Jan. 7, 1941. C. W. HANSELL 2,227,829

ARC DISCHARGE CONTROL DEVICE

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Fig. 1

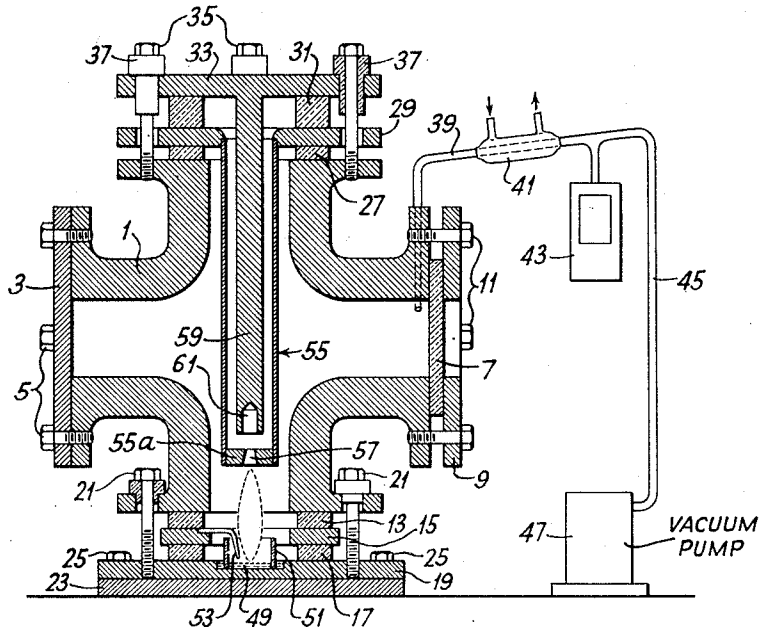
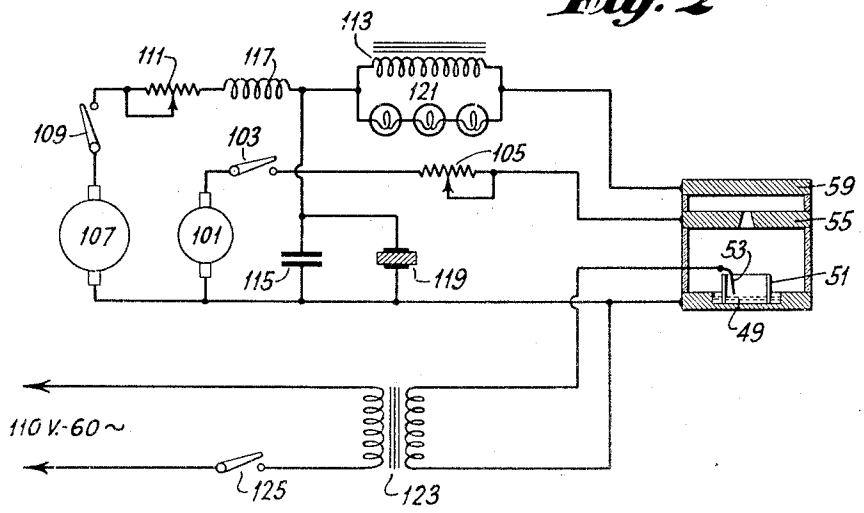


Fig. 2



INVENTOR.
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BY

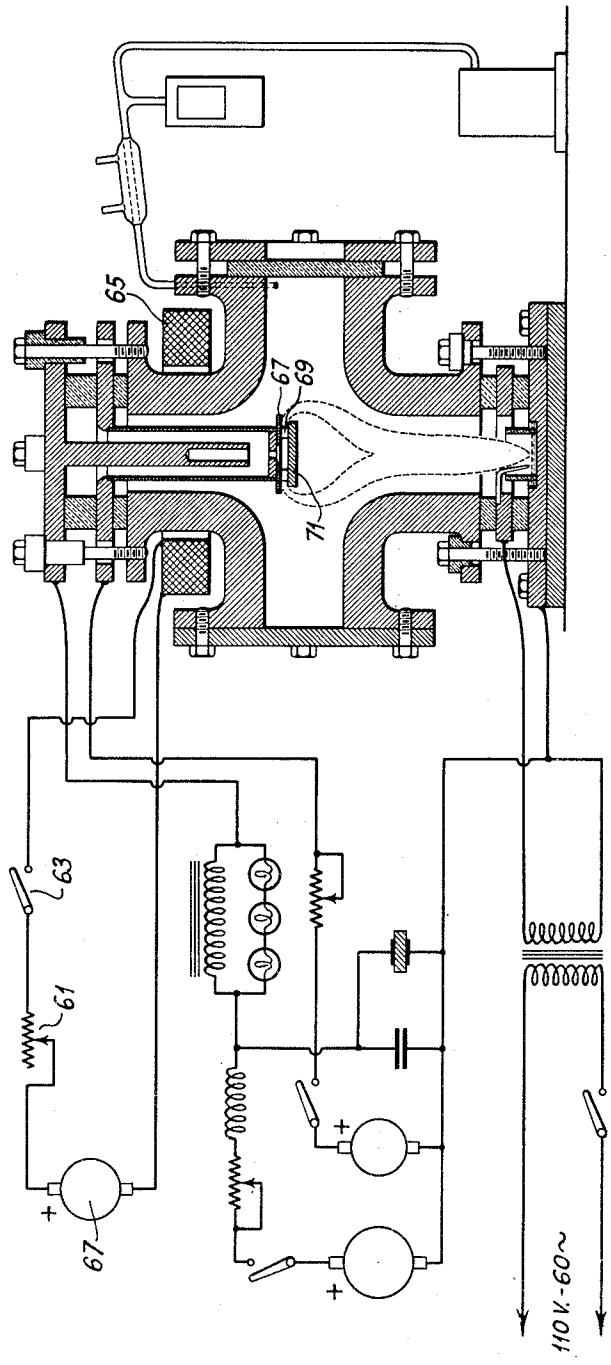
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ARC DISCHARGE CONTROL DEVICE

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Fig. 3



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ARC DISCHARGE CONTROL DEVICE

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Fig. 4

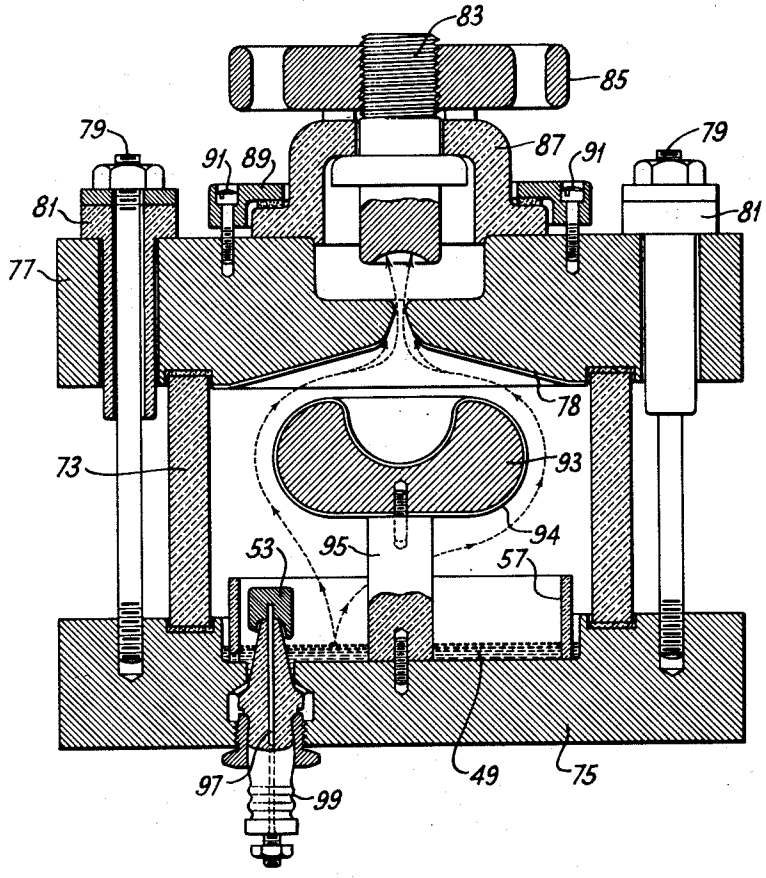
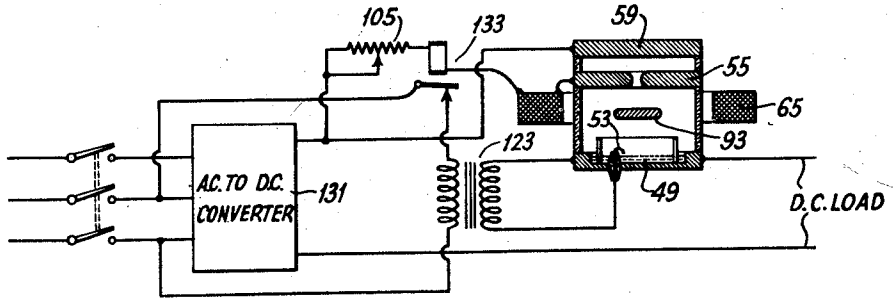


Fig. 5



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ARC DISCHARGE CONTROL DEVICE

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Fig. 6

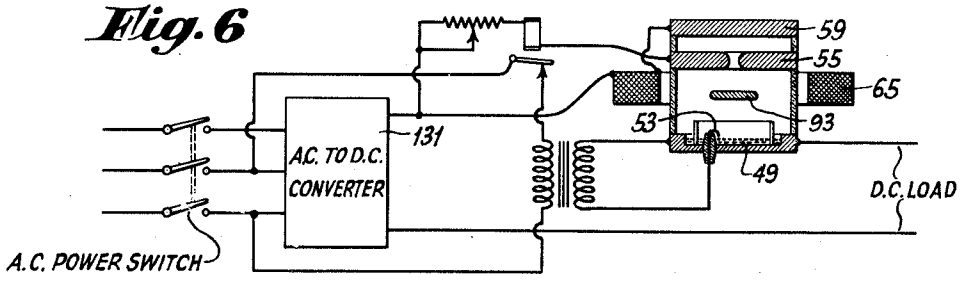


Fig. 7

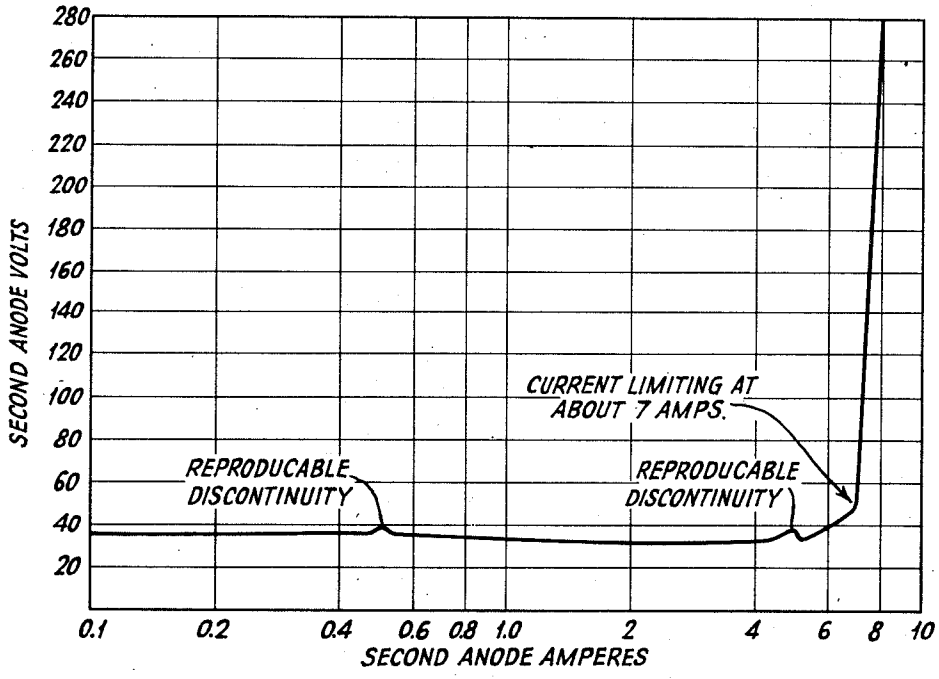
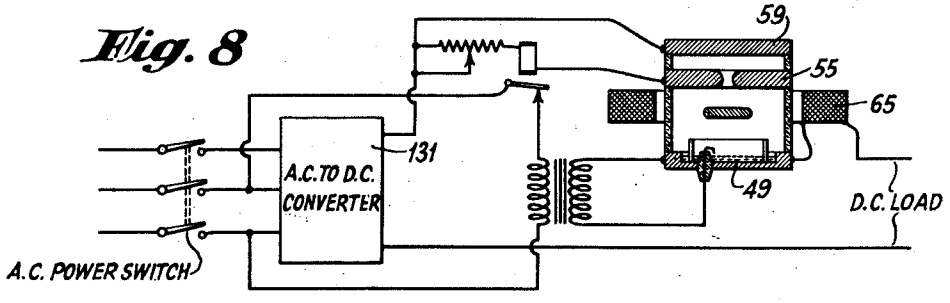


Fig. 8



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Fig. 9

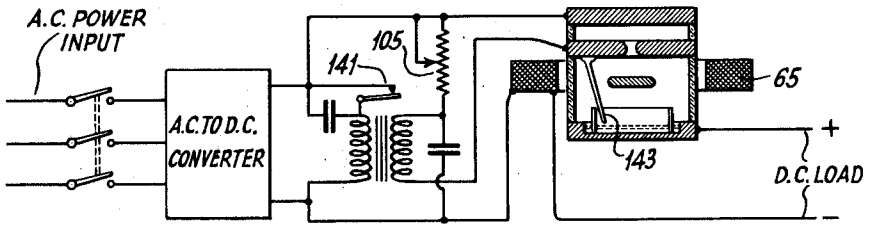


Fig. 10

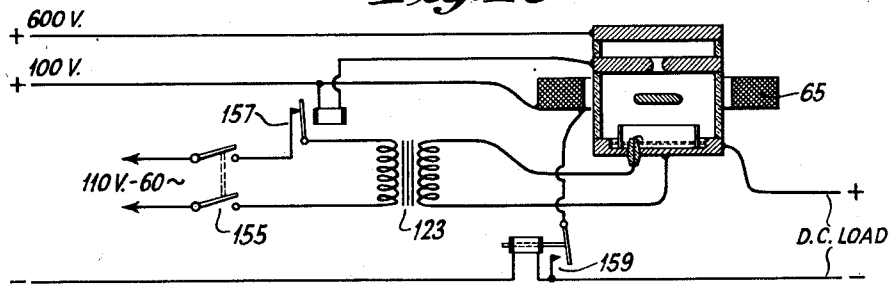


Fig. 11

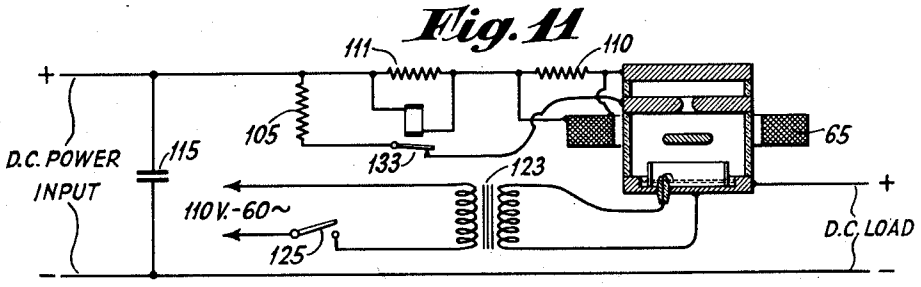
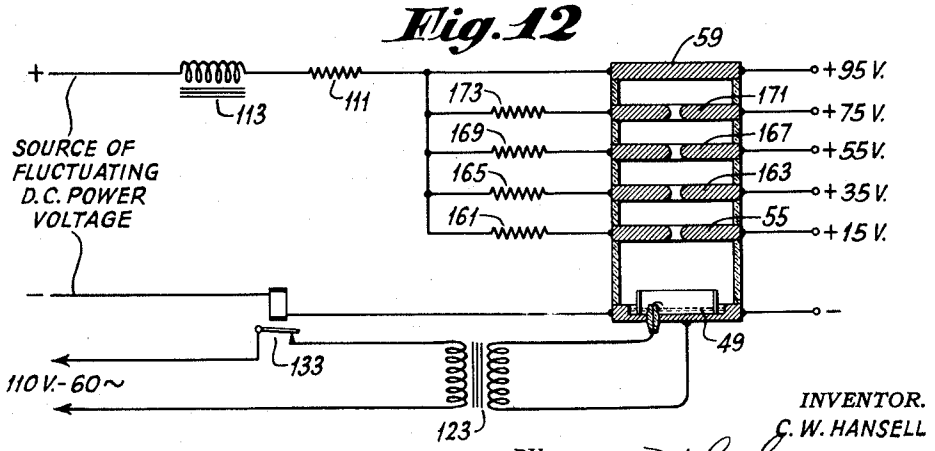


Fig. 12



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ARC DISCHARGE CONTROL DEVICE

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Fig. 13

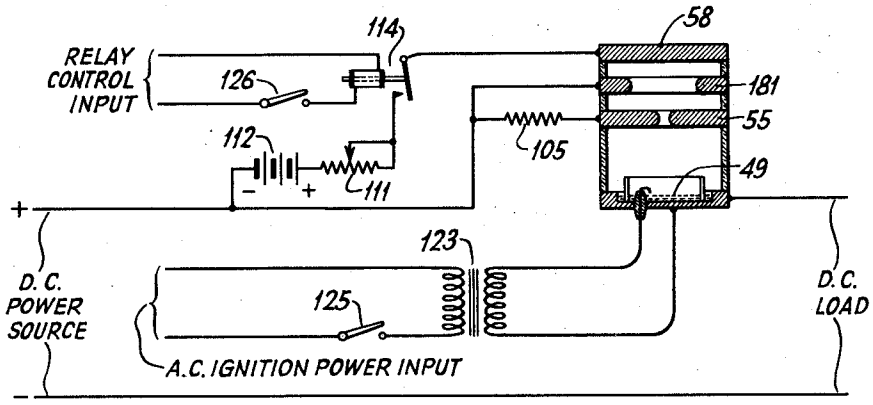
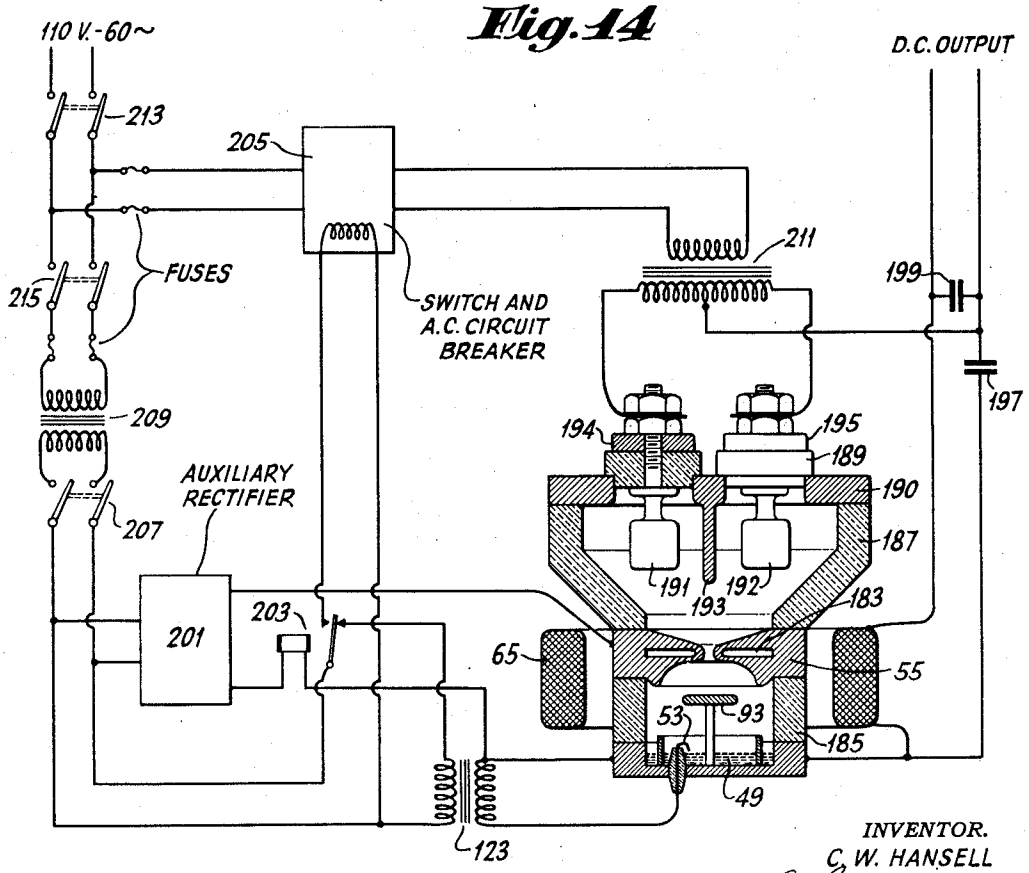


Fig. 14



INVENTOR.
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BY H. S. Grover

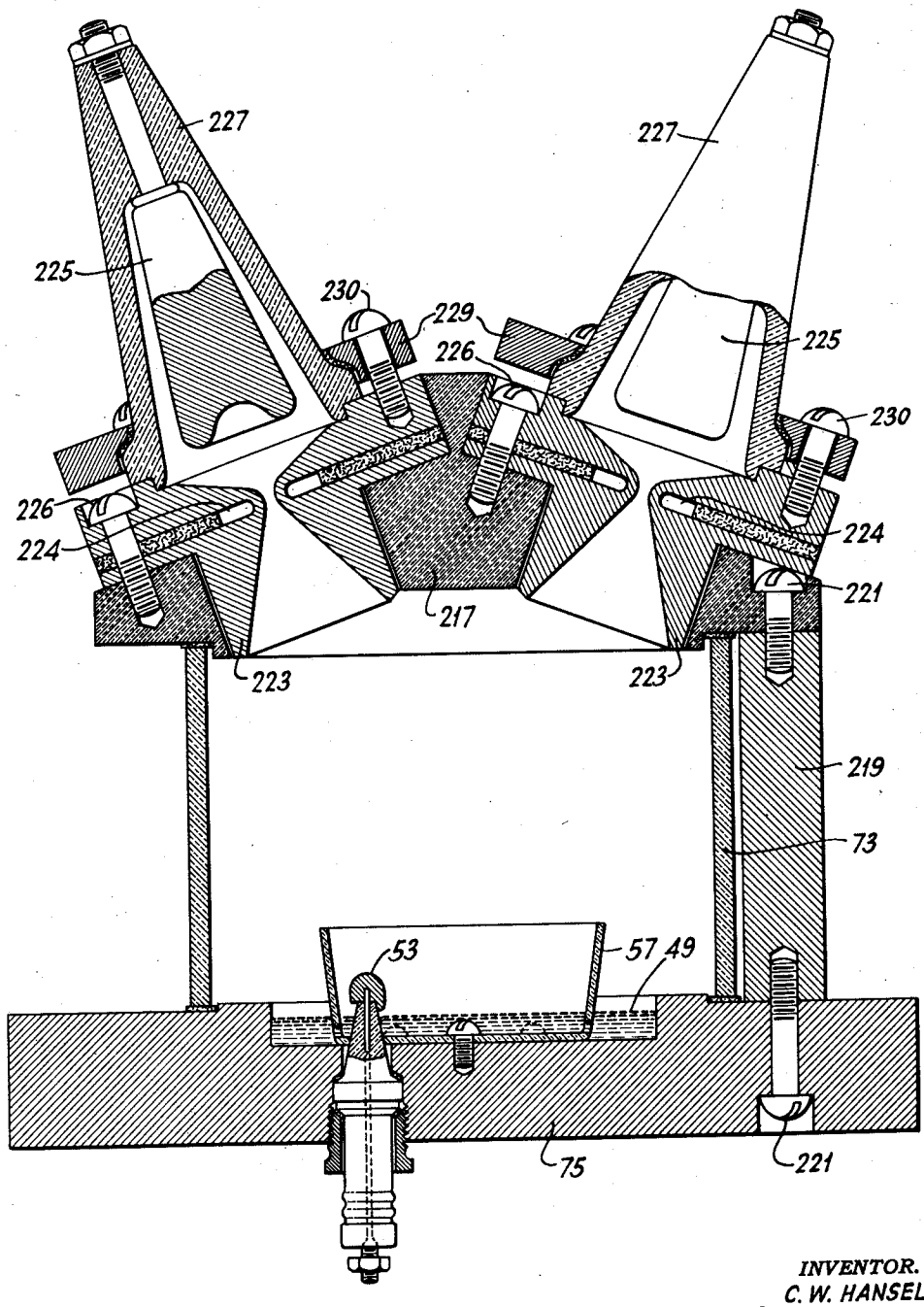
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ARC DISCHARGE CONTROL DEVICE

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Fig. 15



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ARC DISCHARGE CONTROL DEVICE

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Fig. 16

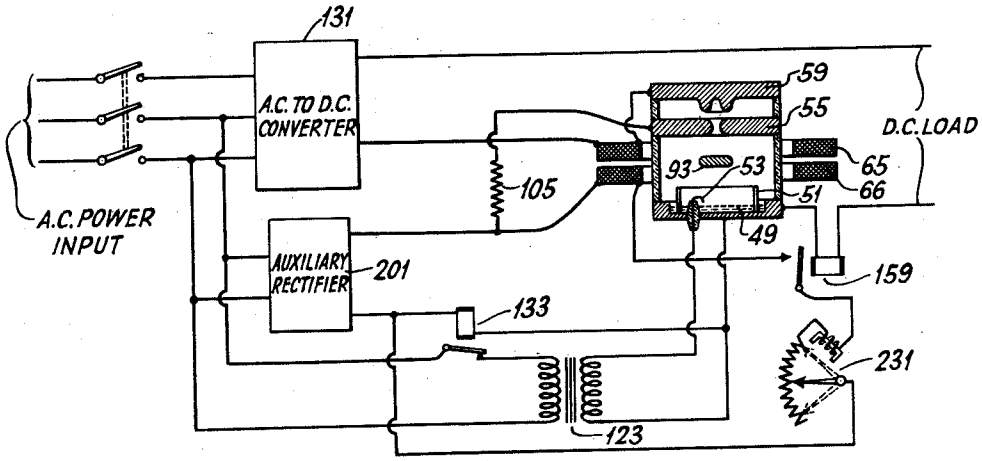
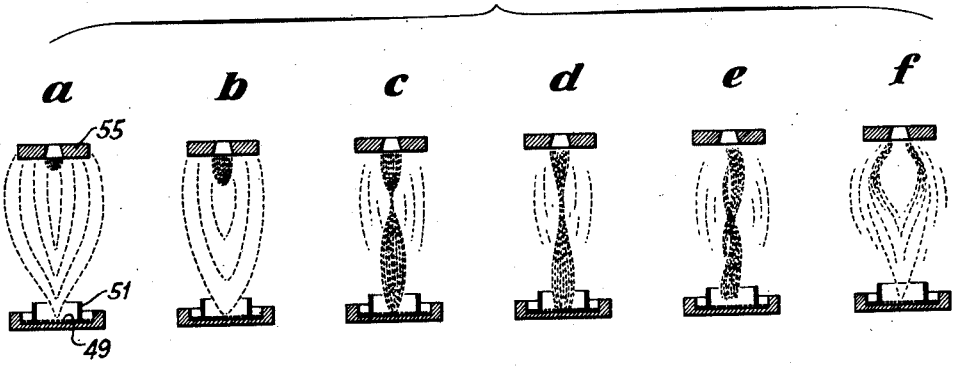


Fig. 17



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Patented Jan. 7, 1941 2,227,829

UNITED STATES PATENT OFFICE

2,227,829

ARC DISCHARGE CONTROL DEVICE

Clarence W. Hansell, Port Jefferson, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application January 7, 1938, Serial No. 183,791

32 Claims. (Cl. 175—363)

This invention relates to electrical arc discharges in low pressure gases and vapors and has for its object the provision of devices suitable for use as relays, switches, controllers, regulators and limiters of electric current. It may be used in connection with both direct and alternating current but is particularly adapted for use in direct current circuits. The invention is based upon studies and experiments with electrical discharges through holes in barriers between chambers containing gas or vapor at low pressure. I have discovered that arcs through holes in metal barriers have peculiar properties not exhibited by ordinary arc discharges and I make use of these properties in my present invention. This discovery was made as a result of my own experiments conducted with electrical vacuum pumps of the general type described in my U. S. Patents #2,022,465, #2,063,249 and #2,063,250 and other devices involving electrical discharges through holes and orifices.

According to my invention two low pressure gas or vapor filled chambers are separated from one another by a metal barrier with a hole in it, one of these chambers being provided with an anode and the other with a cathode. Then, if an arc discharge is established between the cathode and the metal barrier, or first anode, there may also be established a discharge between the cathode and the second anode through the hole in the barrier. The discharge between the cathode and the barrier, which may be considered to be a continuous or holding arc, exhibits the usual low pressure arc discharge phenomena. If the cathode is a mercury pool, for example, the voltage drop between the barrier and the cathode will have a low value of 10 to 20 volts, depending upon the dimensions of the device and, to some extent, upon the vapor pressure. The value of voltage drop remains substantially constant regardless of the current in the arc over a tremendous range of current. In practice, the voltage drop will usually change very little over a range of current as great as 1000 to 1.

The arc from the second anode to the cathode through the hole in the barrier, or first anode, also exhibits a nearly constant arc drop for low values of current but this voltage drop is considerably greater than that between the barrier and the cathode. In practice, I have usually found that the passage of the arc through a small hole in the steel barrier increases the voltage drop for low values of current by about 20 volts.

By placing additional apertured barriers, or barrier anodes, in the path of the arc to an anode, I have found that the voltage drop between anode and cathode is increased by the presence of each barrier. Furthermore, over a large range of currents, the total voltage between any one barrier and the cathode remains almost constant regardless of current flow in the arc and in spite of additional current which may be passed between the barrier and the cathode from some external supply. In other words, over a large range of currents, I may pass any amount of current from any one of the barriers to the cathode in parallel with, and in the same direction as, the anode arc without producing much, if any, change in the voltages from the various barriers and the anode to the cathode. This condition of nearly constant voltage distribution between barriers, anode and cathode holds over a very large range of positive current values. I have also found that the voltage distribution and voltage values are remarkably independent of the gas or vapor density in the path of the arc and substantially unaffected by the pressure variations of a degree common in mercury arc discharge devices.

However, I have also found that if I continue to increase the current in a portion of the arc which passes through a hole in a barrier then, at a critical value of current, the voltage drop in the arc increases almost abruptly and usually an oscillation or fluctuation of current sets in which causes the current to flow intermittently instead of steadily. The critical value of current is dependent upon the shape and size of the hole in the barrier and upon the gas or vapor pressure. It seems to be proportional to the gas or vapor pressure and increases rapidly with increase in the size of the hole but in what proportion I have not yet determined precisely. Very generally, the increase is approximately proportional to the cross sectional area of the hole. With a mercury arc and a conical hole in a 1 inch steel plate, having a minimum diameter of $\frac{3}{16}$ of an inch, limiting has been produced at current values ranging from about 2 amperes to 20 amperes, depending upon the vapor pressure and density. The vapor pressure and density are, in turn, usually dependent almost altogether upon the temperature of the coolest part of the evacuated chamber containing the mercury pool cathode.

It will be noted that the arc discharge through the hole exhibits nearly constant low D. C. voltage drop over all values of current up to nearly the limiting value and then, for the limiting value of current, exhibits nearly constant average or D. C. current for all value of voltage up to the

breakdown voltage of the device and its insulation.

In order that others skilled in the art may be given sufficient information to practice my invention, several specific examples are illustrated in the drawings and will now be described.

In the accompanying drawings, Fig. 1 is a cross-sectional view of a device employing the features and particulars of my invention; Fig. 2 is a wiring diagram of the device and connections therefor; Fig. 3 illustrates a modification wherein a magnetic field coil is employed to produce additional effects and also illustrates a modified form of first anode structure; Fig. 4 is a cross-sectional view of a further modification of my invention which is somewhat more compact; Figs. 5, 6 and 8 to 11 show wiring diagrams for utilizing the device shown in Figs. 3 and 4; Fig. 7 is a graph explanatory of my present invention; Fig. 12 illustrates diagrammatically a further modification of my invention, particularly desirable where several values of fixed voltages are desired; Fig. 13 shows diagrammatically a further modification of my device and its associated wiring diagram; Fig. 14 shows still another modification of my invention employing a fluid cooled electrode and plurality of second anodes to be used for a full-wave rectifier; Fig. 15 is a cross-sectional view of another modification of my invention particularly suited to push-pull or full-wave operation; Fig. 16 shows a wiring diagram for my device utilizing a plurality of magnetizing coils connected in bucking relation; Fig. 17 illustrates the behavior of the mercury arc in my invention under various conditions.

Referring to Fig. 1, which is a drawing of a particular arrangement which I have used, there is shown an outer envelope 1 which is obtained by altering a standard 4 inch steel pipe cross. This pipe cross has four openings. Over one of the openings is fitted a blank plate 3 held in place by bolts 5, and over the diametrically opposite opening is fitted a high temperature glass or quartz plate 7 held in place by steel flange 9 and bolts 11. Over the lower opening is fitted an assembly including insulators 13 and 25, steel ring 15 and steel flange 19, all held tightly in place by insulated bolts 21. An additional plate 23 is provided to serve as a mounting plate and is attached to plate 19 by bolts 25. Over the upper opening is provided insulator 27, a steel ring 29, a second insulator 31 and a flange 33, held tightly in place by bolts 35, which are accurately fitted together and joined by means of gaskets of thin varnished silk, thus making a hermetically sealed container.

The container is evacuated through connection 39, a water cooled condenser trap 41, connection 45 and vacuum pump 47. A mercury vacuum gauge 43 is connected to connection 45.

Held in a depression in flange 19 is a mercury pool 49 to serve as a cathode. Standing in this pool of mercury is a short cylinder of high temperature glass, the function of which is to restrict the arc to the area of the mercury surface within the cylinder. Connected with ring 15 is an arc starter point 53 made of a carborundum compound commonly known as "Thyrite." This point is mounted so that its tip is within about $\frac{1}{8}$ of an inch from the surface of the mercury.

Mounted on steel ring 29 is a first anode 55 consisting of a steel cylinder closed at the lower end with a steel plate 55a. Through the steel plate is a hole 57. Mounted on steel flange 33 is a cylindrical second anode 59, the end of which is located immediately over hole 57. The second anode is drilled at the end as shown at 61. The depth of this drilled hollow may be varied as desired. The function of this hollow is to distribute the power losses at the second anode over a larger area and control the behavior of the arc.

Fig. 2 shows a schematic diagram of the essential elements used in the power and control circuits for demonstrating my invention. A. D. C. generator 101 supplies power through a switch 103 and a current limiting resistance 105 to first anode 55. A second D. C. generator 107 supplies power through switch 109, variable resistance 111 and reactance or choke 117 and load reactance 113 to the second anode 59. A large condenser 115 and a surge arrester 119 are used to keep high frequency and transient currents out of the generator circuit. A load resistance consisting of incandescent lamps 121 is connected across reactor 113.

For starting the arc, a transformer 123 is provided which is supplied with 60 cycle, 110 volt A. C. power through push button switch 125. The transformer, which is of the type commonly employed in oil heating plants for electric ignition, develops an open circuit A. C. voltage of about 15,000 volts but is designed to have a high leakage reactance and secondary resistance so that secondary current is always limited to a low value. A transformer for neon lamp excitation has similar characteristics and could as well be used. The secondary winding of the transformer is connected between steel flange 19 of Fig. 1 and steel ring 15 and through these applies the 15,000 volts starting potential across the small gap between the starter point 53 and mercury pool 49 within the isolating cylinder 51. By applying potential to first anode 55 and then momentarily energizing transformer 123 by closing switch 125, it is possible to start an arc between the first anode and the mercury path. This arc will continue indefinitely and is the means for maintaining continuous ionization in the chamber between the first anode and cathode.

By closing switch 109 a current can be drawn through the hole 57 to the second anode 59. This current can be varied at will by varying the value of resistance 111 and the voltage of generator 107 from a value of a few milliamperes up to a critical limiting value ranging from 1 to 50 amperes in one particular case, depending upon dimensions of the hole 57 and the gas or vapor pressure in the vicinity of the hole.

After the critical or limiting value of current is reached any further attempt to increase the current results substantially in only increasing the voltage drop between the mercury pool cathode and the second anode. Fig. 7 is a typical current versus voltage characteristic of a mercury arc through a hole, measured with the arc discharge device and circuits illustrated in Figs. 1 and 2. The hole in the first or barrier anode was tapered, with a $\frac{1}{8}$ inch minimum diameter at the end nearest the second anode. The cup in the second anode was 1 inch in diameter and 1 inch deep. The small increase in current with increasing voltage after limiting in Fig. 7 is believed to be due to increasing vapor pressure, taking place during measurement, rather than to an inherent characteristic of the arc. At any rate, other measured characteristics have given both slightly increasing and slightly decreasing current with increasing voltage after limiting.

I have found that, if the average or D. C. voltage drop exceeds about 50 or 60 volts, the cur-

rent through the hole in the barrier anode to the second anode oscillates or is subject to intermittent interruption. In the presence of a holding arc to the barrier anode continuous oscillations in second anode current may take place during current limiting. In the absence of a holding arc the first interruption or oscillation of second anode current interrupts the arc permanently unless the arc is restarted. Such an arrangement, in series with a power circuit, will act as a quick break instantaneous circuit breaker to interrupt any current which reaches the limiting value.

I have also found that if I place a coil of wire around the arc discharge device shown in Fig. 1 and energize the coil with direct current in such a way as to set up a magnetic field approximately parallel to the arc path from the cathode, through the hole to the anode, I can produce a very pronounced but controllable lowering of the value of current which causes limiting and if the magnetic field is strong enough, I can interrupt the anode current by means of the magnetic field. So far as I know, this is the first case on record where a mercury arc current, at ordinary pressure, has been controlled by means of a magnetic field. Since the strength of field required was quite moderate I believe the magnetic field control of an arc, which I have found, as well as the circuit interrupting properties of arcs through holes, without a magnetic field, may have very important practical applications.

Fig. 3 shows a modification of the device and circuits of Figs. 1 and 2 in which a magnetic field coil **65**, and the source of controllable current **67** for energizing it is added. The electrodes are shortened to facilitate observation of the arc through the high temperature glass window in one arm of the cross-shaped vessel. The barrier or first anode is insulated by means of a glass tubing slipped over it and a ring-shaped glass plate **67** placed over the end, so that the arc to the first or barrier anode is forced to terminate near the hole. An insulated steel arc deflector **71** is also suspended upon insulated posts **39** under the hole in the barrier electrode as shown. With this arrangement the arc from both anodes to the mercury pool cathode is forced to travel over a radial path near the hole in a region where an intense magnetic field can be produced. With this arrangement the anode current can be cut off much more easily and held cut off more easily than without the deflector. I was able to cut on and off an anode current of as much as 40 amperes from a 400 volt source with this arrangement with a moderately strong magnetic field. As a further modification of this figure, a $\frac{1}{16}$ inch hole may be drilled in the center of the steel deflector plate **71** to allow a small stream of electrons to shoot up through the hole in the deflector and the cathanode. The small stream of electrons keeps ionization alive near the anode and makes it much more difficult to hold the anode current cut off. Without this hole, after the anode cuts off, it stays cut off until the arc to the steel plate expands over the edge of the plate.

When the anode current is cut off the small stream or pencil of electrons passing through the $\frac{1}{16}$ inch hole in the steel plate, and up through the cathanode hole, is clearly visible.

With this and similar arrangements all of the phenomena described here in connection with arcs through holes and with the whirling arc have been demonstrated and the behavior of the arc has been observed directly.

I have found that the voltage drop between a cathode and the barrier is substantially unaffected by the magnetic field which, I believe, is in accordance with the common experience. It might also be assumed that a magnetic field parallel to the arc path through the hole in the barrier should have no effect upon the voltage drop through the arc since a current parallel to the magnetic field made up of electrons and ions moving parallel to the field would not be influenced by the field. The observed strong influence upon the arc, therefore, requires explanation.

In observing arcs through holes and barriers, I have noted that on the cathode side of the barrier the arc seems to be in the form of a white cone or flame having the apex of the cone in the hole in the barrier. Applying a magnetic field spreads out the base of the cone and, applying a stronger field, often makes it suddenly flatten out into a disc near the barrier and extinguish itself. There must, therefore, be a converging of current toward the hole so that there is a considerable radial component of current flowing from outside toward the axis of the arc, or vice versa, depending upon the conception of direction of current flow. (The conventional assumption of current flow is contrary to the physical motion of electrons constituting the bulk of the current.) This radial component of current flows at right angles to the magnetic field and the electrons and ions constituting the current are deflected by the field in a direction at right angles to their normal path. As a result the magnetic field tends to whirl the electrons and ions around the axis. Molecules present in the space are also carried around in the whirling motion and this results in a low pressure whirlwind centering on the axis of the arc and ending at the hole in the cathanode. This has several effects as follows:

1. The whirling electrons are thrown away from the axis of the tube by centrifugal force and the force of the magnetic field and, when the field is strong, only a few electrons travelling the whole distance from cathode along the axis of the tube can reach the hole in the cathanode. This phenomena is somewhat analogous to the whirlpool in the drain hole of a bath tube when water is being drained from the tub. It is a common observation that the whirling, through centrifugal force, slows up the rate of flow through the drain.

2. The whirling ions and molecules also are thrown away from the axis of the tube by centrifugal force and a relatively high vacuum is created along the axis of the tube and at the cathanode hole. Reduction of ionization near the hole resulting from the decreased pressure prevents neutralization of space charge drop near the hole and substantially reduces or prevents electron current to the hole and the anode.

3. The spiral path followed by the electrons in travelling toward the hole in the cathanode and the slowing up of radial velocity due to the magnetic field greatly increases the electron space charge in the vicinity of the hole and this causes a high space charge voltage drop in the current to the anode.

4. In one form of tube used the cathode hole is in the form of a relatively long but narrow slot. Electrons approaching the hole are necessarily possessed of a considerable component of velocity at right angles to the normal arc path and con-

sequently tend to strike the walls of the slot instead of passing through to the anode.

5. The whirling gas acts like any other rotating conductor in a magnetic field and produces a counter electromotive force due to the rotation which tends to reduce or stop the current. In the complete absence of friction (an impossible case in a practical instance) the velocity of rotation of the whirling gas is limited only by the velocity needed to produce an electro-motive force equal to the applied voltage. In a practical case high velocities of rotation may be expected. In general, the velocities of rotation would be roughly inversely proportional to the degree of ionization and proportional to the square of the voltage gradient or voltage drop in the whirling portion of the arc.

In the presence of a holding arc to a barrier, unless the field is made very strong, the arc, through the hole, after being extinguished, restrikes through the hole and the whole process is repeated over and over again. If the holding arc to the barrier is removed by opening the source of direct current to it before the magnetic field is applied, then the application of a strong magnetic field will extinguish the anode current through the hole and it will remain extinguished permanently until restarted.

These observations of the operation and behavior of the arc, and theory, indicate that there is a radial concentration of current in the arc as we approach the hole from the cathode side. This radial concentration gives us a radial component of current which cuts across the magnetic field and is, therefore, acted upon by forces tending to move the conductor at right angles to the field. This gives a whirling motion of the vapor around the axis of the arc through the hole. The whirling, due to centrifugal force, reduces the vapor and electron density along the axis of the arc and in the hole. Reduced electron and ion densities require higher velocities for a given current and the higher velocities increase the rate of whirling and force the arc to spread out into a broader cone. This, in turn, increases the radial component of current, lowers the electron and ion density near the hole still further and increases the velocity and spread of whirling near the hole. The whole process tends to be regenerative so that, in one design of the device, as the magnetic field is slowly increased, the arc through the hole continues to be relatively unaffected until a critical value of field is reached, at which the whirling suddenly becomes unstable or regenerative and the arc is suddenly extinguished by a scarcity of gas or vapor to maintain ionization in or near the hole. Likewise, I have found that, if the arc is started through the hole and the arc current is kept small, while the magnetic field is on, the arc may continue indefinitely. However, if we increase the current in the arc we thereby increase the whirling and eventually, at a critical maximum value of current in a constant magnetic field and with constant vapor pressure, the arc will suddenly extinguish itself. The critical value of current depends upon the dimensions of the device the vapor density and strength of the magnetic field. Assuming a constant temperature or pressure regulated device of fixed dimensions, the critical value of current at which the arc extinguishes itself is dependent only upon the strength of the magnetic field and is substantially inversely proportional to the strength of the field.

One long felt need in connection with all kinds of rectifiers, for converting alternating to direct current, is a device for use as a switch and circuit breaker for the direct current outputs of the rectifiers. At present neither low voltage, high current nor high voltage low current rectifiers are ordinarily provided with circuit breakers in their direct current output circuits. One reason for this is that direct currents are very hard to interrupt by means of ordinary circuit beakers. In alternating current applications circuit breakers work fairly well because the current goes through zero twice per cycle and can be prevented from building up again, after going through zero, by providing for rapid deionization. In the case of direct currents the current does not oscillate above and below zero and deionization is far more difficult to accomplish. Direct currents may be controlled in a device of the present invention with the magnetic field producing the whirling arc in the manner described.

It will be noted that the regenerative tendency in the whirling of the arc gives the cut-off of anode current a suddenness and positiveness or "snap-action" equivalent to the effect sought deliberately in relays, quick break switches, thermostats, etc. It is very desirable in an arc discharge device which might be used as a controlled circuit breaker, automatic overload circuit breaker or equivalent of an instantaneous fuse. The arc in such a device has either a very low resistance or infinite resistance and a rapid transition from one condition to the other. Due to the rapid transition from low resistance to open circuit, the speed of which increases with increasing current, heating of the device is kept small and it can interrupt relatively enormous amounts of power without damage to itself.

In practice, if there is no holding arc to the barrier, the arc to the anode, after extinguishing itself, remains extinguished. I have also found that, with a suitably designed device, if the magnetic field is made strong enough the field can be applied, or increased, to cut off the anode current and the anode current will remain cut off even though there is a continuous holding arc to the barrier. To obtain this condition it is necessary that the holding arc, or a portion of it, be made to follow a more or less radial path terminating near the hole in the barrier. This is the purpose of the insulated deflecting discs 67 and 71 shown in the modification of Fig. 3. Then the holding arc current can produce enough whirling to maintain such low vapor pressure at and near the hole that, once the anode arc is extinguished, it cannot strike through again. With this arrangement we may start the anode current again at will by reducing momentarily either the magnetic field or the holding arc current.

I have also found that, with the arrangement just described, I can either start or stop the anode current by setting the magnetic field at a suitable constant value and then varying the arc current to the barrier. A high barrier arc current will extinguish the anode current and a low barrier current will permit it to strike through again. In some cases, due to the whirling added by the anode current itself, I have found that the anode current can be made to start and stop itself repeatedly. In other cases, where the anode current is not great enough to start and stop itself, a surprisingly small percentage variation in the barrier arc current can be made to control the anode current. In other words, the device

can be made to show a tremendous power amplification or ratio of controlled power to control power. Since both the barrier current and the anode current add to the whirling of the arc, there is a sort of regeneration in the control of the anode current by means of the barrier current.

Fig. 4 shows an alternative form of construction for a whirling arc type of tube which is more compact than that of Figs. 1 and 3. In this modification the body is formed of a cylinder 73 of a high temperature glass. At the lower end of the cylinder steel plate 75 is provided. This plate has a hollowed out portion to contain the mercury pool cathode 49. At the upper end of the body 73, is provided steel plate 77 which serves as the first anode; plates 75 and 77 are clamped together by means of bolts 77. These bolts are insulated from plate 77 by means of insulators 81. The inner surface of plate 77 may be coated with a porcelain enamel insulating coating 78. This enamel may be of the type commonly used for bath tubs, wash bowls and kitchen utensils. To the top surface of plate 77 the second anode insulator 87 is attached by means of flange 89 and screws 91. The second anode 83 is clamped to the insulator 87 by means of anode 85. This anode is made rather large in diameter and is provided with fins to increase its heat radiating ability. In this modification the arc deflector 93 is attached by means of an insulating bolt 95 to the lower plate 75. The arc deflector is preferably of magnetic material, such as iron or steel and is coated with a porcelain enamel insulating coating 74 of the same type as used on the first anode 77. The starter electrode 53 is supported by rod 98 which passes through an insulator 99 fastened through a hole in plate 75. The depression shown in the top of the arc deflector and the insulation on it serve to reduce losses and heating due to high velocity ions pulled through the hole in the barrier anode. Under some conditions, particularly when the current through the hole to the first anode is being interrupted, bombardment of the arc deflector may be quite severe. The arc deflector is not at all essential in connection with my invention but it does give a greater sensitiveness or ease of control by restricting the arc path, making the path more nearly radial, intensifying the magnetic field in the arc restricted path and reducing circulation of vapor which would tend to prevent establishing a high vacuum in the hole.

I have not shown the magnetic field coil in Fig. 4 but its presence encircling the axis of the device should be assumed. It should also be assumed that the electrodes may contain passages for the circulation of a cooling liquid, as shown in subsequent figures, and that the temperature of the liquid may be controlled with a thermostat and radiator of the type commonly used in automobiles, or of any other suitable type.

Fig. 5 shows one of many possible circuits for using my arc discharge device. In this case, it is shown in a circuit for controlling the direct current output of a converter for converting alternating current power into direct current power. This converter may be a rectifier, a motor generator or rotary converter.

The arrangement shown includes a high voltage transformer 123 and spark gap ignition of the arc with a relay 133 for removing the ignition current as soon as the arc to the barrier anode is started. However, the ignition current may be left on continuously in a suitably designed system if desired. The current to the barrier anode flows through a rheostat 105, for adjusting the value of current to the magnetizing field coil 65, through the arc to the cathode and then out through the load and back to the source. The main anode current passes through the arc through the hole in the barrier, to the cathode, out to the load and back to the source. If the load is one which may be completely interrupted at times a small load current obtained by shunting a resistance or some local apparatus across the output circuit may be desired in order to keep the arc going continuously, but it is not essential.

With the arrangement of Fig. 5, the normal direct current can flow out through the load uninterruptedly and with relatively small voltage drop in the arc. However, if a short circuit occurs in the load, the whirling of the arc increases momentarily and interrupts the main arc current. In many cases, short circuits are only momentary, particularly if they occur in some branch line which is itself equipped with circuit breakers or fuses and, after interruption, the load is fully energized by the arc starting through the hole again. Thus a momentary short circuit causes only a momentary interruption or reduction of power.

If the short circuit is permanent, the arc through the hole will repeatedly strike through and then extinguish itself almost instantly thereafter so that only a small average short circuit current can flow and no damage results. The whirling arc device protects itself from damage even on short circuit because, as previously pointed out, it has either a very low or very high resistance with rapid transition from one condition to the other so that high average power loss in the device is impossible. A condenser connected across the load circuit and series reactors may be desirable in some cases for smoothing out pulsing currents into a short circuit or low resistance load and for holding down peak currents through the arc.

In the arrangement of this figure it is possible, by adjusting the temperature of the arc discharge device and by adjusting the rheostat 105 to cause current limiting at any desired value of load current. If, for example, the full load current is 1000 amperes, then the arc discharge device may be set to start limiting at this value and the power source will be automatically protected from overloads.

Fig. 6 is another circuit modification in which the field coil is connected in series with the main anode and the load. In this arrangement the simultaneous increase in magnetic field and arc current through the hole with increasing load gives a sharper cut-off or limiting adjustment which is less dependent upon temperature and vapor pressure in the device. The reactance of the field coil also tends to reduce rapid fluctuations in load current.

Fig. 8 is a further modification in which the field coil is in series with the connection to the cathode so that it carries all of the load current. If desired, two field coils having different numbers of turns and size of conductor might be used in series with the connections to the two anodes instead of a single coil in the cathode circuit.

Fig. 9 is a modification having a vibrator induction coil 141 for arc starting. In this arrangement, as soon as power is thrown on, the vibrator operates until an arc is started to the barrier anode after which the current to the barrier anode through one coil of the vibrator holds

the vibrator contact open. The starter point 143, in this case, is mounted directly on the barrier anode. It should preferably be made of a high resistance material such as baked graphite and clay or a carborundum compound, such as "Thyrite." In this figure the magnetic field coil is shown in series with the negative return lead of the load. This gives a similar effect to that in the modification shown in Fig. 8 where the field coil is in series with the cathode.

Fig. 10 shows another arrangement for utilizing my arc discharge device as a current limiter and overload circuit breaker. In the arrangement shown, if we close switch 155 to the 110 volts, 60 cycle power supply, the arc is started automatically and power delivered to the load. The relay 157, which is connected in series with the barrier anode, removes the ignition potential as soon as the arc is started. In case of overload or short circuit in the load circuit a relay 159 in the ground or negative return lead operates and energizes field coil 65 and interrupts the current. Depending upon the type of relay used the interruption may be momentary or permanent. Also relays may be used to give various numbers and spacings of reclosings followed by lockout if the short circuit persists, or by cancellation of timing sequence arrangements if the short circuit is cleared and locked out. Such arrangements are well known in the power industry. In this arrangement we may use the arc device as a direct current switch by adding manually or remotely operated switches or relays for applying and removing the field coil energization.

Fig. 11 is a further modification in which ignition is applied manually by means of push button switch 125 and the connection to the barrier anode is opened by means of relay 133 as soon as the arc from the anode through the hole is established. The field coil 65 in this modification is connected in series with the second anode supply lead. Resistance 110 and 111 are connected across the field coil and the relay, respectively, in order to protect them against overvoltage and/or heavy current flow. By adjusting the number of turns in the field coil 65 or by varying the shunt resistance 110 the tube may be made to limit the load current to any desired value. In the arrangements in this figure an overload or short circuit interrupts the load permanently until the circuit is re-established by applying the ignition power manually.

Fig. 12 shows another arrangement of my device with a plurality of series barriers 55, 163, 167 and 171, each having a hole therethrough in which an arc may be established. With this arrangement a series of differently regulated power voltages may be obtained. The arrangement may serve as voltage divider, voltage regulator and as a group of condensers of extremely large capacity for bypassing A. C. compounds of load on the various voltage taps. My device gives control of the various voltages through a choice of hole dimensions, as well as choice of gas and electrode material, and is capable of handling relatively high power. The resistances 161, 165, 169 and 173 shown connected in series between the positive power source and the barrier anodes should preferably be tungsten filaments, such as lamps, operated at a moderate temperature, so that their values of resistance will increase with increasing current and reduce the effect of voltage variations of the power source.

Fig. 13 shows an alternative form of control device in which two anodes have their currents passed through a hole in a barrier. One of these anodes 58, which may be called a control anode, provides straight path for the arc through the hole. The other anode 181, which may be called the controlled anode, requires a curved arc path between itself and the hole to the cathode. In the absence of limiting the arc to the controlled anode 181, has no difficulty in following a curved path in the ionized gas or vapor. However, in the presence of limiting with accompanying low gas or vapor pressure and insufficient ionization the arc cannot follow a curved path readily. Consequently, applying or increasing the current and voltage on the control anode can decrease or cut off the current from the controlled anode. This action is improved by the presence of a magnetic field parallel to the axis of the hole, which may be supplied in any of the ways shown in the previous figures.

In this figure I have shown manual arc starting by means of push button 125 and manual control of relay 114 by means of the switch 126 for applying or removing the controlled anode current for controlling the operation of the device.

Fig. 14 illustrates an application of my invention to a single phase full wave rectifier. I have shown a rectifier having a liquid mercury cathode 49, cathode insulator 185 and a spark gap arc starter 53. The first or barrier anode 55 is provided with water cooling passage 183; the water supplied to the cooling passage should preferably be temperature controlled. The anode mounting plate 190 is insulated from the barrier anode 55 by means of insulator 187. Through apertures in plate 190, anodes 191 and 192 are mounted by means of insulators 189. The anodes are clamped to this insulator by means of nuts 194 and 195. A barrier 193 is provided to isolate the two anodes. A magnetic field coil 65 is provided for establishing an axial magnetic field, more or less parallel to the arc as described in previous modifications. In the particular circuit shown the field coil is in series with the direct current output circuit of the rectifier to make it serve both as an arc controlling means and as a reactor for a smoothing filter to take out voltage ripples. Power is supplied to the rectifier through transformer 211 which is connected to the main power line through switch and circuit breaker 205 and disconnect switches 213. I have shown condensers 199 and 197 across the output circuit on each side of the field coil to further improve the smoothing. In addition, the condenser nearest the rectifier improves the regulation or constancy of output voltage with variation in load by facilitating the flow of high peak currents through the arc. The other condenser may also serve to bypass A. C. components or fluctuations in load current. In this modification I have indicated an auxiliary rectifier 201 for maintaining an arc to the barrier anode and a relay 203 with its coil in series with the connection to the barrier anode for removing the ignition power after the arc is established. This same relay controls operation of the main rectifier switch and circuit breaker so that anode power is applied only while the arc is established to the barrier anode. The auxiliary rectifier and ignition transformer are supplied from the main A. C. input lines through disconnect switch 215, step-down transformer 209 and control switch 207. In operation of the device it is only necessary to close the control switch 207 to start up the whole rectifier and to open the same switch to close it down.

The rectifier is self-protected against overloads

and short circuiting in the output because, if the average or D. C. current through the hole in the barrier and through the field coil becomes too high limiting sets in automatically due to the whirling arc and current limiting phenomena at the hole in the barrier or first anode 55, as previously described.

Fig. 15 shows, in cross section, another form of current limiting rectifier in which each of two main anodes draws current through individual holes in a barrier anode. In this modification the mercury pool cathode 49 is contained in a depression in the base plate 75. The body 73 is formed of a cylinder of high temperature glass such as "Pyrex." The first or barrier anodes 223 are clamped by screws 226 to the barrier anode support 217 which may be made either of metal, such as steel, or of insulating material. The barrier anode support 217 and base plate 75 are clamped together by means of screws 221 which screw into insulator posts 219. To the barrier anode structures are clamped anode supports 227 by means of clamping rings 229 and screws 230. These anode supports, each of which are in the shape of a hollow cone of insulating material, such as porcelain, have the anodes 225 clamped thereto by bolts passing through the small end. The barrier anodes 223 are shown supplied with water cooling passages 224 for the purpose described in the description of Fig. 14.

In this modification if the holes in the barrier anodes 223 have a suitable size and the temperature and pressure of gas or vapor are properly controlled, such as by means of the water passages shown, this rectifier is self-protected by virtue of simple limiting of the type indicated in Fig. 7, although, if desired, a magnetic field may also be used to assist in controlling the limiting point as shown in Fig. 14. Although the device shown in this figure is used for a rectifier it may also be used as a push-pull type of oscillator for converting direct current into high frequency alternating current power.

Fig. 16 shows a modification of Fig. 6 employing two field coils for producing a magnetic field parallel to the axis of the electrodes and the arc. Each of these coils are so designed that the normal maximum current is much larger than necessary to cut off the anode current. As shown in the figure, the anode to cathode path in the whirling arc tube is connected in series with the direct current output leads of rectifier 131 and in series with field coil 65. By means of the magnetic field established by coil 65 the load current from the rectifier through the tube to the direct current load is held to a relatively low value which can be tolerated continuously. In a rectifier designed to deliver, say, 1000 amperes at 600 volts, the field coil might be designed to limit the load current to 10 amperes, or less.

Assuming, now, that the rectifier is operating the series field coil 65 will then substantially prevent the flow of load current. In order to permit the normal load current to flow a second field coil 66 is provided which is energized from an auxiliary rectifier 201. This field coil is energized in a direction to oppose the magnetic field of the first coil. The higher the current is raised in the opposing field the higher will be the load current drawn from the rectifier up to a point where the current is limited substantially only by the resistance of the load. This is the normal operating condition. If the load resistance then changes to cause an overload the balance between the field coils will be disturbed and the current will then be limited by the drop in the tube to nearly the normal full load value. If, on the other hand, the load resistance increases, thus lowering the load current, the tube will begin to limit its current and effectively disconnect the rectifier 131 from the load. The current of the bucking field coil 66 must then be reduced to allow load current to flow again. Thus it will be seen that the system shown in this figure may be adjusted manually for minimum voltage drop in the tube for any normal load value and will automatically cut off the load if anything happens to disturb the load current too much in either direction, that is, if the load current is either increased or decreased excessively.

In this figure I have also shown an automatic arc starting system using the ignition transformer 123 and its control relay 133, as shown and more fully described in the description of Fig. 5. Automatic overload interruption of the bucking field coil current is accomplished by means of overload relay 159 in the D. C. load circuit operating and breaking the circuit to the bucking field coil 66. The starting control 231, which may be a conventional direct current motor starting box, is provided to gradually apply the field current to the bucking coil 66 and thus gradually apply full load current to the direct current load. In the case of failure of the auxiliary rectifier 201 the series holding coil of the starting device 231 will release and effectively limit the load current.

Regulation of the voltage on the load may also be obtained by connecting a field coil in shunt with the load. If desired, this coil may have "Thyrite" resistors in series with it to make the field current vary more rapidly with the variation in load voltage and therefore hold the load voltage more nearly constant.

Fig. 17 illustrates the behavior of the arc in the tube. With no magnetic field, or with a weak field, a drop shaped relatively intense glow is present on the under or cathode side of the hole through the barrier anode, and the main body of the tube, between the barrier anode and mercury pool cathode, is filled with a more or less uniform glow somewhat as illustrated in Fig. 17A.

If a moderate magnetic field is applied the drop shaped glow is stretched out or elongated somewhat as illustrated in Fig. 17B and the glow in the main body of the tube is reduced and slightly concentrated toward the center. A still more intense magnetic field elongates the glow still more and another region of intense glow appears stretching up from the cathode giving an arc with something like a sinuously moving hour glass shape, very much like a miniature tornado, somewhat as illustrated in Fig. 17C. A still higher field gives a sinuously moving intensely lighted arc discharge extending all the way from the barrier anode hole to the cathode somewhat like that illustrated in Fig. 17D. At the same time an "anode dark space" begins to appear in and near the barrier anode hole. For about the same or a somewhat greater magnetic field the intense path of glow from the barrier anode hole and the path of glow from the cathode frequently seem to separate from one another and twist one about the other in a continually changing and unstable manner as illustrated in Fig. 17E. For a somewhat higher field the "anode dark space" near the cathanode hole grows in size quickly and extinguishes the anode current. If there is current to the anode only, the anode current can be completely extinguished and remain extinguished.

However, if there is a holding arc current to the cathanode or barrier anode, the anode current usually re-establishes itself and extinguishes itself intermittently.

Application of a magnetic field of increasing strength gives a whirling motion to the arc and the gas and vapor near the cathanode hole and along the axis of the arc. This whirling motion, caused by radial components of current, sets up centrifugal forces which lowers the gas and vapor density near and in the cathanode hole. This lowering of the gas and vapor density is visible in its effects through an increase in the free path of ions drawn through the cathanode hole. As a result of the increase in free path of the ions the intensely illuminated glow around the hole is elongated in the manner illustrated in Fig. 17. For quite strong fields the pressure along the axis of the whole path of the arc becomes so low that a large proportion of the ions drawn from the cathanode hole travels almost all the way to the cathode before striking a molecule. This indicates that the whirling arc actually does produce a relatively high vacuum along the axis of the tube, in the cathanode hole and in the anode chamber.

The hour glass shape of the arc in Fig. 17C is due to the tendency for the arc to whirl in opposite directions at its two ends. Concentration of arc current at the cathanode hole and at the cathode spot gives radial components of current in opposite directions and therefore opposite rotation of the arc.

The double whirling arc of Fig. 17D is also undoubtedly a result of two overlapping oppositely whirling arc paths.

It should be distinctly understood that the present invention is not limited to the precise arrangements and design features shown in the various figures since these have merely been illustrated for the purpose of setting forth the principles of the present invention and alterations within the scope of the appended claims may be made.

I claim:

1. An arc discharge circuit breaker comprising an anode, an apertured barrier anode and cathode, means for establishing an arc between the cathode and the barrier anode, means for establishing a second arc between the cathode and the anode and means responsive to an increase in the second arc current for interrupting said arc.

2. An arc discharge circuit breaker comprising means for establishing an arc discharge in an ionizable medium, means comprising an apertured barrier anode providing a restricted arc discharge path whereby the arc discharge current is interrupted at a predetermined value and a magnetic field parallel to said arc discharge path for varying said predetermined value.

3. An arc discharge circuit breaker comprising an anode, an apertured barrier anode and a cathode, means for establishing an arc between the cathode and the barrier anode, means for establishing a second arc between the cathode and the anode, and magnetic means responsive to an increase in the second arc current for interrupting said arc.

4. An arc discharge switch comprising an anode, an apertured barrier anode and a cathode, means for establishing an arc discharge between the barrier anode and the cathode, means for establishing an arc between the cathode and the anode, a source of direct current and load circuit, said second arc connected between said source and said load circuit and means responsive to a change in resistance of the load circuit for interrupting said arcs.

5. An arc discharge switch comprising an anode, an apertured barrier anode and a cathode, means for establishing an arc between the cathode and the barrier anode, means for establishing an arc between the cathode and the anode, a source of direct current and load circuit, said second arc connected between said source and said load circuit and means for maintaining the second arc current within predetermined limits.

6. An arc discharge switch comprising an apertured first anode, a second anode and a cathode, means for establishing an arc between the cathode and the first anode, means for establishing an arc between the cathode and the second anode through said first anode, a source of direct current and a load circuit, the arc between said cathode and said second anode being interposed between said source and said load circuit and means responsive to a change in the resistance of load circuit for interrupting the arc between said second anode and the cathode.

7. A mercury arc switch comprising a cathode, an anode and an apertured barrier anode within an evacuated casing, means for establishing an arc between said cathode and said barrier anode, means including a direct current source and a load circuit for establishing an arc between said cathode and said anode through said barrier anode, a magnet coil surrounding said casing and so arranged that its axis is coincident with the arc path and means for energizing said magnet coil whereby said arc is caused to rotate.

8. A mercury arc switch comprising an evacuated casing having therein a cathode and an anode and a barrier anode having a central aperture therein, means for establishing an arc between said cathode and anode through the aperture in said barrier anode, means for establishing an auxiliary arc between the cathode and the barrier anode; a direct current source and a load circuit, the first mentioned arc being in series between said source and said load, a magnet coil surrounding said casing and in co-axial relationship with the hole in the barrier anode, means between the barrier anode and the cathode for spreading the arc and means for energizing said magnet coil whereby a whirlpool rotation is imparted to said arc.

9. A mercury arc switch comprising an evacuated casing having therein a mercury pool cathode, an anode and a barrier anode having a central aperture therein, means for establishing an arc between said cathode and anode through the aperture in said barrier anode, means for establishing an auxiliary arc between the cathode and the barrier anode, a direct current source and a load circuit, the first mentioned arc being in series between said source and said load, a magnet coil surrounding said casing and in co-axial relationship with the hole in the barrier anode, means between the barrier anode and the cathode for spreading the arc and means for energizing said magnet coil whereby a whirlpool rotation is imparted to said arc.

10. A mercury arc switch comprising an evacuated casing having a mercury pool cathode at one end, an anode at the other end and a barrier anode having an aperture therethrough between the cathode and the anode, means for establishing an auxiliary arc discharge from said cathode to said barrier anode, means for establishing an arc discharge from the cathode to the anode through the aperture in the barrier anode, said

aperture being so dimensioned that the arc discharge current cannot exceed a predetermined value.

11. An arc discharge circuit breaker comprising an anode, an apertured barrier anode and cathode, means for establishing an arc between the cathode and the barrier anode, means for establishing a second arc between the cathode and the anode through the aperture in the barrier anode, and means responsive to an increase in the second arc current for interrupting said arc.

12. An arc discharge circuit breaker comprising an anode, an apertured barrier anode and a cathode, means for establishing an arc between the cathode and the barrier anode, means for establishing a second arc between the cathode and the anode through the aperture in the barrier anode, and magnetic means responsive to an increase in the second arc current for interrupting said arc.

13. An arc discharge switch comprising an anode, an apertured barrier anode and a cathode, means for establishing an arc discharge between the cathode and the barrier anode, means for establishing an arc between the cathode and the anode through the aperture in the barrier anode, a source of direct current and a load circuit, said second arc being interposed between said source and said load circuit and means responsive to a change in resistance of the load circuit for interrupting said second arc.

14. An arc discharge switch comprising an anode, an apertured barrier anode and a cathode, means for establishing an arc between the cathode and the barrier anode, means for establishing an arc between the cathode and the anode through the aperture in the barrier anode, a source of direct current and a load circuit, said second arc being interposed between said source and said load circuit, said aperture being so dimensioned that the second arc current is maintained within predetermined limits.

15. A mercury arc switch comprising an evacuated casing having therein a cathode, an anode and a barrier anode having a central aperture therein, means for establishing an arc between said cathode and anode through the aperture in said barrier anode, means for establishing an auxiliary arc between the cathode and the barrier anode, a magnet coil surrounding said casing and in co-axial relationship with the hole in the barrier anode, a direct current source and a load circuit, the first mentioned arc and said magnet coil being in series between said source and said load whereby said first mentioned arc is caused to rotate, the velocity of rotation increasing with increasing current through said arc and said coil up to a critical value where the arc collapses.

16. A mercury arc switch comprising an evacuated casing having therein a cathode and anode and a barrier anode having a central aperture therein, means for establishing an arc between said cathode and anode through the aperture in said barrier anode, means for establishing an auxiliary arc between the cathode and the barrier anode, a direct current source and a load circuit, the first mentioned arc being in series between said arc and said load, a magnet coil surrounding said casing and in co-axial relationship with the hole in the barrier anode and means for energizing said magnet coil whereby said arc is caused to rotate.

17. An arc discharge device comprising an evacuated casing having therein an anode at one end, a mercury pool cathode at the other end and a plurality of barrier anodes between the cathode and the anode, each barrier anode having a central aperture, means for establishing an arc discharge between said cathode and anode, means for establishing an arc discharge between the cathode and each of the barrier anodes and means for maintaining each of said barrier anodes at a predetermined potential with respect to the cathode.

18. An arc discharge device comprising an evacuated casing having therein an anode at one end, a mercury pool cathode at the other end and a plurality of barrier anodes between the cathode and anode, each barrier anode having a central aperture, the apertures being in axial alignment, means for establishing an arc discharge between said cathode and anode through the apertures in the barrier anodes, means for establishing an arc discharge between the cathode and each of the barrier anodes and means for maintaining each of the anodes at a predetermined potential with respect to the cathode.

19. An arc discharge device comprising an evacuated casing having therein a cathode at one end, a control anode at the other end and a plurality of anodes each having a central aperture between said cathode and control anode, a source of direct current and a load circuit, means for establishing an arc discharge between the said cathode and each of said anodes, the cathode and the second apertured anode being connected in series with the direct current source and the load, and means for varying the arc discharge current between the cathode and the control anode whereby the current in the arc to the second apertured anode may be controlled.

20. A mercury arc rectifier comprising an evacuated casing having at one end a mercury pool cathode, at the other end a plurality of anodes and an apertured barrier anode between the cathode and the anodes, means for establishing an arc discharge between the cathode and the barrier anode, a source of alternating current connected to said cathode and anodes for establishing an arc between said cathode and each of said anodes through the aperture in the barrier anode, a direct current output circuit connected to said rectifier, a magnet coil surrounding said casing and in axial alignment with the aperture in the barrier anode, said coil connected in series with the output circuit whereby an increase in the direct current output above a predetermined value will extinguish the arc through the barrier anode.

21. A mercury arc switch comprising an evacuated casing having therein a cathode at one end, an anode at the other end and a barrier anode having a central aperture therein between said anode and said cathode, means for establishing an arc between said cathode and said anode through the aperture in said barrier anode, means for establishing an auxiliary arc discharge between the cathode and the barrier anode, a plurality of magnet coils surrounding said casing and in co-axial relationship with the aperture in the barrier anode, a direct current source and a load circuit, the first mentioned arc and one of the magnet coils being connected in series between said source and said load whereby said first mentioned arc is given a whirlpool rotation limiting the arc current to a predetermined value,

means for energizing the other of said magnet coils to an opposing sense to that of the first whereby the limiting effect of the first is removed, and means for de-energizing said second mentioned coil when the current drawn by the load exceeds a predetermined value.

22. A mercury arc switch comprising an evacuated casing having therein a cathode at one end, an anode at the other end and a barrier anode having a central aperture therein between said anode and said cathode, means for establishing an arc between said cathode and said anode through the aperture in said barrier anode, means for establishing an auxiliary arc discharge between the cathode and the barrier anode, a plurality of magnet coils surrounding said casing and in co-axial relationship with the aperture in the barrier anode, a direct current source and a load circuit, the first mentioned arc and one of the magnet coils being connected in series between said source and said load whereby said first mentioned arc is given a whirlpool rotation limiting the arc current to a predetermined value, and means for energizing the other of said magnet coils to an opposing sense to that of the first whereby the limiting effect of the first is removed.

23. A mercury arc discharge device comprising a base plate having a depression containing a mercury pool, a barrier anode plate having a central aperture, an insulating cylindrical wall member separating said base plate and said barrier anode plate, means for clamping said plates together forming a cathode chamber, and an anode and an anode supporting cup clamped over the aperture in the barrier anode forming an anode chamber, an insulating ring within the depression in the base plate for retaining the cathode spot on the mercury surface and an arc deflecting plate mounted in said cathode chamber in alignment with the aperture in the barrier anode.

24. A mercury arc discharge device comprising a base plate having a depression containing a mercury pool, a barrier anode plate having a central aperture, an insulating cylindrical wall member separating said base plate and said barrier anode plate forming a cathode chamber, means for clamping said plates together, an anode and an anode supporting cup clamped over the aperture in the barrier anode forming an anode chamber, an insulating ring within the depression in the base plate for retaining the cathode spot on the mercury surface, an arc deflecting plate mounted in said cathode chamber in alignment with the aperture in the barrier anode, the surface of the arc deflecting plate and the barrier anode being covered with an insulating enamel.

25. A mercury arc discharge device comprising a base plate having a depression containing a mercury pool, a barrier anode plate having a central aperture, an insulating cylindrical wall member separating said base plate and said barrier anode plate forming a cathode chamber, means for clamping said plates together, an anode and an anode supporting cup clamped over the aperture in the barrier anode forming an anode chamber, an insulating ring within the depression in the base plate for retaining the cathode spot on the mercury surface, an arc deflecting plate mounted in said cathode chamber in alignment with the aperture in the barrier anode, the surface of the arc deflecting plate and the barrier anode being covered with an insulating enamel, and a high resistance arc starter point supported near the mercury pool surface by an insulated connection through the base plate.

26. A mercury arc discharge device comprising a base plate having a depression containing a mercury pool, a barrier anode plate having a central aperture, an insulating cylindrical wall member separating said base plate and said barrier anode plate forming a cathode chamber, means for clamping said plates together, an anode and an anode supporting cup clamped over the aperture in the barrier anode forming an anode chamber, an insulating ring within the depression in the base plate for retaining the cathode spot on the mercury surface, an arc deflecting plate mounted in said cathode chamber in alignment with the aperture in the barrier anode, the surface of the arc deflecting plate and the barrier anode being covered with an insulating enamel, and a high resistance arc starter point supported near the mercury pool surface by an insulated connection through the base plate, the barrier anode plate having cooling passages surrounding the central aperture thereof.

27. A mercury arc discharge device comprising a base plate having a depression containing a mercury pool, a barrier anode supporting plate having a plurality of apertures therethrough, an insulating cylindrical wall member separating said supporting plate and said base plate forming a cathode chamber, means for clamping said plates together, an apertured barrier anode in each aperture in the barrier anode supporting plate, an anode and an anode supporting cup clamped over the aperture in each barrier anode forming anode chambers, an insulating ring within the depression in the base plate for retaining the cathode spot on the mercury surface and a high resistance arc starter point supported near the mercury pool surface by an insulated connection through the base plate.

28. A mercury arc discharge device comprising a base plate having a depression containing a mercury pool, a barrier anode supporting plate having a plurality of apertures therethrough, an insulating cylindrical wall member separating said supporting plate and said base plate forming a cathode chamber, means for clamping said plates together, an apertured barrier anode in each aperture in the barrier supporting plate, an anode and an anode supporting cup clamped over the aperture in each barrier anode forming anode chambers, an insulating ring within the depression in the base plate for retaining the cathode spot on the mercury surface and a high resistance arc starter point supported near the mercury pool surface by an insulated connection through the base plate, each barrier anode having cooling passages surrounding the central aperture thereof.

29. An arc discharge device comprising a cathode, an anode and an apertured barrier anode within an evacuated casing, means for establishing an arc between said cathode and said barrier anode, means including a direct current source and a load circuit for establishing an arc between said cathode and said anode through said barrier anode, a magnet coil surrounding said casing and so arranged that its axis is coincident with the arc path, means for energizing said magnet coil whereby said arc is caused to rotate and means within said casing for concen-

trating the magnetic field from said magnet coil.

30. A mercury arc discharge device comprising an evacuated casing having therein a cathode, an anode and a barrier anode having a central aperture therein, means for establishing an arc between said cathode and said anode through the aperture in in said barrier anode, means for establishing an auxiliary arc between said cathode and said barrier anode; a direct current source and a load circuit, the first mentioned arc being in series between said source and said load, a magnet coil surrounding said casing and in coaxial relationship with the hole in said barrier anode, a ferromagnetic arc deflecting plate between said barrier anode and said cathode for spreading the arc and means for energizing said magnet coil whereby a whirlpool rotation is imparted to said arc, said arc deflecting plate acting to concentrate the field from said coil.

31. An arc discharge circuit breaker comprising means for establishing an arc discharge in an ionizable medium, a barrier anode having an aperture therein and so arranged that said arc discharge must pass through said aperture, the dimensions of said aperture being so chosen that the path of said arc discharge is restricted whereby the arc discharge current is interrupted at a predetermined value and means for establishing a variable magnetic field parallel to the axis of said aperture whereby said predetermined value may be varied.

32. An arc discharge circuit breaker comprising means for establishing an arc discharge in an ionizable medium, a barrier anode having an aperture therein and so arranged that said arc discharge must pass through said aperture, the dimensions of said aperture being so chosen that the path of said arc discharge is restricted whereby the arc discharge current cannot exceed a predetermined value, and means for establishing an auxiliary arc discharge in said medium for maintaining said medium in an ionized condition.

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