

Dec. 26, 1939.

C. W. HANSELL

2,184,740

MERCURY ARC OSCILLATOR

Filed Dec. 8, 1937

3 Sheets-Sheet 1

Fig. 1

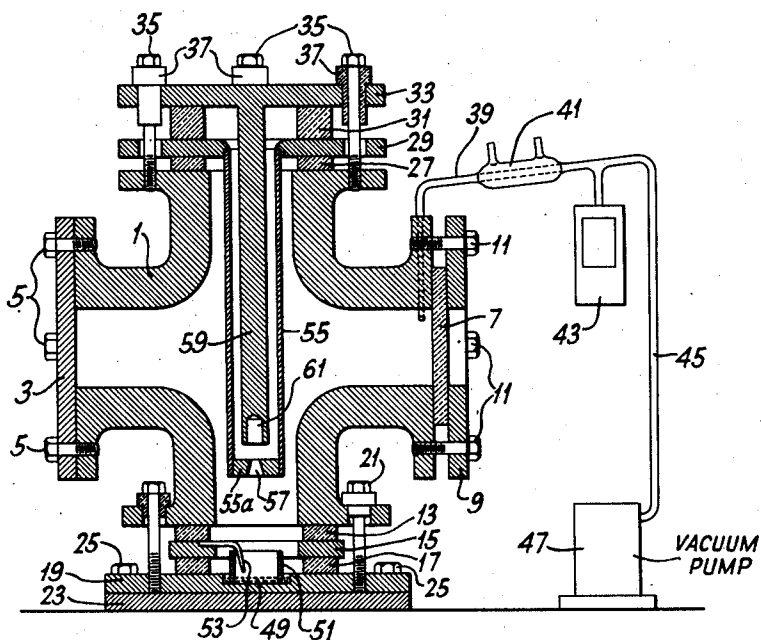
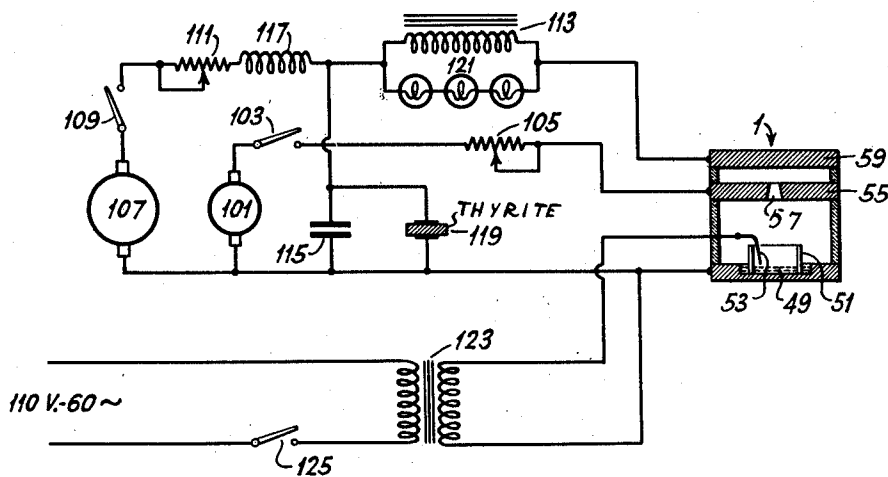


Fig. 2



INVENTOR.
C. W. HANSELL

BY

H. B. Swer
ATTORNEY.

Dec. 26, 1939.

C. W. HANSELL

2,184,740

MERCURY ARC OSCILLATOR

Filed Dec. 8, 1937

3 Sheets-Sheet 2

Fig. 3

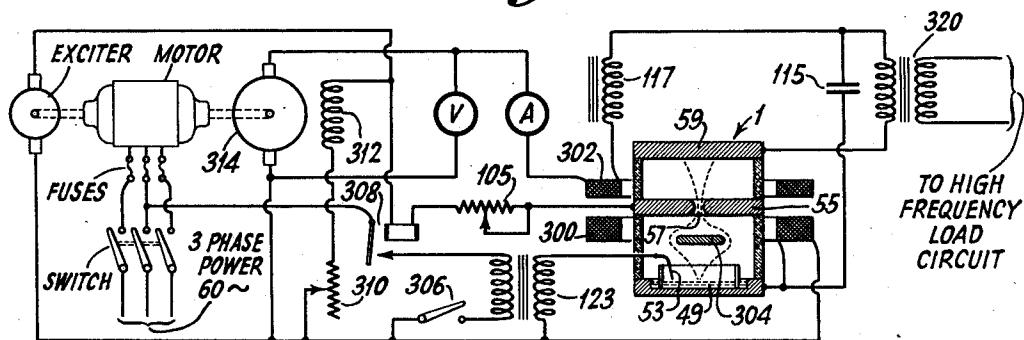


Fig. 4

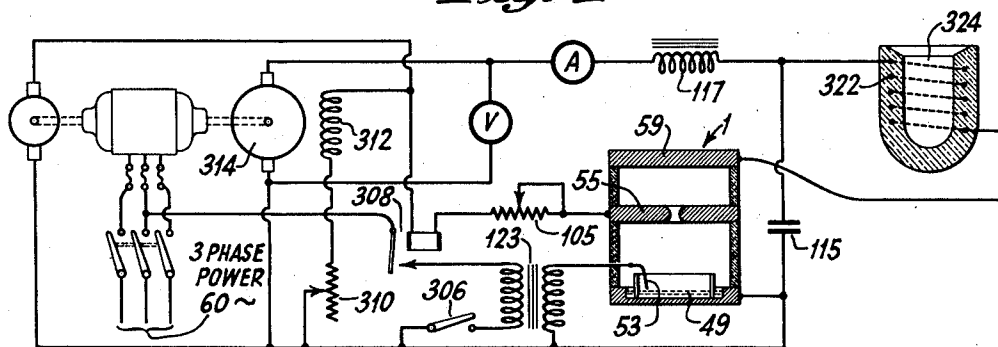
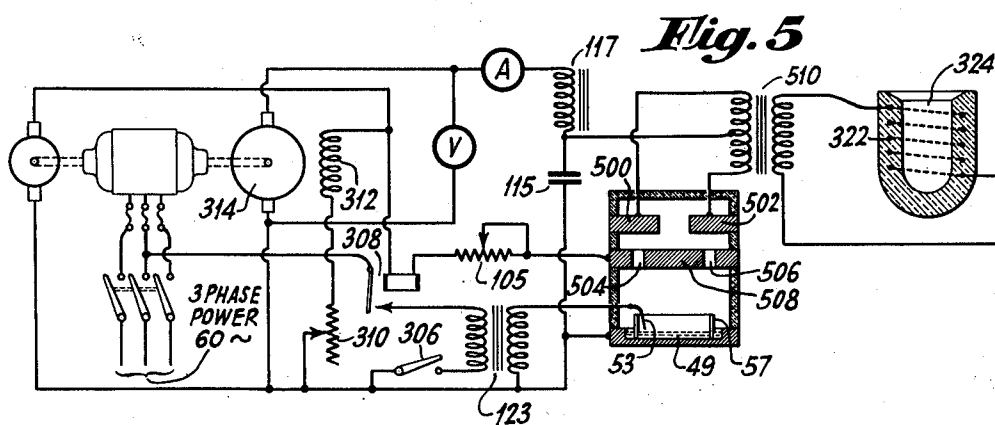


Fig. 5



INVENTOR.
C. W. HANSELL

BY

H. S. Grover

ATTORNEY.

Dec. 26, 1939.

C. W. HANSELL

2,184,740

MERCURY ARC OSCILLATOR

Filed Dec. 8, 1937

3 Sheets-Sheet 3

Fig. 6

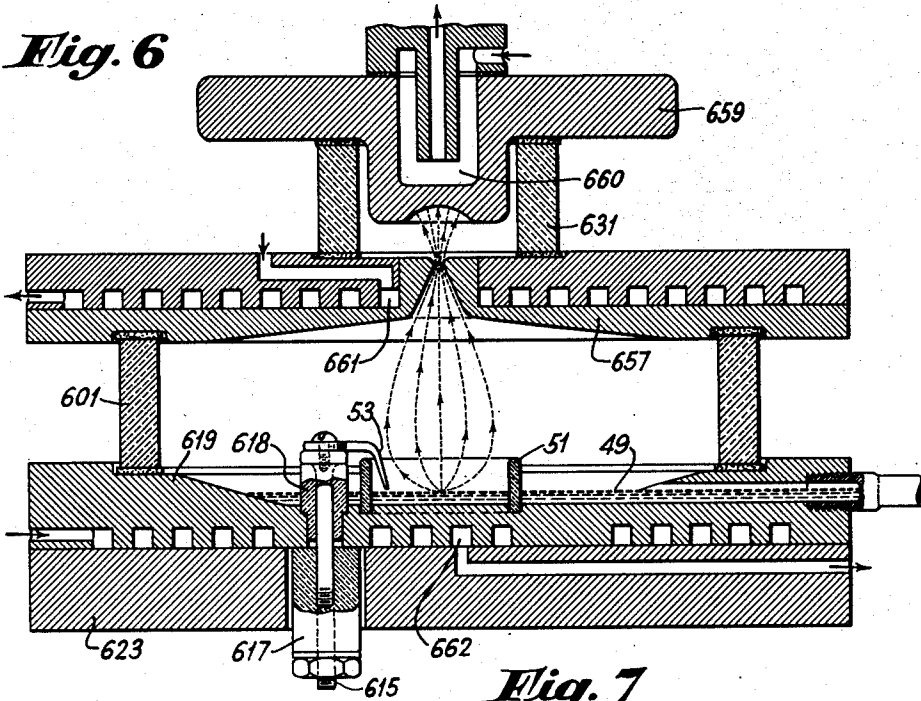
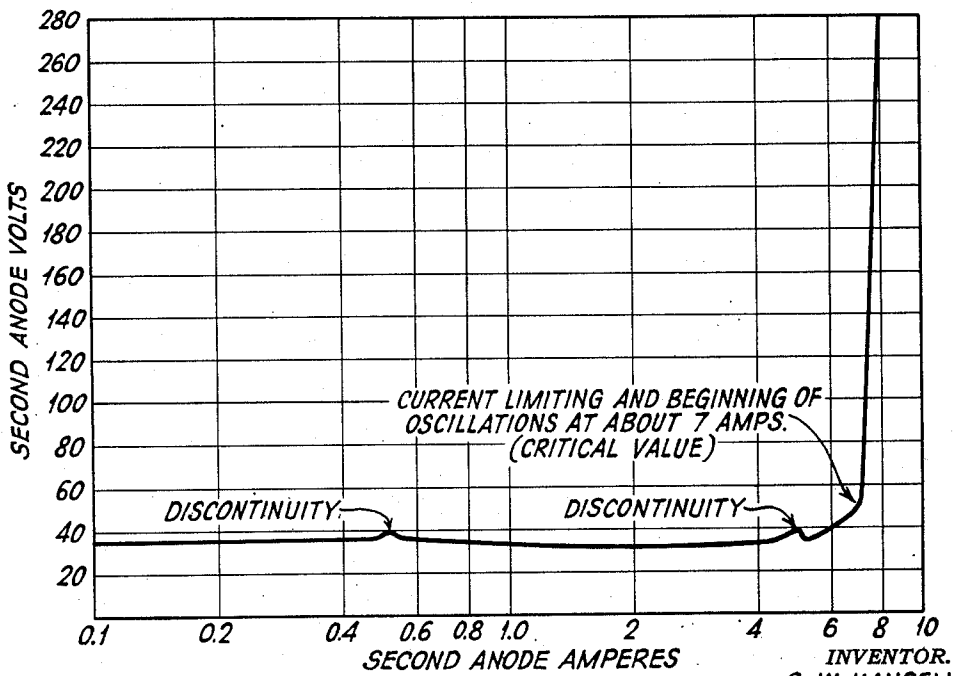


Fig. 7



BY

H. S. Swer

INVENTOR.
C. W. HANSELL

ATTORNEY.

UNITED STATES PATENT OFFICE

2,184,740

MERCURY ARC OSCILLATOR

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

Application December 8, 1937, Serial No. 178,695

16 Claims. (Cl. 250—36)

This invention relates to the art of producing and controlling alternating current energy and is particularly applicable to the production of currents having frequencies ranging from very low values up to 1,000,000 cycles per second although it is to be understood that my invention is not limited to any particular value of frequency. Such currents have many uses in industry including (1) induction heating of parts in vacuum during the manufacture of vacuum devices, (2) induction furnaces for the reduction and distillation of metals, such as zinc, mercury, arsenic, magnesium, calcium, strontium and barium from their ores, and for melting of precious metals, alloys, etc., where cleanliness and accurate control of the product are essential, (3) electrical cooking where control of the application and distribution of heat is essential, (4) high frequency arc and resistance welding. In addition, my invention is applicable to ordinary power generation and distribution, particularly in connection with high voltage direct current power distribution, to radio transmitters and to many other purposes.

My present invention is generally based upon the discovery that an electric arc, in low pressure gas or vapor, can be made to produce continuous oscillation by passing the arc through a suitably dimensioned hole or opening in a plate or barrier. 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.

In constructing a preferred form of my oscillator, I include within an evacuated container a liquid mercury cathode with arc restraining insulator, arc starting means, a first anode for striking and holding an arc to the cathode and a second anode through which oscillations are to be developed. The construction and arrangement of the device is such that the second anode is in a chamber entirely separated from the cathode chamber by the first anode, except for a hole through the first anode through which an arc can be drawn to the second anode. With such a tube I find that, after an arc discharge to the first anode is established, I can draw a current through the hole to the second anode. The arc drop to the first anode may be on the order of 10 to 20 volts, depending upon the mercury pressure and tube dimensions. The arc drop to the second anode may be on the order of 20 to 40 volts and is substantially constant regardless of

the value of current up to a critical value of current after which the voltage drop begins to rise abruptly and the current is held almost constant. In some instances, I have found that increasing voltage, up to about 350 volts, produces a slight increase of current and in other cases a slight decrease of current.

In all cases, I have found that oscillations, or a starting and stopping of the current to the second anode, began whenever the voltage drop to the second anode exceeded about 50 to 60 volts. I have found the oscillations increased in intensity, steadiness and efficiency quite rapidly as the voltage was increased.

If the second anode were supplied with current through an inductive circuit, without loading, the oscillations were accompanied by the production of very high voltages which usually arced over the apparatus. These high voltages are attributable to the abrupt manner in which the current is interrupted during oscillation. By means of a cathode ray oscilloscope, it has been found that during oscillation, the arc to the second anode has very low resistance during one part of the cycle and very high or open circuit resistance during the remaining part of the cycle. In other words, the arc to the second anode changes abruptly from a very low resistance to a substantially infinite resistance and back again for each cycle of oscillation. For this reason losses in the arc during oscillation are relatively small. Therefore, the efficiency of conversion of input power from direct current or low frequency alternating current, to high frequency output current in an oscillator is quite high. I have obtained anode circuit power conversion efficiencies ranging up to about 95% with only about 350 volts direct current input power voltage. If the voltage is increased to say 3500 volts, for example, then it appears from theoretical considerations that conversion efficiencies as high as about 99% should be obtainable. In any case, I believe my new type of oscillator is one of the most efficient known forms of power converter for the production of high frequency currents.

In response to power output, by way of example, I have obtained an output up to 3 kilowatts from an oscillator without water cooling and with a round hole, $\frac{1}{4}$ inch diameter and $\frac{1}{2}$ inch long, through a steel plate forming part of the first anode. By using water or other circulating liquid cooling, particularly around the hole in the first anode, by using lower vapor pressures and correspondingly larger holes and by means of suitable insulation, power outputs running up

to hundreds or thousands of kilowatts from a single arc should be obtainable.

As to the frequency of the oscillation a very wide range is obtainable. The frequency is determined principally by the tube dimensions, the gas or vapor pressure and the voltage applied to the second anode. It is not usually primarily dependent upon the circuits associated with the tube to form the complete oscillator although the circuit may determine which of two or more modes and frequency ranges of oscillation are taken by the arc. In this respect its behavior is analogous to the behavior of electronic oscillators of the Barkhausen and magnetron types.

Although I may not have a complete and accurate theory to explain the mechanism by which the oscillations are produced, I believe the explanation is that the arc produces a pumping effect or motion of ions and molecules of gas and vapor toward the cathode. When the arc is passed through a hole, and the current is made large enough, the pumping effect exceeds the back diffusion of the gas and vapor. This results in a relatively high vacuum on the anode side of the hole and in the hole. The high vacuum extinguishes the arc momentarily until the arc path is refilled with gas or vapor, at which time the arc is established again only to extinguish itself as before and this process repeated rapidly is the oscillation of anode current observed. For low voltage arcs the frequency of oscillation may be determined by the time required to evacuate and refill the whole anode chamber, which gives a low frequency mode of oscillation. For higher voltage arcs the rate of pumping may be so high that only the arc path is evacuated each cycle, rather than the whole anode chamber, and the frequency can be very high since it is determined by gas or vapor diffusion through only a short distance, at right angles to the path of the arc. As evidence of this, I have obtained oscillation of an arc through a hole even after other holes had been drilled to prevent complete evacuation of the anode chamber. It should not be concluded from this that there is no steady state or average evacuation of the anode chamber by the arc during high frequency oscillation since I have independent proof, through pressure measurements, that an average or steady state pumping, superimposed upon the rapidly fluctuating pumping, does take place.

In order that others skilled in the electronic arc may be given sufficient information to practice my invention several specific examples of oscillating arc power converters are illustrated in the drawings and will now be described.

In the accompanying drawings, Figure 1 is a cross-sectional view of a device employing the features and principles of my present invention; Figure 2 is a wiring diagram of the device and connections therefor; Figure 3 illustrates a modification wherein magnetic field coils are employed to produce additional effects; Figure 4 is a further modification showing the manner in which an arc oscillator built according to my present invention may be utilized for inductive heating; Figure 5 is a modification of Figure 4 showing a push-pull arrangement; Figure 6 is a cross-sectional view of a modification of my device employing fluid cooled electrodes; and Figure 7 is a graph explanatory of my present invention.

Referring to Figure 1, which is a drawing of a particular oscillator arrangement which I have

used, there is shown an outer envelope 1 which was obtained by altering a standard 4 inch steel pipe cross, designed for 350 lbs. per square inch steam pressure. This pipe cross has four openings. Over one of the openings was fitted a blank flange 3 held in place by bolts 5, and over the diametrically opposite opening was fitted a "Pyrex" sight glass 7, held in place by steel flange 9 and bolts 11. Over the lower opening was fitted an assembly including Mycalex insulator 13, steel ring 15, Mycalex insulator 17 and steel flange 19, all held tightly in place by electrically insulated bolts 21. An additional steel flange 23 was provided to serve as a mounting plate to which the assembly was attached by bolts 25. Over the upper opening was provided Mycalex insulator 27, a steel ring 29, Mycalex insulator 31 and steel flange 33, all held tightly in place by bolts 35 and insulators 37. To seal all joints, where the various parts came together, the surfaces were accurately fitted and joined together by means of gaskets of very thin varnished silk thus making a hermetically sealed container.

The container was evacuated through connection 39, a water cooled mercury condensation trap 41, McLeod vacuum gauge 43, connection 45 and vacuum pump 47. The vacuum pump used was obtained from the Central Scientific Company and is sold under the trade designation of "Cenco Hyvac Pump". The particular pump used was found capable of producing a minimum foreign gas pressure, as measured on the McLeod gauge, of about 0.2 micron but, while the arc was operating, considerably higher pressures were observed. Usually best results were obtained with a foreign gas pressure of 5 microns or less. Later experiments have been made with a larger vacuum pump and larger diameter but shorter vacuum pumping connections with greatly improved maintenance of vacuum.

Held in a depression in flange 19 was a pool of liquid mercury, 49, to serve as a cathode. Standing in this pool of liquid mercury was a short cylinder of "Pyrex" glass 51, the function of which was to restrict the location of the cathode spot, or true arc cathode, to the area of the mercury surface within the cylinder. The restraining insulator prevents the cathode spot wandering to the sides of the pool and extinguishing itself. At the same time the insulator keeps out dirt and contaminated mercury returning from the walls of the vessel because the dirt floats on the surface of the pool outside the insulator.

Connected with ring 15 was a starter point 53 made of a carborundum compound manufactured and sold by the General Electric Company under the trade name of "Thyrite". This starter point passed over the top edge of the "Pyrex" insulator 51 and was mounted with its tip about $\frac{1}{8}$ inch, or less, from the mercury surface within the cylinder. By applying a 60 cycle voltage, of 15,000 volts maximum value obtained from a transformer, to the starter point, by connection through ring 15, it was found possible to start an arc from the mercury surface inside insulator 51 to the first anode 55, without difficulty. The high reactance of the transformer held the current through the "Thyrite" starter point to a low value and the high resistivity of the "Thyrite", together with its ability to change resistivity automatically, served to prevent arcing to the starter point. In other words, the starter point was virtually an insu-

lator so far as arc potentials and currents were concerned.

Mounted on steel ring 29 was a first anode 55, consisting of a steel cylinder closed at the end with a steel plate 55a. Through the steel plate was a hole 57. Mounted on steel flange 33 was a cylindrical steel second anode 59, the end of which was located immediately over the hole 57. The second anode was drilled at the end to form a hollowed portion 61. The depth of the hollow may be varied, as desired. The function of the hollow was to distribute the power losses at the second anode over a greater area and to control the behavior of the arc to the second anode by varying the length of electron path from the hole to the anode and by varying the dimensions of the free space enclosing the arc.

Figure 2 shows a schematic diagram of the essential elements used in the power and control circuits of the oscillator. A D. C. generator 101 supplied power through a switch 103 and a current limiting variable resistance 105 to the first anode 55. A second D. C. generator, of manually variable voltage, 107 supplied power through a switch 109, current limiting protective variable resistance 111 and reactor 113 to the second anode 59. A large condenser 115 having a value adjustable up to about 50 microfarads, a choke coil 117 and "Thyrite" surge arrester 119 were used to keep high frequency and transient currents out of the generator circuit. A load resistance consisting of incandescent lamps 121 was connected across reactor 113. The power dissipated in the load lamps could be measured readily by adjusting another comparison lamp to equal brilliance from a D. C. or 60 cycle source and then measuring the power in the comparison lamp.

For starting the arc, transformer 123 was provided which was supplied with 60 cycle, 110 volt A. C. power through momentary contact push button switch 125. The transformer, which was of a type commonly employed for electric ignition in oil burners for domestic heating plants, developed an open circuit A. C. voltage of 15,000 r. m. s. was designed to have high leakage reactance and secondary resistance so that the secondary current was always limited to a low value. A transformer for neon lamp excitation has similar characteristics. The secondary winding of the transformer was connected between steel flange 19 (of Fig. 1) and steel ring 15 and through these applied the 15,000 volts starting potential across the small spark gap between starter point 53 and the surface of the mercury pool 49, inside the "Pyrex" insulator cylinder 51. By applying potential to first anode 55 and then momentarily energizing transformer 123 by closing switch 125 it was possible to start an arc between the first anode and the mercury pool. This arc would continue indefinitely and was the means for keeping continuous ionization in the chamber between the first anode and the cathode.

By closing switch 109 a current could be drawn through the hole 57 to the second anode 59. This current could 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 about 1 to 50 amperes in any particular case, depending upon the dimensions of the hole 57 and the gas or vapor pressure in the vicinity of the hole. In general, the critical or limiting

value of current seems to be approximately proportional to the cross-sectional area of the hole 57 and to the gas and vapor density and pressure near the hole. The critical value of current also depended upon the length of the hole 57 and the length of electron path from the hole to the surface of the second anode 59. A long electron path from the hole to the second anode tended to increase the number of ions, per ampere of current, produced between the hole and the second anode and this seemed to increase the size of the arc and so cause a lower critical value of current.

After the critical or limiting value of current was reached any further attempt to increase the current resulted substantially in only increasing the voltage drop between the mercury pool cathode (and/or the first anode) and the second anode. Figure 7 is a typical measured characteristic of current to the second anode versus voltage between the second anode and the cathode in my tube of Figure 1. In this case, it will be noted that the critical value of current was about 7 amperes.

By increasing the potential or voltage on the second anode, after the critical value of current was reached, it was found that the anode current began to fluctuate or oscillate whenever the voltage exceeded about 50 volts. Also the intensity and frequency of oscillation increased rapidly with increasing voltage and the power which could be developed in load lamps 121 likewise increased rapidly with increasing voltage. I have succeeded in obtaining a maximum of 3 kilowatts into load lamps 121, using three 1.5 kilowatt lamps in series. I have also measured power conversion efficiencies ranging up to about 95% with only about 350 to 375 volts D. C. applied to the second anode.

With my oscillator tube I found that (see Figure 3) by wrapping coils of wire around the tube and passing an electric current through them to produce a magnetic field substantially parallel to the path of the arc, I could profoundly affect the behavior of the arc. In my experiments I used magnetizing forces ranging up to about 15,000 ampere turns. In explaining the effect of the magnetic field it may be noted that the arc current to the second anode, passing through the hole in the first anode, approaches the hole from the cathode side over a path resembling a cone with its apex in the hole. As a result we have a radial component of current which cuts across the magnetic field. This radial component of current, in the magnetic field, gives a whirling motion to electrons and ions, and by collisional forces also to neutral molecules, around the axis of the arc. Therefore, we have a rapidly revolving or whirling arc with a vortex passing through the hole. The whirling arc, due to centrifugal force, reduces the gas or vapor density along the axis of the tube, increases the diameter of the arc and tends to pump a high vacuum in the hole and in the space above the hole which encloses the second anode.

As a result of the whirling arc the presence of the magnetic field lowers the limiting or critical value of current through the hole and can be used to control the limiting value of current. However, the whirling arc itself produces a form of instability or oscillation if the magnetic field is strong enough. The whirling of the arc can pump a high vacuum in the chamber containing the second anode, and in the hole,

and this high vacuum can extinguish the arc to the second anode. After the arc to the second anode stops the whirling stops, or slows down, the gas or vapor refills the second anode chamber and the hole and the arc strikes through again. This oscillation, due to starting and stopping of the whirling arc to the second anode, can take place at a low rate ranging down to as low as about 0.1 cycle per second at low second anode voltages.

This whirling arc phenomenon has opened up a whole new field for inventions, some of which will be described and claimed here and in other patent applications. Generally, only those features of the use of magnetic fields which have a direct bearing upon the behavior and usefulness of my new form of oscillator will be described here.

As one example of the use of a magnetic field reference is again made to the schematic diagram shown in Figure 3. In this figure, I have shown an arc type oscillator, with associated circuits, in which two field coils, 300, 302 are used. One coil (300) is connected in series with the connection to the cathode in such a way that the current for both anodes goes through it. The other coil 302 is connected in series with the second anode power supply. With this arrangement the whirling of the arc, by lowering the vapor pressure at the hole in the first anode, makes it possible to use a larger hole for a given value of limiting current. The larger hole is better adapted to the dissipation of power and so can allow higher current and voltage and greater power input and output from the oscillator. In addition, the field coil in series with the power supply to the second anode gives an automatic control of the magnetic field strength which is an aid to stabilizing the value of current to the second anode. It also serves as an automatic protection to the oscillator and its power circuits by cutting off the arc to the second anode intermittently in case of short circuits in the load or in the wiring. To increase the positiveness of control of the magnetic field, I have on some occasions employed an arc deflector 304 consisting of a disc of steel, or of insulating material, suspended by suitable supports (not shown) in the cathode chamber under the hole in the first anode. The deflector forces the arc to follow a more nearly entirely radial path to the hole in the first anode. The deflector makes it possible to use weaker magnetic fields, but it tends to introduce some instability in the oscillations.

In Figure 3, I have indicated a system in which the arc is started automatically by closing a starter switch 306 after which a relay with its coil 308 in series with the power circuit to the first anode 55 removes ignition energy from the starter as soon as the arc to the first anode is established. The voltage applied to the second anode 59, and therefore the power input and output of the oscillator are controlled by means of a field rheostat 310 in series with the field 312 of the main generator 314. A voltmeter and ammeter, as shown, and, if desired, a wattmeter may be used to measure output voltage, current and power.

Figure 4 is similar to Figure 3 except that the magnetizing field coils for the oscillator have been omitted. Also the choke coil 320 in series with the second anode has been shown as an induction coil 322 around an insulated crucible 324 in which ores, precious metals, alloys, or other

materials may be heated or melted. For most installations the coil around the crucible would be made up of two parallel hollow conductors through which water or other cooling liquid would be circulated to cool the coil and the second anode of the oscillator. Circulating liquid cooling should also preferably be applied to the first anode, particularly in near the hole.

In Figure 5, I have indicated a mercury arc oscillator with two second anodes 500, 502 and two holes 504, 506 in the first anode 508. Such an oscillator has the advantage of higher input and output rating and permits the use of an output transformer 510 in which the direct current magnetizing effects of input currents to the two second anodes are balanced out in the transformer core. This very greatly reduces the transformer size and cost for a given power rating. I may, by careful design, employ polyphase oscillators of any reasonable number of phases. Two phase and three phase oscillators, for example, should be relatively easy to construct and operate. So long as all arc paths to the various anodes are substantially identical the power transformer circuits will serve to couple the arcs together to force polyphase operation.

In Figure 6 I have shown in cross-section an alternative form of mercury arc oscillator to that shown in Figure 1. The oscillator of Figure 6 is simpler in construction and more compact.

In this form of my invention the body 601 is formed of a cylinder of high temperature glass such as "Pyrex", closed at one end by the steel plate 619 which is provided with a depression to hold the mercury cathode pool 49. The underside is provided with a spiral groove 662 and steel plate 623 is fastened to the bottom of plate 619, thus closing the spiral groove 662 and forming a water passage. The first anode 657 closing the other end of tube 601 is also formed of a steel plate with a similar spiral water passage 661. The first anode and bottom plate are clamped together by insulated bolts (not shown). The second anode 659 is also provided with a cooling water passage 660 and is separated from the first anode by insulator 631 and clamped thereto by insulated bolts which are also not shown. In this modification the arc starter point 653 may conveniently be supported by means of an arrangement like an automotive spark plug consisting of a bolt 615 passing through an aperture in the bottom plates and insulated therefrom by insulators 617 and 618. In practice, the temperature of the circulating cooling water should be thermostatically controlled in temperature in a manner similar to that employed for the control of cooling water temperature in modern automobile engines. The control of temperature will give a more nearly constant mercury vapor pressure and, therefore, more nearly constant input current. The input current can be regulated or controlled by varying the temperature of the circulating water and the oscillator. In applying the cooling water it is best to pass the water through the various oscillator parts in series. The ingoing water should first be passed through the passages in cathode plate 619, then through first anode plate 657 and finally through second anode 659. This assures correct temperature distribution inside the oscillator to prevent mercury condensation on the anodes and in the hole in the first anode. The cooling water may easily have sufficient resistivity so that rubber hose or porcelain

connections between electrodes will give sufficient insulation. Preferably, cooling water to the second anode should be applied through hollow conductors forming the inductance for the second anode output circuit in order to prevent high frequency losses in the cooling water.

In practicing my invention there are many alternative arrangements of the oscillator and associated circuits which may be used. For example, the mercury pool cathode may be replaced with a heated or thermionic cathode of the kind used in some mercury arc rectifiers. Other cathode materials and vapors than mercury may be used, such as sodium. Also, in the case of either hot or cold cathodes, inert gases such as neon, argon, helium, etc. may be used to carry the arc. In other words, any of the gases or vapors suitable for use in rectifiers, voltage regulators, lightning arrestors, glow discharge lamps, etc., which operate by means of electrical discharges at low pressures, may be used in applying my invention.

In place of the spark gap arc starter used in my experimental oscillator I may use contact breaking arc starters just as well. One type which may be used employs an arc starter point of carborundum or "Thyrite" in contact with the mercury pool which, in the art, is called an "igniter." The cylindrical insulator for restraining the cathode spot may alternatively be made of fused quartz, enameled steel or any other material which will serve as an insulator and withstand thermal shock.

For power input I may employ alternating currents, in some cases, or I may employ direct current obtained from rectifiers instead of motor generators and I may control the input power voltage by varying the alternating current power voltage input to the rectifier, or, in the case of grid controlled rectifiers I may control the D. C. voltage input to my oscillator by bias or excitation phase control of the rectifier grids.

For vacuum pumping I may employ a Langmuir mercury condensation pump, or an electrical arc discharge pump in series with a mechanical pump. The mechanical pump may be automatically started and stopped by the pressure existing at its inlet connection. In this connection I may point out that mercury condensation in trap 41 of Fig. 1, and consequent flow of mercury vapor into the trap, causes also a carrying along of foreign gases into the pump connection in a manner to assist in maintaining a vacuum inside the evacuated vessel.

Instead of varnished silk gaskets for making sealed joints I may use vacuum rubber or rubber covered with steel foil, aluminum rings, coated copper-asbestos gaskets, mechanical joints sealed with liquid mercury, platinum-coated porcelain and soldered joints or any of the known means of making vacuum tight connections.

Since my oscillator has much in common with mercury arc and gas filled rectifiers and control devices, I contemplate using all necessary features of the known art relating to them.

It should be distinctly understood that the present invention is not limited to the precise arrangements and design features shown since these have merely been illustrated for the purpose of setting forth the principles of the present invention.

I claim:

1. An arc discharge oscillator comprising a closed vessel, an apertured first anode dividing said vessel into two chambers, a second anode in one of said chambers, a mercury pool cathode in

the other chamber, means for establishing an arc discharge between said cathode and said first anode, means for establishing an arc discharge between said cathode and said second anode through the aperture in the first anode, said second arc being of sufficient intensity in the aperture to expel the ionized gases therein so that the space becomes momentarily non-conducting.

2. An arc discharge oscillator comprising an evacuated casing having a mercury pool cathode at one end and an anode at the other end, a barrier anode therebetween dividing said casing into an anode chamber and a cathode chamber, an aperture in said barrier anode, a source of energy connected to said anode and cathode, means for establishing an arc discharge between said cathode and said barrier anode, means for establishing an arc discharge between said anode and said cathode through the aperture in the barrier anode, the arc current density through the aperture being so adjusted that the arc is periodically extinguished at the desired frequency and alternating current utilization means connected to the anode.

3. An arc discharge oscillator comprising a closed vessel, an apertured first anode dividing the vessel into two chambers, a second anode in one of said chambers and a mercury pool cathode in the other chamber, means for establishing an arc discharge between the cathode and the first anode and between the cathode and the second anode through the aperture in said first anode, the aperture providing a so constricted arc discharge path that the arc is periodically extinguished.

4. An arc discharge oscillator comprising a closed vessel, an apertured first anode dividing the vessel into two chambers, a second anode in one of said chambers and a mercury pool cathode in the other chamber, means for establishing an arc discharge between the cathode and the first anode and between the cathode and the second anode through the aperture in said first anode, the aperture providing a so constricted arc discharge path that the arc is periodically extinguished, means within the cathode chamber for initiating the arc discharges comprising a high resistance arc starting electrode supported near the surface of the mercury pool and a source of alternating current adapted to be connected to said cathode and said electrode.

5. An arc discharge oscillator comprising a closed vessel, an apertured first anode dividing the vessel into two chambers, a second anode in one of said chambers and a mercury pool cathode in the other chamber, means for establishing an arc discharge between the cathode and the first anode and between the cathode and the second anode through the aperture in said first anode, the aperture providing a so constricted arc discharge path that the arc is periodically extinguished, means within the cathode chamber for initiating the arc discharges comprising a starting electrode having a resistance varying inversely as the voltage impressed thereon supported near the surface of the mercury pool forming a spark gap and a source of alternating current connected to said cathode and said electrode for momentarily establishing a high voltage across said spark gap.

6. An arc discharge oscillator comprising a closed vessel, an apertured barrier anode dividing the vessel into two chambers, an anode in one of said chambers and a mercury pool cathode in the other chamber, means including a direct

current source connected to said anode and said cathode for establishing an arc discharge therebetween through the aperture in the barrier anode, means for establishing an arc discharge
5 between the cathode and the barrier anode, means for establishing a magnetic field parallel with the first arc path whereby the arc is caused to rotate, the strength of the magnetic field and the arc current density in the aperture being so
10 adjusted that the arc is periodically extinguished.

7. An arc discharge oscillator comprising a closed vessel, an apertured barrier anode dividing the vessel into two chambers, an anode in one of said chambers and a mercury pool cathode in
15 the other chamber, means including a direct current source connected to said anode and said cathode for establishing an arc discharge therebetween through the aperture in the barrier
20 anode, means for establishing an arc discharge between the cathode and the barrier anode, means for establishing a magnetic field parallel with the first arc path whereby the arc is caused to rotate, the strength of the magnetic field and the arc current density in the aperture being so
25 adjusted that the arc is periodically extinguished, and an arc deflector in the cathode chamber in the path of the arc for spreading the arc to increase the effect of the magnetic field thereon.

8. An arc discharge oscillator comprising a closed vessel, an apertured barrier anode dividing the vessel into two chambers, an anode in one of said chambers and a mercury pool cathode in the other chamber, means including a direct
30 current source connected to said anode and said cathode for establishing an arc discharge therebetween through the aperture in the barrier anode, means for establishing an arc discharge between said cathode and said barrier anode, a magnet coil surrounding said vessel and in co-
35 axial relationship with the aperture in the barrier anode, said coil being connected in series with the direct current source and the anode whereby the arc is caused to rotate, the velocity of rotation increasing with increasing arc current whereby at
40 a critical value of arc current the arc is periodically extinguished.

9. An arc discharge oscillator comprising a closed vessel, an apertured barrier anode dividing the vessel into two chambers, an anode in one of said chambers and a mercury pool cathode in the other chamber, means including a direct
50 current source connected to said anode and said cathode for establishing an arc discharge therebetween through the aperture in the barrier anode, means for establishing an arc discharge between said cathode and said barrier anode, a magnet coil surrounding said vessel and in co-
55 axial relationship with the aperture in the barrier anode, said coil being connected in series with the direct current source and the anode whereby the arc is caused to rotate, the velocity of rotation increasing with increasing arc current whereby at a critical value of arc current the arc is periodically
60 extinguished, and an arc deflector in the cathode chamber in the path of the arc for spreading the arc to increase the effect of the magnetic field thereon.

10. An arc discharge oscillator comprising an evacuated vessel, an apertured barrier anode dividing the vessel into two chambers, an anode in one of said chambers and a mercury pool
70 cathode in the other of said chambers, means including a direct current source connected to said anode and said cathode for establishing an arc discharge therebetween through the aper-

ture in the barrier anode, means for establishing an arc discharge between said cathode and said barrier anode, and a pair of magnetic coils surrounding said vessel, each in co-axial relationship with the other and with the aperture in the barrier anode, one of said coils being connected in series with the direct current source and the anode and the other of said coils being connected in series with the direct current source and the cathode whereby the arc is caused to rotate, the velocity of rotation increasing with increasing arc current whereby at a critical value of arc current the arc is periodically extinguished.

11. An arc discharge oscillator comprising an evacuated vessel, an apertured barrier anode dividing the vessel into two chambers, an anode in one of said chambers and a mercury pool cathode in the other chamber, means for establishing an arc discharge between the cathode and the barrier anode and between the cathode and the anode through the aperture in said barrier anode, the apertures providing a so constricted arc discharge path that the arc is periodically
25 extinguished, said means for establishing the arc discharges comprising a high resistance arc starter point supported near the surface of the mercury pool and means for momentarily applying a high voltage alternating current across the gap between the point and the surface of the mercury.

12. An arc discharge oscillator comprising an evacuated vessel, an apertured barrier anode dividing the vessel into two chambers, an anode in one of said chambers and a mercury pool cathode in the other chamber, means for establishing an arc discharge between the cathode and the barrier anode and between the cathode and the anode through the aperture in said barrier anode, the aperture providing a so constricted arc discharge path that the arc is periodically
40 extinguished, said means for establishing the arc discharges comprising a high resistance arc starter point supported near the surface of the mercury pool and means for momentarily applying a high voltage alternating current across the gap between the point and the surface of the mercury, said arc starter point being constructed of a material the resistance of which varies inversely as the voltage applied thereto.

13. An arc discharge oscillator comprising an evacuated vessel, an apertured barrier anode dividing the vessel into two chambers, a pair of anodes in one of said chambers and a mercury pool anode in the other chamber, means including a direct current supply for establishing an arc discharge between the cathode and the barrier anode and between the cathode and each of the anodes through the apertures in said barrier anode, said apertures providing a so constricted arc discharge path that each of the arcs through the apertures is periodically extinguished.

14. An arc discharge oscillator comprising an evacuated vessel, an apertured barrier anode dividing the vessel into two chambers, a pair of anodes in one of said chambers and a mercury pool anode in the other chamber, means including a direct current supply for establishing an arc discharge between the cathode and the barrier anode and between the cathode and each of the anodes through the apertures in said barrier anode, said apertures providing a so constricted arc discharge path that each of the arcs through the apertures is periodically extinguished, said means for establishing the arc discharges comprising a high resistance arc starter point sup-
75

ported near the surface of the mercury pool and means for momentarily applying a high voltage alternating current across the gap between the point and the surface of the mercury.

5 15. A counter-phase arc discharge oscillator comprising an evacuated casing having a mercury pool cathode at one end and a pair of anodes at the other end, a barrier anode therebetween
10 dividing said casing into an anode chamber and a cathode chamber, a pair of apertures in said barrier anode, a source of energy connected to said anodes and said cathode, means for establishing an arc discharge between said cathode
15 and said barrier anode, means for establishing an arc discharge between each of said anodes and said cathode through the apertures in the barrier anode, the arc current density through the apertures being so adjusted that each of the
20 arcs are periodically extinguished at the desired frequency and alternating current utilization means connected to said anodes.

16. A counter-phase arc discharge oscillator comprising an evacuated casing having a mercury pool cathode at one end and a pair of anodes at the other end, a barrier anode between said cathode and said anodes, dividing said casing into
5 an anode chamber and a cathode chamber, a pair of apertures in said barrier anode, a source of energy connected to said anodes and cathode, means for establishing an arc discharge between said cathode and said barrier anode, means for
10 establishing an arc discharge between each of said anodes and said cathode through the apertures in the barrier anode, the arc current density through the apertures being so adjusted that each of the arcs are periodically extinguished at the
15 desired frequency and alternating current utilization means connected to the anodes.

CLARENCE W. HANSELL.

20