap comprising means forming a cathode of porous iron, means forming an anode spaced from said cathode, an envelope enclosing said anode and cathode, a pool of mercury in said envelope in contact with said cathode, said envelope being filled to a pressure above atmospheric with an inert gas, a pair of spaced terminals, and conducting means connecting said terminals through said envelope to said cathode and anode.

8. In a high voltage impulse circuit of the type providing a multiplicity of capacitor banks, chokes and spark gaps, a charging circuit connecting said capacitor banks in parallel by way of said chokes, and a discharge circuit connecting said capacitor banks in series by way of said spark gaps, the improvement which comprises, providing said discharge circuit with a pair of spark gaps in series between each of said capacitor banks, a plurality of high value resistors, said resistors interconnecting the common points of all of said pairs of spark gaps.

9. In a high voltage impulse type electron accelerator system, an electron accelerating tube having an electron window, a movable conveyor in front of said window, means for repetitiously supplying high voltage impulses to said tube, and means for synchronizing the repetition rate of said impulses with the rate of movement of said conveyor.

10. In an electron accelerator, means providing an electron discharge tube and a high voltage impulse circuit therefor, said impulse circuit comprising a multiplicity of series-connected units, each unit comprising at least one spark gap and in series therewith a network of capacitors and wave shaping inductances, the relative values of said capacitors and inductances being such that the discharge of said capacitors are shaded slightly in time with respect to each other, so as to produce as square a pulse as possible, each of said units being bypassed by a charging choke, and a low voltage charging circuit connected in parallel with said units, whereby said capacitors are charged to a low voltage by said low volt-

age charging circuit by way of said charging chokes and are discharged in series across said spark gaps and through the discharge tube.

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