

Feb. 13, 1951

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2,541,028

CONCENTRATED ARC DISCHARGE DEVICE

Filed Aug. 10, 1949

3 Sheets-Sheet 1

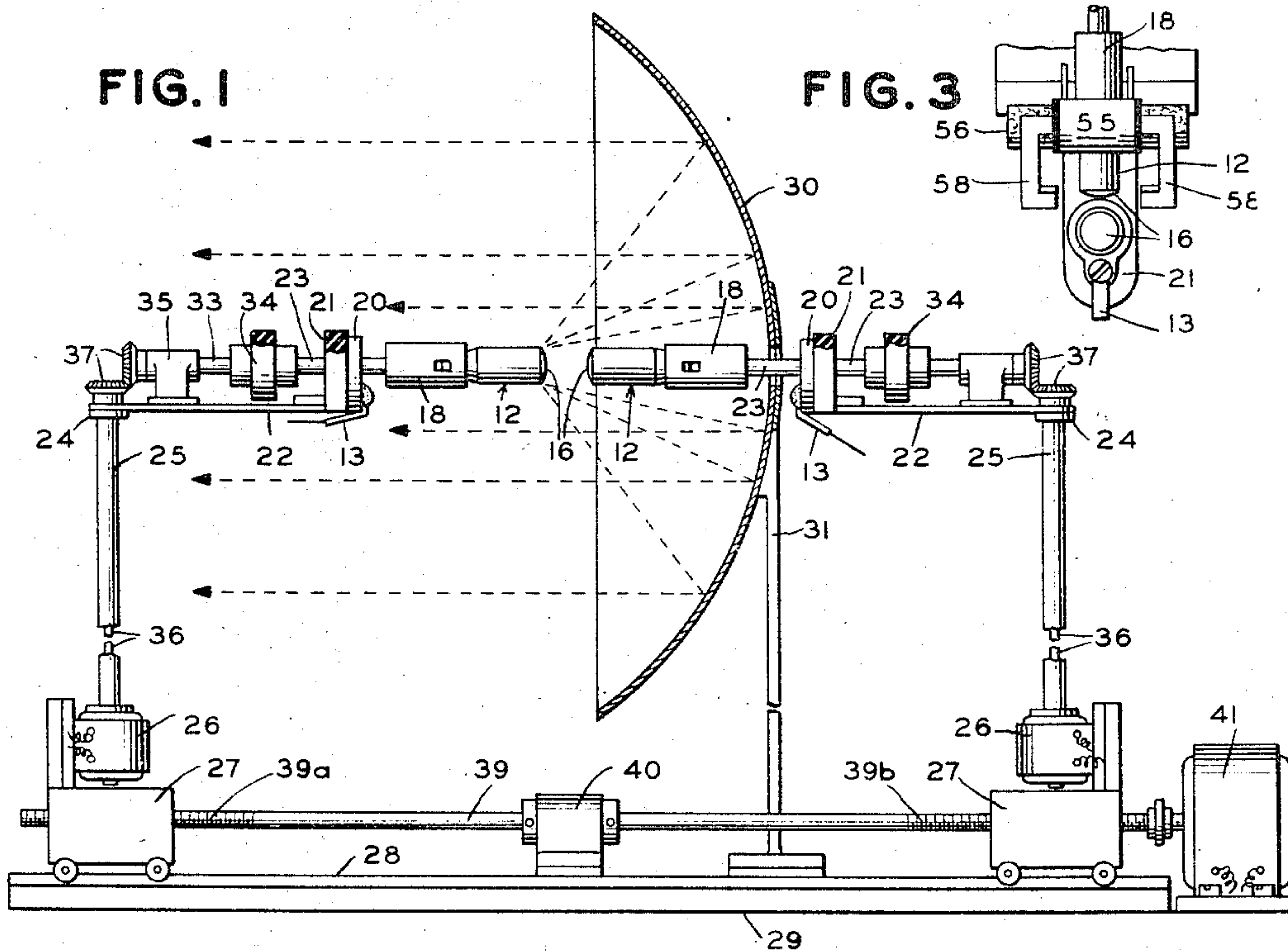
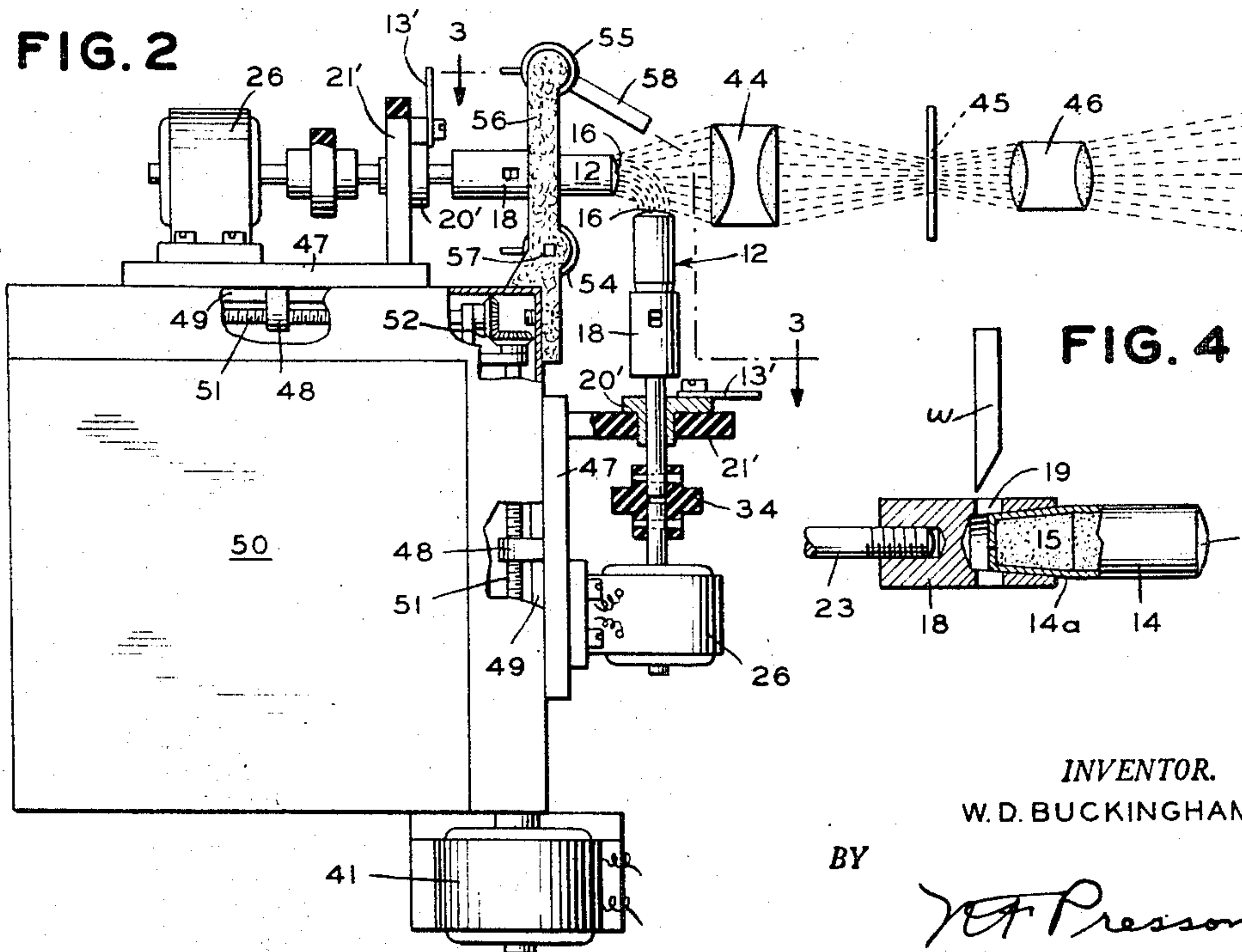


FIG. 2



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FIG. 5

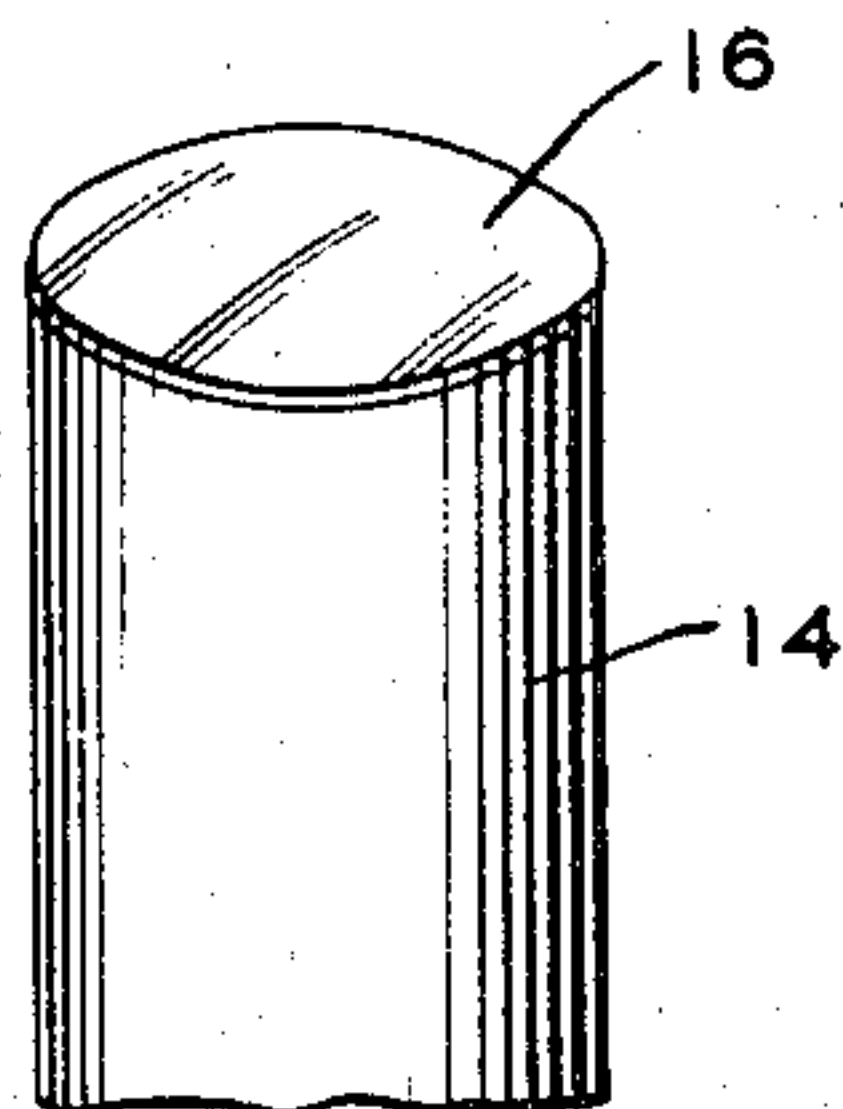


FIG. 6

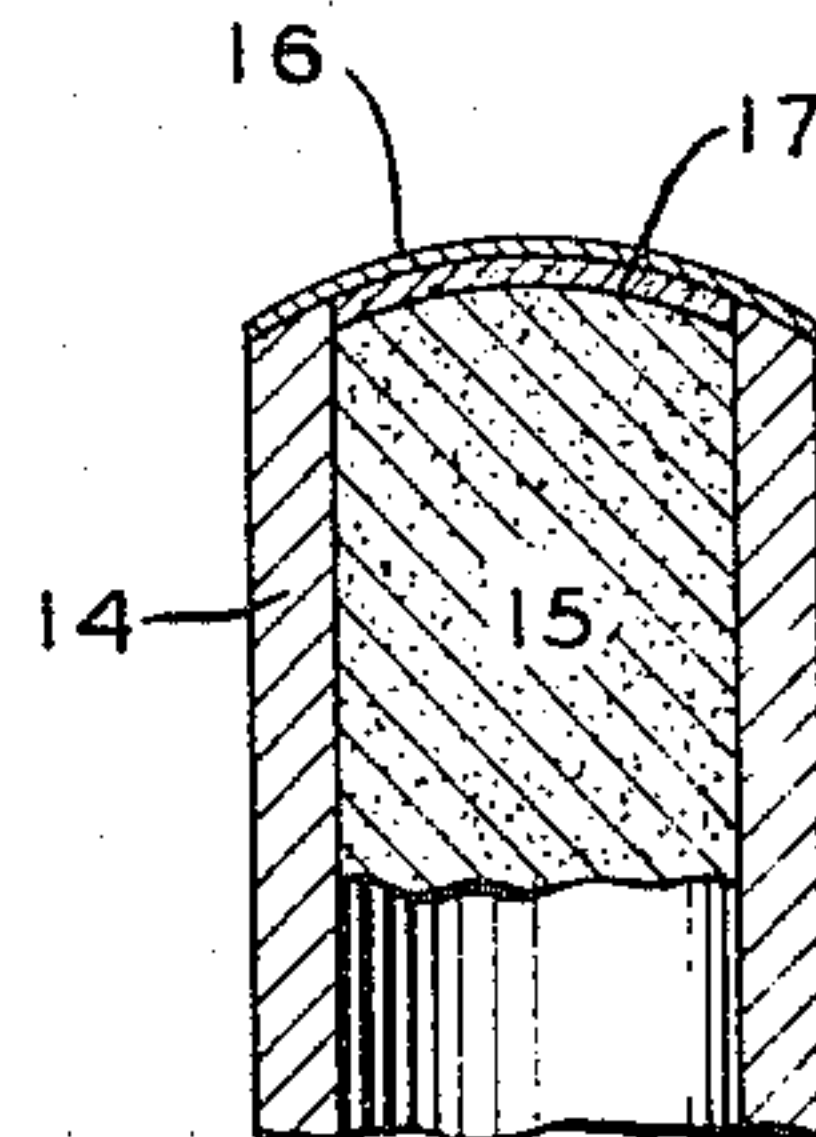


FIG. 7

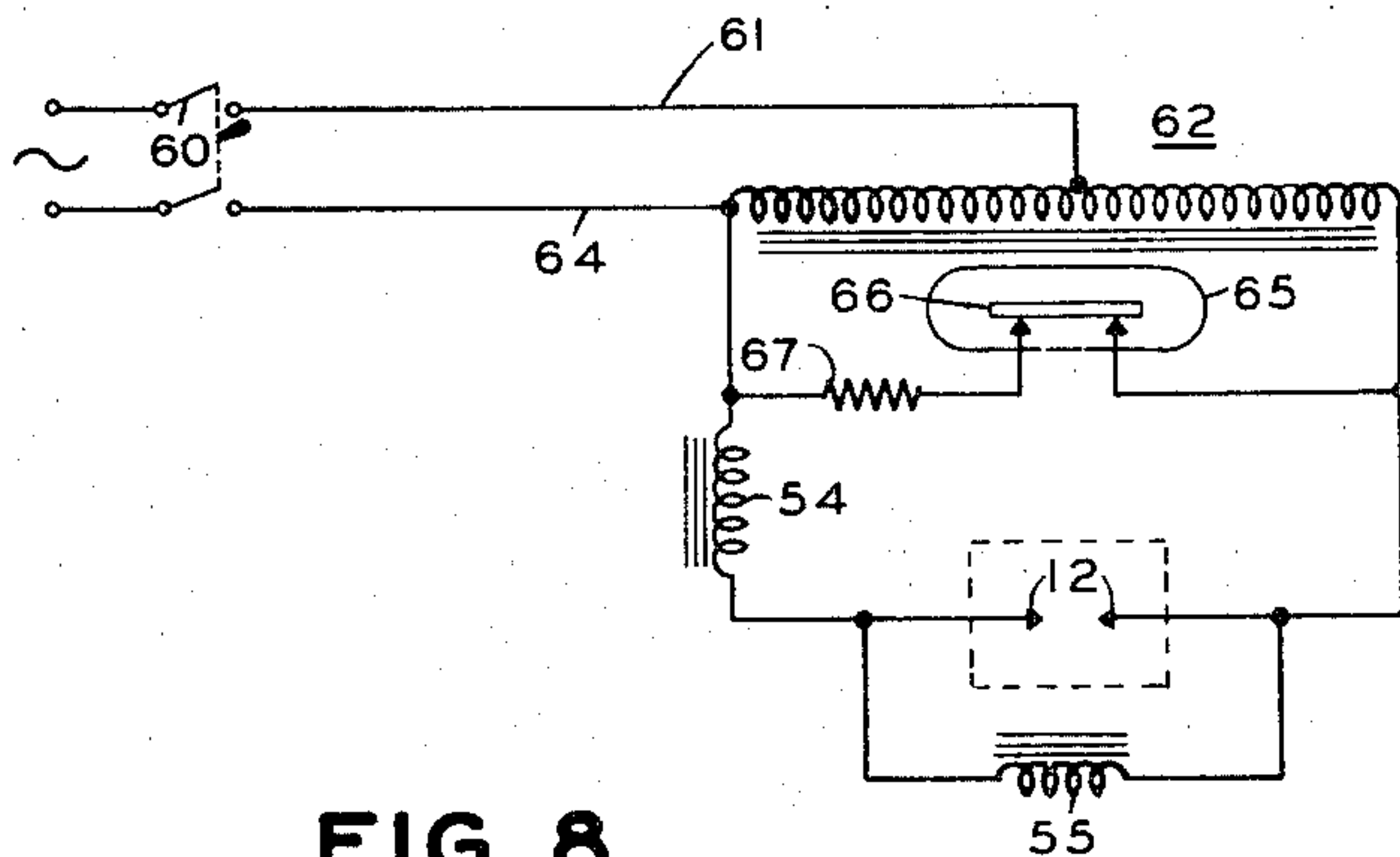
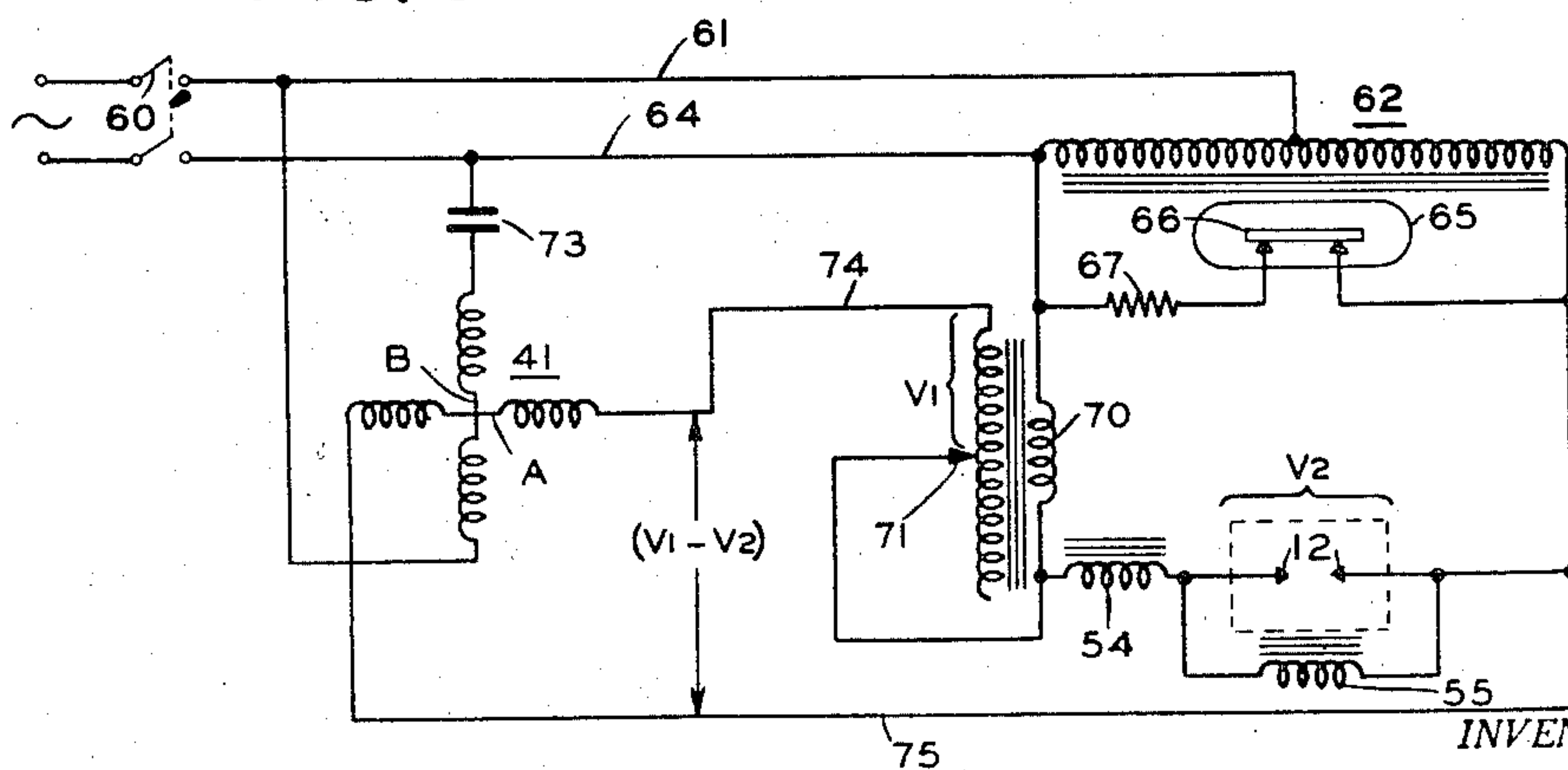


FIG. 8



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FIG. 9

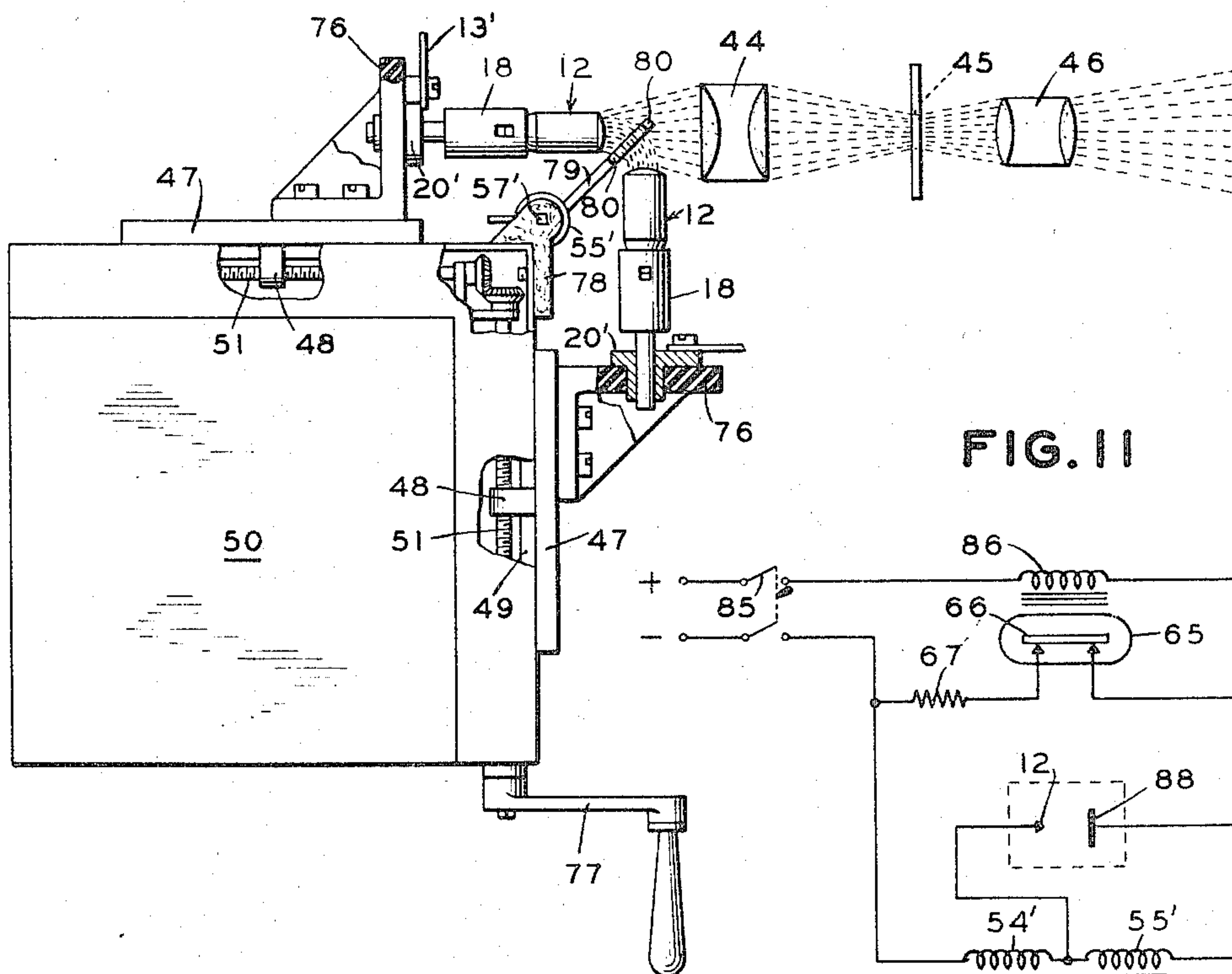


FIG. 11

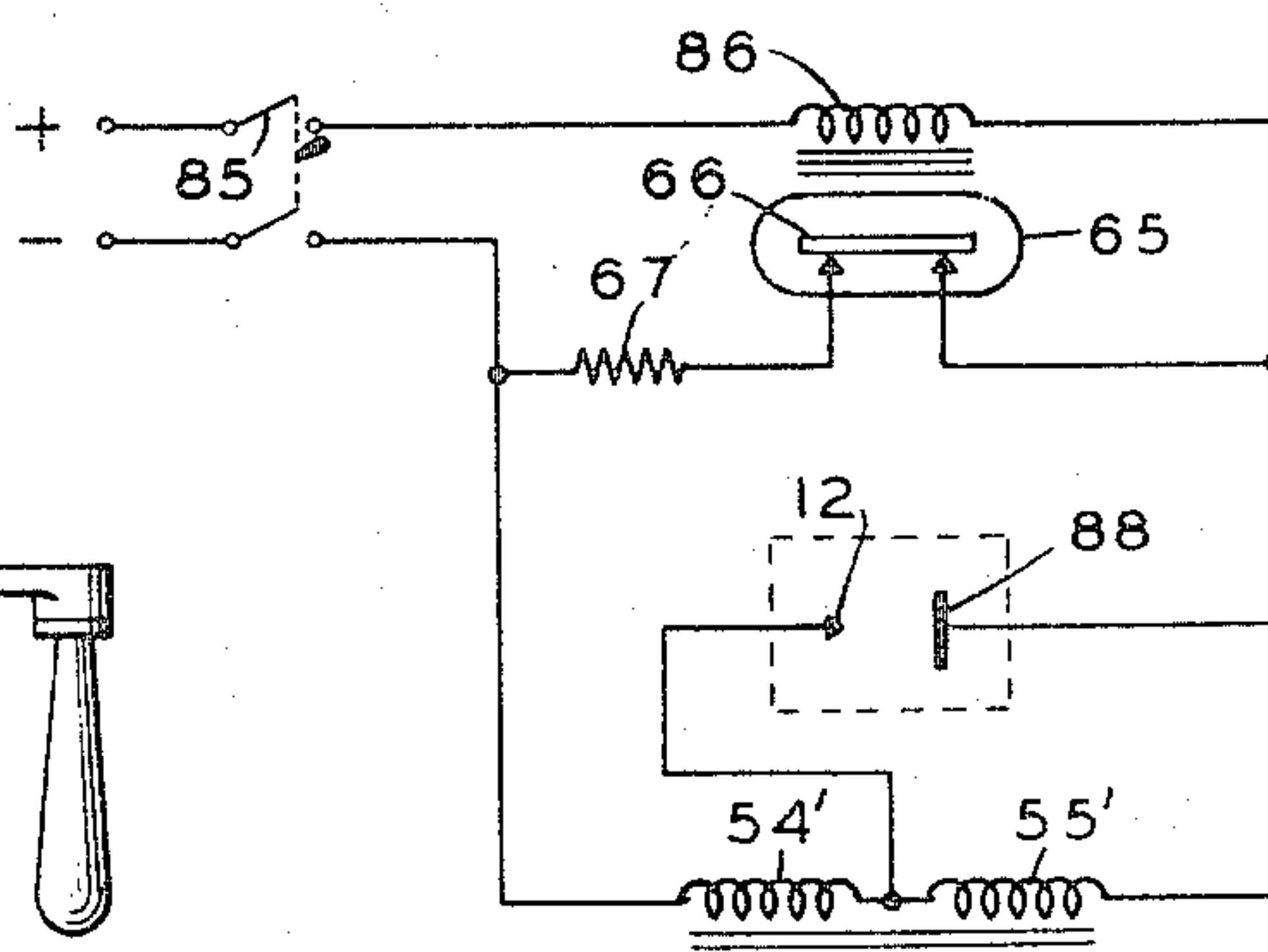
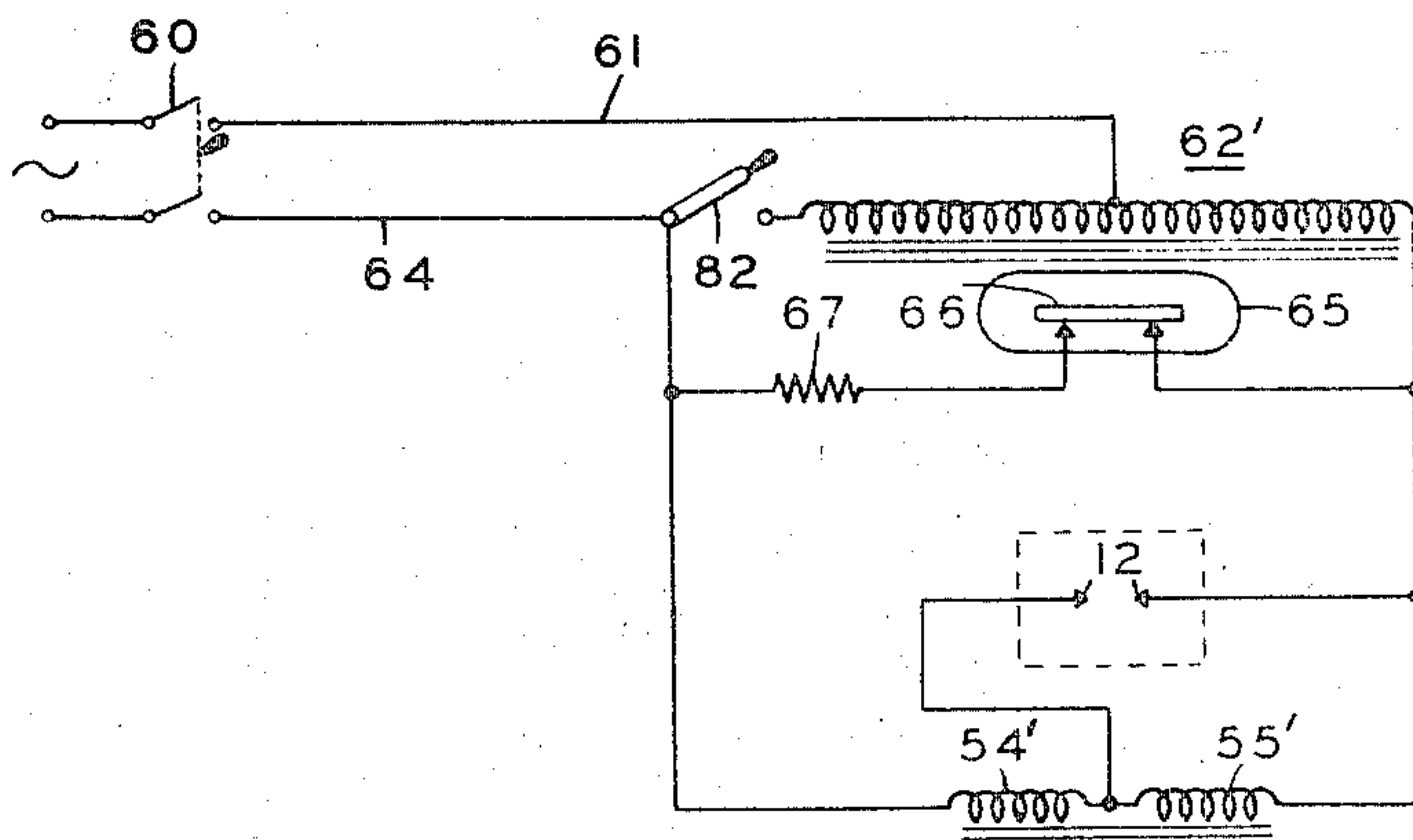


FIG. 10



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UNITED STATES PATENT OFFICE

2,541,028

CONCENTRATED ARC DISCHARGE DEVICE

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Application August 10, 1949, Serial No. 109,456

11 Claims. (Cl. 176—118)

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This invention relates generally to concentrated arc discharge devices, including arc lamps, rectifiers and the like, of the type described in Buckingham and Delbert Patent No. 2,453,118, and in my copending application Serial No. 83,151, filed March 24, 1949, which operates with a highly concentrated arc discharge in contradistinction to a low pressure diffused or glow discharge, the disclosures of which patent and application are incorporated herein by reference thereto, and more particularly to an improved arc lamp of the character disclosed in my aforesaid application and which is especially adapted for operation in the open air.

In concentrated arc devices in accordance with the foregoing Patent 2,453,118, the anode could be composed of a suitable metal or alloy which would dissipate the heat produced there without getting hot enough to vaporize or produce any considerable radiation due to its own incandescence; tungsten, tantalum and molybdenum were used because of their high melting temperatures, molybdenum being preferred. In such a lamp the cathode usually comprises a holder for the active cathode material, which holder is formed from a wire or tube of a high melting point metallic substance of good electrical and thermal conductivity, for example, tantalum, tungsten, molybdenum and the like. One end of the holder contains an active electrode material comprising two adjoining layers, the underlying layer being composed of a metallic compound which has a melting point much higher than that of the base metal which has high electron emissive properties at the very high temperature at which the device operates but which is not a sufficiently good electron emitter at lower temperatures to cause the electrons to be emitted in sufficient quantity to support an arc of high current density until the metal has reached incandescent temperatures, well above the melting point of the metal of which the compound is composed. Preferably, zirconium oxide or hafnium oxide was employed as the metallic compound.

When, for example, zirconium oxide was employed, the oxide powder usually was packed into a hole in the cathode body, after which the assembly was inserted within a glass envelope, which could be the envelope of the lamp, and the envelope evacuated and the envelope and electrode assembly then heated to assure degassing of the various parts, after which the envelope was filled with a gas, preferably argon, that is inert with respect to the material of the electrodes, and the cathode then formed by causing

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an arc to strike between the anode and the oxide to raise the temperature of the surface of the oxide to or about 3000° C. The molten oxide on the surface flowed and bonded itself to the inner side of the metal body, forming a smooth glassy surface on the end of the cathode material.

In the molten state and under the intense ionic bombardment of the arc some of the zirconium oxide was reduced or decomposed to metallic zirconium and formed a very thin molten film of this metal over the surface of the cathode. Zirconium metal is a better electron emitter at high temperatures than is the oxide, and it also has a lower melting temperature; thus, as soon as the thin metallic zirconium surface film is formed, the temperature of the cathode drops slightly, and the underlying oxide solidifies and supports the film of molten metal on its surface. It is this film of molten metal which is the chief source of the visible radiation from the lamp. The film, once formed during manufacture, remains to be heated and to become incandescent whenever the lamp is relighted. It is so thin that surface tension holds it to the oxide backing so that the lamps may be burned in any position.

As nearly as can be determined the active surface film is of the order of a few molecules in thickness when first formed, and if this layer can be kept very thin in service it results in a much more efficient light source since the candle power per watt input will be much greater. In the structure of Patent 2,453,118 the reduction of the zirconium or hafnium oxide at the surface caused oxygen to be released, and a substantial portion of the released oxygen combined with the molybdenum, tantalum, tungsten or other oxidizable material of the anode and cathodes bodies. Since the metal of these electrodes took up the oxygen that was released at the surface of the cathode, the reduction of the underlying oxide continued down through the layer of oxide as the lamp was used thereby forming an increasingly thicker cap or layer of the base metal. With the thicker layer of metal, the heat insulating value of the underlying structure was reduced, and the layer of metal provided greater lateral thermal conductivity to the side wall of the cathode tube, so that for the same amount of watts input the area of the highly heated incandescent spot on the surface became smaller.

In the arrangement of my aforesaid copending application a state of equilibrium was substantially maintained between the layer of underlying oxide and the surface film by causing the oxygen liberated at the surface to be made avail-

able, or to make available oxygen from another source as from the atmosphere, to recombine with the metallic zirconium or hafnium on the surface thereby to prevent continued reduction of the underlying oxide. The reversible reaction between the metal and the free oxygen thus enabled a balance substantially to be maintained between the reduction of the oxide beneath the surface and the oxidation of the metal on the surface, so that the film of very hot zirconium or hafnium was not continuously increasing in thickness and reducing the underlying oxide. This oxygen balance was maintained by insuring that there was a supply of free oxygen available at the cathode surface to combine with the free zirconium or hafnium atoms that have gained sufficient energy to leave the cathode surface and which are present in the arc stream in the immediate vicinity of the cathode surface, and also to combine with the highly heated metal film on the active surface, this being facilitated by constructing the plate electrode and the cathode body from a metal or alloy which is substantially free from progressive oxidation tendencies at the operating temperature of the lamp. This enabled the concentrated arc lamp to be operated in the open air since the oxygen in the air is available to combine with the free atoms and the active surface film of the metal, the highly heated zirconium or hafnium having a high affinity for oxygen.

Zirconium oxide or hafnium oxide preferably was used as the filling material for the cathode structure in the arc device disclosed in my aforesaid application. Such an oxide, however, is a conductor of electricity only when it is heated to a dull red heat or higher. Thus, it was sometimes difficult to strike an arc between such electrodes when they were cold, even though the arc was started with a high voltage pulse generated by a choke coil and vacuum switch combination. When the oxide was used in the electrodes, the arc usually had to be established first to the outer metallic tube, and the heat of this arc then raised the oxide to a temperature where it became conducting so that the arc would then strike to the oxide surface. It was attempted to add some material to the oxide to make it conductive when cold so that the arc could strike directly to the oxide when the lamp was being started, and a number of materials such as carbon, carborundum and other electrically conductive substances which could withstand high temperatures were mixed with the oxide filling in an attempt to make it conductive when cold. These either burned out of the mixture quickly or poisoned the oxide so that it would not maintain a normal type arc. Also, another difficulty with the oxide as a filling material was the inadequate bond between it and the outer tube, and in service it occasionally happened that the fused oxide bead which formed on the end of the electrode during operation of the arc would be knocked off.

An object of the instant invention is to provide a concentrated arc discharge device of the character described, and an electrode structure therefor, in which the foregoing undesirable effects are obviated, and which is especially adapted to operate in the open air.

Another object is a concentrated arc lamp of the character described, in which an exceedingly thin active film of the emissive material on the active cathode surface is maintained during long

continued operation of the lamp, and in which the progressive reduction of an oxide filling is no longer a factor.

A further object is a concentrated arc lamp operable in the open air and which exhibits extreme brightness both initially and during the life of the lamp.

Still another object is to enable the filling material of the electrode initially to be composed of the base metal which forms the active surface film and in which the active surface film is nevertheless supported by a thin underlying layer of an oxide of the metal, and in which progressive oxidation of the base metal beneath the oxide layer is minimized or prevented.

Other objects and advantages of the invention will be apparent from the following detailed description of several illustrative embodiments thereof, taken in connection with the accompanying drawings, in which:

Fig. 1 is a view, in elevation, of a high wattage alternating current lamp operable in the open air and embodying the instant invention, the arrangement disclosing two electrodes mounted on a common horizontal axis and having means for rotating the electrodes about this axis and for automatically maintaining the electrodes at the correct distance from each other during operation of the device;

Fig. 2 is a view, in elevation, of a high wattage open air lamp in which the electrodes are mounted approximately at right angles to each other, together with suitable magnetic structure for automatically controlling the position of the arc stream and means for automatically maintaining the correct distance between the electrodes;

Fig. 3 is a fragmentary view of the magnetic structure for controlling the position of the arc stream, taken along the line 3—3 of Fig. 2;

Fig. 4 shows certain details of mounting the electrodes and also means to facilitate removal of the electrodes from their supporting sockets;

Fig. 5 is an enlarged fragmentary view of one of the electrode structures, showing the active surface layer bonded to the end of the metal cathode container;

Fig. 6 is a longitudinal sectional view of the electrode structure of Fig. 5, showing the interior composition thereof;

Fig. 7 shows a circuit arrangement for operating an alternating current lamp, with means for automatically controlling the position of the arc stream;

Fig. 8 shows a circuit arrangement for operating an alternating current lamp, with means for automatically maintaining the correct distance between the electrodes, in addition to means for automatically controlling the position of the arc stream;

Fig. 9 is a view of a modified arrangement for controlling the position of the arc stream in an alternating current lamp, together with manually operable means for maintaining the electrodes at the correct distance from each other;

Fig. 10 shows a circuit arrangement for controlling the position of the arc stream in the manner illustrated in Fig. 9, together with a modified starting and running circuit for the lamp; and

Fig. 11 shows a circuit arrangement for automatically controlling the position of the arc stream in a direct current lamp embodying the

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invention, together with a starting and running circuit therefor.

Fig. 1 of the drawings shows a construction adapted for high wattage lamps, such as those used in flood lamps, searchlights and the like, operating in the open air and powered from a source of alternating current supply. The lamp utilizes two electrodes 12, which may be identical in construction if desired, and which alternately operate as anodes and cathodes during each cycle of the alternating current supply which may be the 110 volt, 60 cycle current commonly available. In this embodiment the electrodes are arranged on a common horizontal axis so as to face each other in the mounting structure. Each of the electrodes 12 comprises a generally cylindrical metal tube or shell 14 which, as seen in Fig. 4, is closed at one end and is filled with the electrode material 15, the thin active surface film of the electrode material at the open end of the tube being indicated at 16. The shell 14 may have a conical or tapered portion 14a which is received with a tight fit within a conical bore in a metal electrode holder 18. A transverse slot 19 through the body of the holder enables a wedge-shaped tool *w* to be inserted for forcing the electrode out of the holder in order to insert a new electrode whenever desirable or necessary. Each electrode may be as long as desired, for example, several inches long in the large size lamps, thereby to compensate for burning of the active end of the electrode which does slowly erode away under the action of the high intensity arc.

Figs. 5 and 6 are greatly enlarged fragmentary views of one of the electrodes 12. The electrode comprises a tubular metal body portion 14 into which has been packed the core 15 of cathode material. The first experimental electrodes of this type used platinum for the containing tube 14 because it can be operated at bright red heat in the open air without burning. Platinum, however, is much too expensive for regular commercial use and so a variety of other metals was tested as substitutes, these including stainless steels and various other alloys which are substantially free from progressive oxidation tendencies. Platinum, palladium and nickel proved to be more satisfactory, and of this group nickel has proved to be very practical since it is obtainable at a low cost and readily may be worked. When subjected to high temperatures in the presence of oxygen, nickel oxidizes very slowly, but the first thin film of oxide which forms on its surface acts as a protective coating which retards further oxidation.

Zirconium metal powder was first tried as the filling material, and was pressed into the nickel tube under considerable pressure and then sintered at a bright red heat in an atmosphere of argon or nitrogen. It was hoped that the solid zirconium metal core thus produced would bond tightly to the nickel tube so that during operation of the lamp only the exposed end of the zirconium would oxidize, and if this oxide cap were thin the starting spark could jump through it to the underlying zirconium metal to give easy starting. Such electrodes did start easily the first time they were used, but after a number of hours of operation all of the zirconium metal had been progressively converted to the oxide and the electrodes were no better than those which had been packed initially with the oxide.

I have discovered that if the zirconium metal powder is mixed with a material which protects

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all but the active end of the zirconium core from oxidation, progressive oxidation of the zirconium metal beneath the oxide layer can be prevented. Powdered nickel, in the proportion of about one part of nickel to three parts of zirconium metal powder, was found to produce a mixture which would not progressively oxidize throughout its entire volume as had the pure zirconium. These electrodes acquire only a thin cap of zirconium oxide 17, Fig. 6, at the active end, and the underlying conductive nickel and zirconium mixture 15 remains to aid in starting the lamps. The zirconium oxide caps are well bonded to both the nickel tube 14 and the underlying metal mixture, and the electrodes using the zirconium-nickel mixture start easily, run well and have well bonded caps. The zirconium powder is first passed through a 325-mesh screen to insure that only very fine particles of the powder are present in the filling 15, the diameter of a particle being no larger than 50 microns and usually being much smaller down to a few microns. Also, the nickel powder was ground very finely, and preferably as fine as or finer than the zirconium powder. I have also found that an even better electrode is produced with a small percentage of a metallic substance, such as an oxide, which can withstand high temperatures in the presence of oxygen without changing, and is a conductor when cold, and which does not poison or otherwise deleteriously affect the zirconium-nickel mixture or the operation of the lamp. Magnetite, which is an oxide of iron with a composition of Fe_3O_4 , is especially suitable and is added to the zirconium-nickel mixture 15. Magnetite is a conductor of electricity even when cold and being an oxide it can withstand high temperatures. Apparently, it increases the electrical conductivity through the fused oxide cap 17 when the electrode is cold and thus aids in starting. Preferably, the mixture, after being pressed into the tube 14 under considerable pressure, is sintered in an atmosphere of argon or nitrogen; sintering is not indispensable, but it improves the bond between the mass 15 and the tube 14 and also increases the protective property of the nickel.

An electrode using approximately 87% zirconium, approximately 9% nickel and 4% magnetite gives excellent results, the mixture being pressed into the nickel tubes with a four ton press. The electrodes are heated with a bombarder in an atmosphere of nitrogen to a temperature of about 1000°C . where a reaction takes place in the core material as indicated by a sudden glowing of the mixture. The heating and sintering operation requires about three minutes, after which the core is very hard and the electrodes are ready for use.

The exact proportions of the metals and oxide in the core mixture do not seem to be critical. However, if more than 40% of nickel is employed in the mixture, excessive smoking occurs and the electrode erodes away more quickly; if less than 5% of nickel is employed the protective action of the nickel is not present. With respect to the conductive material, such as magnetite, from 2% to 15% may be employed: if more than 15% is used it decreases the brilliance of the lamp and the rate of erosion is increased; if less than 2% of magnetite is used the lamp becomes hard to start. When the latter is used, the bead formed on the end of the electrode is brownish in color; otherwise it is

generally gray in color although sometimes it has a golden color probably due to the presence of zirconium nitride in the surface film.

The fact that powdered nickel or other of the powdered metals having properties analagous thereto in connection with the instant invention substantially prevents progressive oxidation of the metal powder beneath the oxide layer 17 has been proved in practice, although the exact phenomena involved is difficult to ascertain. This is principally because the particles in the mixture 15 are so very minute that even under a powerful microscope longitudinal sections of the electrodes fail to disclose clearly the precise action involved. It may be that the nickel particles at the sintering temperature melt and flow around the minute zirconium particles thereby to form a protective layer which prevents oxidation of zirconium. On the other hand, if sintering is dispensed with then the electrode is made, very little progressive oxidation of the zirconium is noticed in samples which have been burned in the lamp for many hours, although it is possible that in the operation of the lamp heat generated within the electrode is sufficient to cause the nickel to melt and form a very thin layer or coating around each zirconium particle, at least in the neighborhood of the surface layers 16 and 17. Some of the specimens examined under a microscope had portions thereof which appeared to show that the nickel particles operate to separate the zirconium particles from each other, and thus prevent the flow of oxygen from one zirconium particle to an adjoining zirconium particle and thereby preclude progressive oxidation. It may also be that some alloying action takes place between the nickel and zirconium which prevents progressive oxidation.

It will be understood that as the electrode slowly erodes during operation of the lamp, that portion of the zirconium which is exposed to the arc does oxidize thereby to maintain the oxide layer 17, but further oxidation of the mass 15 below the oxide layer 17 does not take place to any substantial extent. Since the mass 15 does not oxidize and the metal of the wall 14 is not subject to progressive oxidation tendencies, good electrical contact is maintained between the mass 15 and the inner wall of the tube 14, thereby providing a path of good electrical conductivity for the arc current.

In Fig. 6, the mass 15 comprising the core is a mixture of zirconium metal powder, nickel powder and iron oxide powder, all thoroughly mixed by ball milling, and sintered. The layer 17 is a relatively thin fused layer with nickel particles and semi-fused zirconium oxide and magnetite, this layer being firmly bonded to the underlying core 15. In a 750 watt size lamp, the outside diameter of the tube 14 is approximately $\frac{1}{4}$ inch and the thickness of the wall of the tube 14 is $\frac{3}{8}$ inch, thus leaving an inside diameter of $\frac{1}{8}$ inch. The thickness of the layer 17 is approximately $\frac{1}{16}$ inch. The upper layer 16 is the thin film of molten metal which is formed and rendered highly incandescent by the action of the arc during operation of the lamp, and which comprises the active surface layer. When the energizing current is disconnected, however, the thin layer of hot metal 16 oxidizes so that when cold this layer principally comprises the oxide of the underlying layer 17 except that the nickel and magnetite have been volatilized or burned off by the action

of the arc and, therefore, are not present in any substantial amounts in the surface layer.

Referring again to Fig. 1, each of the holders 18 is carried by a rotatable metal shaft 23. Surrounding each shaft, and in good electrical contact therewith, is a metal collector block or collar 20 to which is secured, as by soldering or by screws, the external terminals 13 of the lamp. The collector block is secured to an insulating block 21 that is mounted on a bracket 22, and the bracket is rigidly mounted on a collar or flange 24 on the upper end of a vertically extending tubular housing 25. The lower end of the housing is rigidly mounted on the casing of a small electric motor 26, and the motor 26 is mounted on a carriage 27 which is adapted to travel on guide rails 28 of a base member or bed plate 29 in a manner hereinafter described.

The shaft 23 of the right hand electrode 12 passes through an opening in a reflector 30 mounted on a bracket 31, the bracket being rigidly supported by the base or bed plate 29. The reflector preferably is parabolic and serves to project parallel light rays in the direction indicated by the arrows, the projected light beam principally coming from the highly incandescent surface film 16 on the left hand electrode which faces the reflector, although a certain amount of light is directly projected by the incandescent surface film of the right hand electrode.

If desired, and as shown in Fig. 1, the electrodes may be rotated continuously about their longitudinal axes during the operation of the lamp to insure proper centering of the light spots in the activated surfaces of the electrodes. For this purpose each of the shafts 23 is connected, by an electrically insulating coupling 34, to a stub shaft 33 mounted in a bearing 35 carried by the bracket 22. Within each tubular housing 25 is a shaft 36 which by means of bevel gears 37 serves to drive the stub shaft 33 thereby to rotate the electrode 12 about its horizontal axis. Each shaft 36 is driven by the associated small motor 26 which may be either a direct or alternating current type, and the electrodes are thereby rotated at suitable speeds about their common horizontal axis in opposite directions relative to each other. This speed may be quite low, for example, one revolution per minute, and should not be so high as to cause appreciable centrifugal forces to be exerted on the active surfaces of the electrodes or to cause rotation of the arc spot. A symmetrical oxide bead is thus formed and maintained on each electrode and the position of the luminous spot on each electrode is stabilized.

Fig. 1 also shows means for automatically bringing the electrodes together for starting the arc and for maintaining them at a correct distance from each other during operation of the lamp. This is based on a differential action between the arc voltage, i. e., the voltage drop across the arc, and the arc current flowing at any instant. It was attempted to employ balanced voltage-current solenoids, but their non-linear characteristics resulted in inaccurate control and their massive armatures produced hunting problems which were difficult of solution. A satisfactory control was developed, however, by the use of a small two-phase alternating current motor as the balance detecting unit. This motor, shown at 41 in Fig. 1, rotates the shaft 39 in either direction, the shaft being journaled in a bearing 40 secured to the bed 29. The shaft has threaded portions 39a and 39b which engage threaded elements in the carriages 27, and right hand and

left hand threads are used so that when the motor 41 turns in one direction, the carriages and hence the electrodes will move towards each other, and when the motor reverses its direction the carriages and the electrodes carried thereby move away from each other. The motor advances the electrodes until they touch and the arc is struck by the high voltage starting pulse, and when the arc current is established the motor draws the electrodes apart to the proper operating distance and then stops. A suitable spacing between the electrodes generally is from one to two times the outside diameter of the electrodes. As the electrodes slowly burn away, the control motor advances the electrodes to maintain their spacing and the position of the luminous spot constant. The control circuit for the motor, which is shown in Fig. 8, will be explained in connection with the hereinafter described embodiment of the lamp illustrated in Fig. 2.

An important feature of the electrode structure is that the lamp may be operated in the open air, and when thus operated the voltage drop across the lamp is within the range of 50 to 150 volts depending upon the magnitude of the current flowing through the lamp and the length of the arc gap, thereby substantially reducing the losses heretofore occasioned in ballast resistors of the size required with lamps having comparatively low voltage drops and operating from a 110-volt source of supply. In addition, the brightness of the lamp is greatly increased when operating in air; a zirconium metal lamp in air produces from 100 to 132 candles per square millimeter, depending upon the size of the lamp, which is approximately twice the brightness of a zirconium oxide concentrated arc lamp operating in an envelope with a gas filling of argon and the like. This increase in brightness is probably due to the energy produced by the oxidation of the zirconium atoms which have been reduced from the thin layer of oxide by the action of the arc at the active electrode surface. Apparently a state of equilibrium is maintained at or very near to the surface of the electrode between the zirconium oxide, the zirconium metal reduced from the oxide by the arc and the zirconium metal which is being oxidized at the electrode surface. The same effects and advantages are present with powdered hafnium metal as the electrode material and operating in air; a 25 watt lamp has a brilliance of 172 candles per square millimeter, compared to 100 candles with hafnium oxide operating in argon.

A one-quarter inch diameter electrode of the type disclosed herein and operating from alternating current in a 750 watt lamp burns away at the rate of about one-hundredth of an inch or less per hour of lamp operation, and since several inches of the core 15 of the electrode can be packed into an electrode shell 14, this gives a life of many hundred hours even with lamps of larger sizes. In smaller size lamps the burning of the electrode is considerably less and thus the smaller lamps have a life expectancy of one thousand to two thousand hours.

It was at first thought that with the electrodes operating in air from alternating current there would be no appreciable loss of zirconium or hafnium, depending upon which metal was used, during operation of the lamps. This appeared to be confirmed by tests which showed no loss in weight during the first few hours of burning. More extended measurements show that the electrodes first gain and then lose weight. The gain

comes from the oxygen taken from the air to produce the oxide cap, but when this cap is once fully formed the weight decreases at the rate of about 0.05 gram per hour for the one-quarter inch electrode in a 750 watt lamp. This loss is probably due in part to the use of alternating current; the mechanism of recapture of escaping zirconium or hafnium atoms by ionization and attraction is probably disturbed to some extent by the alternating current operation. The reversing potential and the periods of zero current during the alternating current cycles give greater opportunity for the escape of zirconium or hafnium atoms from the region of the electrodes. Whatever the cause, the rate of erosion of the new electrodes is far less than that of any comparable open air electrodes of which I am aware. An ordinary arc carbon is about ten inches long and when used with currents of a magnitude comparable to those which the electrodes of the present invention are adapted to pass, the arc carbon has a life of about one hour whereas an electrode in accordance with the instant disclosure has a life of hundreds of hours and often longer.

Fig. 2 discloses a construction for use with high wattage lamps in which the electrodes 12 are disposed at an angle of approximately 90° to each other, as shown in the figure, in order to provide an unobstructed light output from the lamp. The light, which principally comes from the activated surface 16 of the horizontally disposed electrode passes through a condenser lens 44 and thence through a light aperture 45 and projecting lens 46. The electrodes may be rotated generally in the manner of the arrangement of Fig. 1 to insure proper centering of the light spots on the activated surfaces 16 of the electrodes, and the arrangement in Fig. 2 enables this to be done without having the electrode rotating mechanism in the field of projection of the light.

The elements in Fig. 2 which are identical in construction to those shown in Fig. 1, are identified by the same reference numerals, and those elements in Fig. 2 which perform analogous functions to those in Fig. 1, but which differ somewhat in construction, are identified by the same reference numerals with a prime mark added. The motors 26 which rotate the electrodes are each mounted on slidable blocks 47, one of the blocks resting on the top surface of a cabinet or supporting frame 50, and the other block 47 being mounted on a vertical side of the structure 50. Each of the blocks has a lug 48 which passes through a slot 49 in the frame structure 50, the lug 48 being threaded internally and receiving a threaded shaft 51, so that rotation of the two shafts 51 in either direction moves the slidable blocks 47 in a direction either to increase or decrease the spacing between the ends of the electrodes. The shafts 51 are geared to each other through bevel gears 52, and the vertical shaft is driven by a small two-phase motor 41 which is controlled in a manner hereinafter described in order to maintain a desired spacing between the electrodes.

It will be seen that the arc stream between the active surfaces of the electrodes should follow a curved path, but sometimes the arc stream would tend to concentrate on the edges of the electrodes closest to each other, and other times would tend to rise due to convection currents and also when the arc stream became too long. In order to prevent this there is provided an electromagnet

comprising a coil 54 which is in series with the arc electrodes of the lamp, and an electromagnet 55 which is bridged across the electrodes, these magnets being mounted on an insulating support structure 56 which is secured to the casing 50. The magnet 54, which is the current coil, is wound around a straight core 57 of magnetizable material, and the coil 55 is wound around a U-shaped core of magnetizable material having projecting leg portions 58, as seen in Fig. 3. The electromagnet 54, which is in series with the electrodes, may comprise for example 200 ampere turns for use with a 750 watt lamp, and the second electromagnet 55 which is connected across the electrodes may have for example 100 ampere turns. The current coil 54 is poled so that its external magnetic field tends to force the arc stream outwardly, whereas the voltage coil 55 is poled so that its external magnetic field tends to force the arc stream inwardly and keep the arc from rising. The resultant field maintained by the two electromagnets operates to keep the arc stream centered on each of the active surfaces 16 of the electrodes and cause it to follow the curved path indicated by the broken lines in Fig. 2. Since the magnetic effect of one of the windings is proportional to the current flowing in the arc stream and the magnetic effect of the oppositely poled winding is proportional to the voltage drop across the arc, the resultant effect of their magnetic fields tends to maintain the voltage-current relationship and hence the length of the arc constant.

Fig. 7 shows a starting and running circuit suitable for use with smaller sizes of the concentrated arc lamp in which it is not necessary to rotate the electrodes or to provide means for automatically maintaining the proper distance between the electrodes. When the line switch 60 is closed, current is applied over a circuit comprising conductors 61 and 64 to a high leakage reactance transformer 62 of the constant current type. The transformer shown is an auto-transformer, and conductor 61 is connected to the midpoint thereof so that if 110 volts of alternating current is applied to the primary part of the transformer, 220 volts will be generated across the secondary of the transformer. Bridged across the transformer is a vacuum switch 65, the switch being of the type in which the circuit is made and broken between solid contacts in a vacuum in response to a magnetic field, such a switch having been found to be very effective to provide the surge required in starting concentrated arc lamps of the type disclosed herein. The transformer 62 has an iron core and an open air gap and hence sets up a magnetic field which, when line switch 60 is closed, attracts the magnetizable bar or armature 66 of the vacuum switch, opening the circuit formerly through the switch contacts, the latter circuit including the electrodes 12 of the arc lamp. Various kinds of such switches are well known; one particularly suitable for the purpose is disclosed in my co-pending application Serial No. 35,928, filed June 29, 1948, the structure of which enables the switch to be mounted in an aperture in the core of transformer 62. Opening the circuit of switch 65 causes a surge of from 1000 to 2000 volts to appear across the electrodes 12 of the lamp, the surge being due to collapse of the field in the transformer 62, this circuit including a resistor 67 and the winding of electromagnet 54 which is a current coil such as referred to in the foregoing

description of Fig. 2. When the gap between the electrodes 12 breaks down due to the voltage surge, the current flowing through transformer 62 from the supply line 60 maintains the arc across the electrodes and also keeps the contacts of switch 65 open so long as the lamp is operating.

Fig. 8 shows a starting and running circuit similar to Fig. 7 and also discloses a suitable circuit arrangement for the operation of regulating means such as the two-phase motor device 41 in Figs. 1 and 2. Connected between one end of the transformer 62 and the electrode terminals is a transformer 70 through which the arc current flows. The secondary winding of the transformer 70 has a variable tap connection 71, the upper end of the secondary winding being connected by means of a conductor 74 to one of the windings A of the two-phase motor, the other end of winding A being connected by a conductor 75 to the right-hand end of the transformer 62. The winding B of the two-phase motor 41 is connected across the supply conductors 61 and 64, a condenser 73 being connected in circuit therewith in order to give a phase displacement so that there will be a suitable phase difference between the currents in the two windings A and B of the motor to provide the necessary starting torque for the motor.

The adjustable contact 71 on the secondary winding of transformer 70 enables the voltage V1 developed across the winding to equal the voltage V2 across the lamp terminals at the proper spacing of the electrodes. When voltage V1 equals voltage V2 the two-phase motor 41 has no voltage on one phase represented by its winding A. When the supply current is applied to the lamp through transformer 62 and before the lamp has started, the voltage V2 is high and voltage V1 is substantially zero, and the motor 41 rotates in a direction to close the gap between the electrodes until they either touch each other or are sufficiently close to start the arc. The voltage V2 then drops rapidly, and the voltage V1 rises rapidly from zero and usually will be greater than V2. Under these conditions the motor 41 will operate to separate the electrodes to the correct spacing as previously determined by the adjustment of the contact 71.

If the arc spacing becomes too great, the voltage V2 increases, and the current through the arc decreases and hence voltage V1 decreases, so that there is a difference between V1 and V2 and this difference causes current to flow through winding A of the motor and causes the motor to rotate in a direction to bring the electrodes towards each other. If the arc spacing becomes too small, the voltage V2 decreases, and the current through the lamp and also the voltage V1 increases, and the current flow through winding A of the motor is opposite in phase to that in the previous case when the gap was too long, so that the motor will turn in a direction to increase the separation between the electrodes. The arrangement thus automatically causes the lamp to be started and to maintain the electrodes at their proper spacing during operation of the lamp. The arrangement has substantially linear characteristics which result in accurate control, and there are no overrunning or hunting difficulties involved.

Fig. 9 shows an arrangement in which the position of the arc stream is maintained in a manner such that rotation of the electrodes 12 is unnecessary to maintain proper centering of the

incandescent light spots on the active surfaces of the electrodes, and also shows how the desired spacing between the electrodes may manually be maintained. In this modification, the electrode holders 18 have shafts which are received within metal bushings 20' to which the external circuit may be connected, and these bushings are mounted in insulating brackets 76. The brackets are carried by the slide blocks 47, and the positions of the slide blocks and hence the spacing between the electrodes 12 may be adjusted by means of lugs 48 which pass through slots 49 in the supporting structure 50, the lugs 48 being internally threaded and coacting with the threaded shafts 51. The vertical shaft 51 may be rotated in either direction by a crank 77 thereby to either advance or retract the electrodes, as desirable or necessary.

A current coil 54', seen in Fig. 10, and a voltage coil 55' are both wound on a straight core 57' of magnetizable material. The electromagnets are supported by an insulating structure 78 which is secured to the frame or casing 50. Extending from one end of the structure 78 is a rod 79 which has secured thereto a small permanent magnet having its poles 80 disposed at one side of the arc stream, for example, an inch to an inch and a half away from the stream. The two poles of the magnet straddle the arc stream, as seen in the figure, and the external field of the magnet lies in a direction which is transverse to the desired direction of the arc stream. The electromagnets 54' and 55' maintain vertical stability of the arc stream and the permanent magnet maintains lateral stability of the arc stream. The resultant effect causes two closely spaced centers to be maintained in the outer end of the flame in the arc stream and there is much less tendency for the arc stream as a whole either to rise or to fall, and the arc stream does not get too hot in any one place so that disturbing convection currents are not so likely to develop. The arrangement centers the arc stream as a whole so that rotation of the electrodes has been found unnecessary even in the larger size lamps.

The permanent magnet 80 may be relatively small in size; for a 750 watt lamp a magnet which is one inch across its pole pieces has been found sufficient to stabilize the arc in conjunction with the electromagnets 54' and 55'. It will be understood that the coils 54' and 55' are differentially wound with respect to each other, and since they may be wound on a common core this substantially simplifies the construction. In Fig. 9, the permanent magnet is shown behind the arc stream, with its legs 80 facing the observer, but the position of the magnet may be reversed, that is, the U-shaped portion may face the observer in which case the legs 80 would be spaced approximately an inch to an inch and a half in front of the arc stream as viewed in the figure. Instead of a permanent magnet 80 an electromagnet may, of course, be employed.

Fig. 10 shows an improved suitable starting and running circuit which may be employed with the arrangement of Fig. 9 or with other of the arrangements hereinbefore described. In this case, the transformer 62' has the left-hand end thereof connected to a manually operable switch 82. When the lamp is to be started, the switch is closed thereby giving a step-up ratio to the transformer so that if a 110 volt alternating current is obtained from the supply 60, the output of the transformer will be 220 volts with switch 82

closed. After the lamp has started, however, in the manner hereinbefore described, switch 82 may be opened so that the right-hand portion of the transformer 62' operates as a ballast impedance for the lamp, and this enables the primary current to be cut in half so that it is no greater in magnitude than the arc current, whereas without the use of switch 82, as in the arrangement of Figs. 7 and 8, the primary current is twice the arc current since the step-up transformer of these figures is always in the lamp circuit.

The arc lamp of the instant invention may also be used with a direct current source of power, in which case one of the electrodes always operates as an anode. The anode may comprise a plate, rod or other known anode construction and, in fact, may be a solid copper rod which is of such construction as to prevent overheating and vaporization at the point of arc contact. Fig. 11 shows a starting and running circuit for a direct current lamp. When the line switch 85 is closed, current is applied from the supply line to a circuit which includes a choke coil 86 and the starting vacuum switch 65. Current flows momentarily through the circuit and the armature 66 of the vacuum switch is attracted by the choke coil 86 since the coil has an iron core and an open air gap and hence sets up an external magnetic field, thus opening the circuit through the switch contacts. This collapses the field in the choke coil and causes a potential of 1000 volts or higher to appear across the electrodes 12 and 88 of the lamp and when the gap breaks down due to the voltage surge the lamp then operates across the supply line 85. The flow of the lamp current through the choke coil maintains the switch 65 in open position so long as the lamp is operating. The electromagnets 54' and 55' coact to control the position of the arc stream in the manner hereinbefore described, and the regulating means shown in Figs. 1, 2, 8 and 9 for controlling the spacing between the electrodes may be employed with the direct current lamp except that it will generally be found necessary to advance or retract only the cathode and not the anode.

The light source which, as hereinbefore stated, comprises a very thin metallic film supported by a thin refractory backing of an oxide of the metal, has various unique advantages. Tungsten filament lamps can be made to increase the light emitted by them if they are burned hotter, but this process is limited in the tungsten filament lamp by the melting point of the tungsten, for if it is reached or even closely approached, the lamp quickly burns out. Concentrated arc lamps of the character disclosed herein are not so limited since the incandescent light source is operated at a temperature far above the melting point of the metal.

A second advantage of the concentrated arc lamp is its life characteristics when operating at these high brilliancies. As the temperature of the filament of a tungsten lamp is increased, lamp life decreases because of evaporation of the filament material. Since the metal source of the concentrated arc lamp operates in a molten condition, it might be expected that it, too, would evaporate. Spectograms taken of the portion of the arc stream very near the cathode in zirconium lamps, for example, show the presence of very strong zirconium lines. This indicates that some evaporation of free zirconium occurs and

under the excitation of the arc the characteristic spectrum is emitted.

It is believed that these phenomena are explained as follows: An atom of zirconium gains sufficient energy to leave the cathode surface and enters the cathode glow region of the arc which extends for a few thousandths of an inch from the cathode surface. Here, under the intense ion bombardment, the zirconium atom has one or more electrons knocked off of it, or in other words, it is ionized. In the normal atom, the positive nuclear charge is just balanced by the negative charges of the surrounding electrons so the atom as a whole is neutral. When electrons are removed, as in the ionized atom, the atom is left with a positive surplus and thus has a positive charge and is attracted and drawn back to the negative cathode it just left. If any zirconium atoms do escape permanently from the cathode, they are replaced by reduction of the thin underlying oxide layer.

Reduction of the oxide surface under the action of the arc may be due to one or more causes, namely: (1) thermal decomposition of the oxide, (2) chemical reduction due to the presence of some foreign substances, (3) electrolytic reduction, (4) decomposition due to ionic bombardment.

The concentrated arc lamp emits radiation from two main sources, viz., the white hot cathode surface film and the cloud of excited gas in the cathode glow region which extends for a few thousandths of an inch from the cathode.

From the foregoing it is apparent that the following characteristics of the cathode material are essential to produce the desired results: (1) the formation and maintenance of an incandescent film or pool of a good thermionically emissive metal and possibly including a metallic compound on the active surface area of the cathode when the lamp is operating; (2) directly beneath and supporting the pool is a layer of a compound of the metal, principally its oxide, that has a considerably higher melting point than the metal on the surface; (3) the oxide layer has comparatively low thermal conductivity so that it acts as a heat insulator; (4) the strong electric field established in the vicinity of the cathode causes the surface metal that is vaporized during operation of the lamp to become ionized and positively charged and return to and condense on the cathode surface, thereby renewing the active surface area; and (5) the metal on the active surface area and presumably the vaporized metal recombines with the free oxygen to maintain substantial equilibrium between the active surface film and the underlying oxide.

The oxides of zirconium and hafnium have very high melting points, with their boiling points ranging considerably higher; the melting and boiling points of their base metals are very much lower, zirconium melting at approximately 1900° C. and boiling at about 2900° C., and hafnium melting at approximately 2200° C. and boiling at about 3200° C.

As hereinbefore set forth, an important characteristic of the metal which principally forms the active surface film of the cathode is that it is not a good electron emitter at temperatures substantially below the high operating temperature of the lamp, thereby to prevent the emission of electrons in sufficient quantity to support the high current density arc until the high operating temperature necessary to give a light source of the desired brightness has been reached. If

the metal were a good electron emitter at lower temperatures, the desired high operating temperature and resultant brilliant light source would not be attained.

The diameter of the cathode spot of a given lamp depends upon the current. If the current is increased, its spot grows larger, taking several seconds to adjust itself to the new condition. While the lamps are designed to operate at a definite current value, it is possible to adjust the spot size by changing the current.

With a lamp in accordance with the instant invention, the current flowing through the lamp may be varied to any desired extent and hence any desired degree of light intensity may be obtained without materially changing the color temperature of the lamp. This is because when the current flowing through the lamp is varied, all that happens is that the size of the total light emissive area, and hence the quantity of light output, is changed. Moreover, electrodes in accordance with the instant invention have a useful life of hundreds of hours or longer, which is many times greater than the useful life of a tungsten filament lamp or the carbons of a carbon arc, of the same size, and when an electrode finally is burned down it is a simple matter to insert a new one.

In addition to its use as a highly concentrated uniform light source, the device may also be employed for various circuit functions such as those of a relay, rectifier, voltage regulator, power tube, and the like.

While there are shown and described herein certain embodiments of the invention, many other and varied forms and uses will present themselves to those versed in the art without departing from the invention, and the invention is therefore not limited either in structure or in use except as indicated by the scope of the appended claims.

I claim:

1. An arc discharge device comprising electrode structures operative in a gaseous medium containing a substantial proportion of free oxygen at a pressure sufficiently high to cause the discharge between the electrode structures to assume the shape of a stable concentrated arc, at least one of said electrode structures being operative as a cathode and comprising a mass of cathode material, said cathode material having a restricted fused surface layer formed by an arc of high current density which is concentrated thereon when the device is operating, said fused surface layer comprising a metallic oxide having thermionic emission properties and which is reducible by the action of the arc to form a thin molten incandescent surface film of the base metal when the device is in operation, said oxide layer supporting said molten film and having low thermal conductivity and a melting point above that of said metal for maintaining the temperature of the film considerably above the melting point of said metal, the action of said arc causing a reversible reaction between reduction and oxidation to occur in said surface layer, the mass of cathode material which is beneath said oxide layer comprising particles of said base metal, and means for preventing progressive oxidation of the base metal beneath the oxide layer, said last named means comprising particles of a conductive metallic substance interspersed with said particles of the base metal, said metallic substance being characterized in that it is substan-

tially free from progressive oxidation tendencies at the operating temperature of the device.

2. An arc discharge device comprising electrode structures operative in a gaseous medium containing a substantial proportion of free oxygen at a pressure sufficiently high to cause the discharge between the electrode structures to assume the shape of a stable concentrated arc, at least one of said electrode structures being operative as a cathode and comprising a body containing a mass of cathode material, said cathode material having a restricted fused surface layer formed by an arc of high current density which is concentrated thereon when the device is operating, said fused surface layer comprising a metallic oxide having thermionic emission properties and which is reducible by the action of the arc to form a thin molten incandescent surface film of the base metal when the device is in operation, said oxide layer supporting said molten film and having low thermal conductivity and a melting point above that of said metal for maintaining the temperature of the film considerably above the melting point of said metal, the action of said arc causing a reversible reaction between reduction and oxidation to occur in said surface layer, the mass of cathode material which is beneath said oxide layer comprising particles of said base metal, and means for preventing progressive oxidation of the base metal beneath the oxide layer, said last named means comprising particles of a conductive metallic substance interspersed with said particles of the base metal, said metallic substance being characterized in that it is substantially free from progressive oxidation tendencies at the operating temperature of the device, said cathode-containing body having at least the exposed surface portions thereof composed of a high melting-point material which is substantially free from progressive oxidation tendencies at the operating temperature of the device.

3. An arc discharge device comprising electrode structures operative in a gaseous medium containing a substantial proportion of free oxygen at a pressure sufficiently high to cause the discharge between the electrode structures to assume the shape of a stable concentrated arc, at least one of said electrode structures being operative as a cathode and comprising a mass of cathode material, said cathode material having a restricted fused surface layer formed by an arc of high current density which is concentrated thereon when the device is operating, said fused surface layer comprising a metallic oxide having high electrical resistance and thermionic emission properties and which is reducible by the action of the arc to form a thin molten incandescent surface film of the base metal when the device is in operation, said oxide layer supporting said molten film and having a melting point above that of said metal for maintaining the temperature of the film considerably above the melting point of said metal, the action of said arc causing a reversible reaction between reduction and oxidation to occur in said surface layer, the mass of cathode material which is beneath said oxide layer comprising particles of said base metal, and means for preventing progressive oxidation of the base metal beneath the oxide layer, said last named means comprising particles of another metal interspersed with said particles of the base metal, said another metal being characterized in that it is substantially free from progressive oxidation tendencies at the operating temperature of the

device, said mass of cathode material including said oxide layer having dispersed therein particles of a conductive metallic substance in an amount to facilitate starting the arc.

4. An open-air arc discharge device comprising electrode structures, at least one of said electrode structures being operative as a cathode and comprising a mass of cathode material, said cathode material essentially composed of particles of a metal of the class consisting of zirconium and hafnium and having a restricted fused surface layer formed by an arc of high current density which is concentrated thereon when the device is operating, said fused surface layer essentially composed of an oxide of said metal having thermionic emission properties and which is reducible by the action of the arc to form a thin molten incandescent surface film of the base metal when the device is in operation, said oxide layer supporting said molten film and having a melting point above that of said metal for maintaining the temperature of the film considerably above the melting point of said metal, the action of said arc causing a reversible reaction between reduction and oxidation to occur in said surface layer, the mass of cathode material which is beneath said oxide layer comprising particles of said base metal, and means for preventing progressive oxidation of the base metal beneath the oxide layer, said last named means comprising particles of a metal of the class consisting of platinum, palladium and nickel interspersed with said particles of the base metal.

5. An open-air arc discharge device comprising electrode structures, at least one of said electrode structures being operative as a cathode and comprising a body containing a mass of cathode material, said cathode material essentially composed of particles of a metal of the class consisting of zirconium and hafnium and having a restricted fused surface layer formed by an arc of high current density which is concentrated thereon when the device is operating, said fused surface layer essentially composed of an oxide of said metal having thermionic emission properties and which is reducible by the action of the arc to form a thin molten incandescent surface film of the base metal when the device is in operation, said oxide layer supporting said molten film and having a melting point above that of said metal for maintaining the temperature of the film considerably above the melting point of said metal, the action of said arc causing a reversible reaction between reduction and oxidation to occur in said surface layer, the mass of cathode material which is beneath said oxide layer comprising particles of said base metal, and means for preventing progressive oxidation of the base metal beneath the oxide layer, said last named means comprising particles of a metal of the class consisting of platinum, palladium and nickel interspersed with said particles of the base metal, said cathode-containing body having at least the exposed surface portions thereof composed of a metal of the class consisting of platinum, palladium and nickel.

6. An open-air arc discharge device comprising electrode structures, at least one of said electrode structures being operative as a cathode and comprising a body containing a mass of cathode material, said cathode material essentially composed of particles of a metal of the class consisting of zirconium and hafnium and having a restricted fused surface layer formed by an arc of high current density which is concentrated thereon

when the device is operating, said fused surface layer essentially composed of an oxide of said metal having thermionic emission properties and which is reducible by the action of the arc to form a thin molten incandescent surface film of the base metal when the device is in operation, said oxide layer supporting said molten film and having a melting point above that of said metal for maintaining the temperature of the film considerably above the melting point of said metal, the action of said arc causing a reversible reaction between reduction and oxidation to occur in said surface layer, the mass of cathode material which is beneath said oxide layer comprising particles of said base metal, and means for preventing progressive oxidation of the base metal beneath the oxide layer, said last named means comprising particles of nickel interspersed with said particles of the base metal, said cathode-containing body having at least the exposed surface portions thereof composed of nickel.

7. A cathode structure for a concentrated arc discharge device, comprising a body having an aperture therein containing a tightly packed mass of comminuted metal of the class consisting of zirconium and hafnium having interspersed therewith a smaller amount of a comminuted conductive metallic substance which is characterized in that it is substantially free from progressive oxidation tendencies at temperatures of the order of 3000° C.

8. A cathode for a concentrated arc discharge device, comprising a sintered mass of a comminuted metal of the class consisting of zirconium and hafnium having interspersed therewith a smaller amount of a comminuted conductive metallic substance which is characterized in that it is substantially free from progressive oxidation tendencies at temperatures of the order of 3000° C.

9. A cathode structure for a concentrated arc discharge device, comprising a body having an

aperture therein containing a tightly packed mass of comminuted metal of the class consisting of zirconium and hafnium having interspersed therewith a smaller amount of a comminuted metal of the class consisting of platinum, palladium and nickel.

10. A cathode structure for a concentrated arc discharge device, comprising a body having an aperture therein containing a tightly packed mass of finely divided metal of the class consisting of zirconium and hafnium having interspersed therewith a smaller amount of a finely divided conductive metallic substance characterized in that it is substantially free from progressive oxidation tendencies at temperatures of the order of 3000° C., the proportion of said metallic substance relative to said metal lying within the range of approximately 5% to approximately 40% by weight of the metal.

11. A cathode structure for a concentrated arc discharge device, comprising a sintered mass essentially composed of comminuted zirconium or hafnium, comminuted nickel and comminuted magnetite, in the following relative proportions by weight: 45 to 93 percent of zirconium or hafnium, 5 to 40 percent of nickel, and 2 to 15 percent of magnetite.

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