ABSTRACT: Multiple arc discharges are maintained in a single envelope by means of mutual inductance in the circuits of the several arc paths. The trajectories or paths of the arcs are stabilized forming segments of circles and the stabilization force increases with the current. Considering a double arc discharge, when the direction of the current in the two arcs is the same, they attract each other and bow inwardly in a concave pattern. This permits large currents in a small envelope without danger of overheating the wall by arc contact.
Fig. 1.

Fig. 2.

Fig. 3.

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HIGH INTENSITY MULTIPLE ARC LAMP

BACKGROUND OF THE INVENTION

In electric discharge lamps, the arc discharge may be wall stabilized or electrode stabilized. The former is common among low intensity lamps such as fluorescent lamps wherein the plasma is allowed to expand out to the envelope wall. The latter is more common among high intensity lamps in which the high-temperature arc would cause damage were it allowed to touch the envelope wall. The arc tends to assume the shortest path between the electrodes and electrode stabilization is most effective in short arc gap lamps. However, convection flow may cause the arc to bow upwards in horizontally operated lamps, particularly in long arc gap lamps. Also, as the discharge current is increased, the problem becomes more serious due to the increased instability of the arc and the higher power density of the plasma.

Some degree of arc stabilization may be effected by means of electromagnetic fields. It has also been proposed to rotate the lamp envelope during operation in order to prevent the plasma from contacting any part of the wall for a prolonged period of time. The effectiveness of these approaches has been limited.

SUMMARY OF THE INVENTION

I have found that it is possible to maintain several arc discharges side-by-side in a single envelope. An electric discharge device is provided with two or more pairs of electrodes, one pair per arc path. The paths are connected in parallel in a circuit which includes means for limiting the current. In addition, the branch circuit in which each path is connected has inductive coupling to the other branch circuits and the mutual reactance between branches affecting a given arc path exceeds the negative resistance characteristic of the path.

The trajectories of the arcs are thereby stabilized and locked in predetermined positions in space forming segments of circles. The stabilization force increases with the current. When the direction of the currents in the two arcs is the same, they attract each other and bow inwardly in a concave pattern. This permits large currents in a small envelope without danger of overheating the wall by arc contact. In addition, a more stable discharge with reduced flicker is achieved.

DESCRIPTION OF DRAWINGS

In the drawings wherein like reference symbols refer to corresponding parts or elements throughout the several figures:

FIG. 1 illustrates a four-electrode double arc lamp embodying the invention.

FIG. 2 illustrates in simplified form an electric circuit for operating the lamp of FIG. 1.

FIG. 3 is a diagram illustrating the magnetic forces acting on the arcs in the lamp.

FIG. 4 illustrates diagrammatically a circuit modification for superimposing a single transverse arc on the double arc system.

FIG. 5 illustrates another modification for superimposing two transverse arcs on the double arc system in order to get further broadening of the luminous area.

FIG. 6 shows a modified lamp construction wherein the double arc system is operated in a vertical plane.

DETAILED DESCRIPTION

Referring to FIG. 1, lamp 1 suitable for the invention comprises a generally ovoid sealed envelope 2 of fused silica. It is provided with pairs of extensions 3, 4 and 5,6 which may be referred to as necks. Electrodes 7,8 and 9,10 consisting of short lengths of tungsten wire project through the necks into the envelope space and are welded to molybdenum foils 11 sealed within the necks and to which are welded external leads 7',8' and 9',10'. The lamp contains an ionizable filling which includes an inert gas such as argon at a low pressure for starting purposes, and a vaporizable metal such as mercury, or a metal salt such as indium iodide, or again a mixture of mercury and indium iodide. After the lamp has been exhausted and filled with the charge, it is tipped off at 12.

FIG. 2 shows lamp 1 connected in a suitable circuit for maintaining a double arc discharge in accordance with the invention. The lamp is connected across an AC source 13 which may be a conventional 60 hertz supply at a few hundred volts. The total current through the lamp is limited by ballasting means, here consisting of a reactor or inductive ballast 14. The branch circuits for the two arc paths are mutually coupled together by current splitting windings 15,16 on magnetic core 17 and 18, 19 on magnetic core 20. Windings 15 and 18 are connected on opposite sides of the arc path defined by electrodes 7 and 8, and windings 9 and 10 on opposite sides of that defined by electrodes 9 and 10. When the mutual reactance coupled into each arc path by the windings exceeds the negative resistance characteristic of the arc path, the lamp will operate stably with two arcs within the envelope. Similarly a lamp will operate stably with three or more arcs by mutually coupling the arc paths by current splitting windings.

FIG. 3 illustrates the trajectories of the arc discharges when the currents in the two arcs are flowing in the same direction. The trajectories of the arc discharges are segments of circles and the forces tending to lock them in predetermined positions in space are proportional to the square of the current. The arcs attract each other and bow inwardly in a concave pattern as illustrated.

The current may be made to flow in opposite directions in the two arcs by reversing the connections in one of the branches, for instance by connecting winding 16 to inlead 10' and winding 19 to inlead 9'. When current flow is opposite in the two arcs, they repel each other but they are still stable in a plane; however, the convex pattern requires that there be a larger envelope to accommodate it and is generally not suitable for high-intensity lamps where compactness is desired.

As represented in FIG. 3, there are two components of force that are responsible for stabilizing the plasma columns: (1) the longitudinal forces $f_1$ which tend to cause the arcs to adopt the shortest path between the electrode ends, that is a straight line between the tip of electrode 7 and the tip of electrode 8, or between the tip of electrode 9 and tip of electrode 10; (2) the force of attraction $f_2$ between the parallel plasma columns which tends to draw them together. The resultant of these forces are the concave trajectories illustrated in FIG. 3.

The operative forces may be analyzed by considering the magnetic energy $E$ stored in the space about the arc using simple theory as follows:

$$E = \frac{1}{2}L_iI_i^2 + \frac{1}{2}L_eI_e^2 - k \sqrt{L_iL_e}I_iI_e$$

where $L_i$, $L_e$ are the self inductances of the arc paths, and $k$ is the coupling coefficient between the two arc paths.

If we let $L_i = L_e = L$, and $I_i = I_e = I$, then

$$E = (1-k)LI^2$$

Since the stores magnetic energy in the space can be considered analogously to conventional potential energy, it can be expected that the two arcs will seek the path which yields $E$ minimum. The stores energy $E$ can be reduced by letting $k$ approach unity which may be achieved by bringing the two arcs together. The stored energy $E$ may also be reduced by decreasing the self inductance $L$, that is by letting the arcs assume the straight line paths between electrode tips. As a result of these two opposing forces, the arc will stabilize in a concave pattern as shown.

Within each arc, the self-created magnetic field develops a force $f_3$ directed inward toward the axis which tends to decrease the cross-sectional area of the current-carrying plasma in the conventional pinch effect. In a single arc discharge, it is the unbalanced component of this force which is responsible for the instability. However, in a double arc discharge, the combined field forces $f_1$ and $f_3$ provide a stabilizing force which tends to localize the plasma between the electrodes and overcome the unbalancing force or instability inherent in a single arc system.
In a double arc lamp with the direction of current flow the same in both arcs, the arcs are stabilized out of contact with the envelope walls. This is a significant advantage in lamp design and facilitates the design of high intensity compact lamps having high efficiency. This follows from the fact that efficiency increases with power density. The improvement in lamp efficiency is also a result of avoidance of arc constriction and reduction of thermal conduction losses. The lamp has the added advantages of substantial elimination of color separation, easy starting and low flicker at line frequency due to the choice of breakdown paths available at starting and during current reversals at each cycle. The arc stabilization provides good control of temperature distribution inside the lamp and prevents contamination of the filling by overheating of the wall, thereby increasing lamp life.

The double arc high-intensity discharge lamp of my invention is not limited to any particular filling or discharge medium. A filling of mercury and an inert starting gas such as argon typical of the common high-pressure mercury vapor lamp may be used. A filling of xenon alone may be used. I have made lamps using mixtures of mercury and various metal iodides such as mercury and indium iodide. Another suitable filling is that commonly used in mercury metal halide lamps for general lighting such as that containing a filling of mercury, sodium iodide, thallium iodide and indium iodide.

By way of example, a double arc lamp such as illustrated in the drawing was made having an ovoid shaped envelope of major (inside) diameter 3.5 cm. and minor diameter 2.5 cm. The filling was argon, mercury and indium iodide. This lamp operated stably in a double arc mode at an input loading of 2.5 kilowatts, the arc drop being 90 volts and current 26 amperes.

The double arc configuration offers particular advantages when the filling comprises highly reactive metal such as sodium or cesium. By utilizing an envelope of high-density aluminia ceramic such as the material sold under the designation Lucalox by applicant's assignee, a high-intensity sodium or cesium lamp may be made. The use of a double arc in such case permits accurate control of the temperature distribution inside the lamp whereby the attack of the reactive metal on the envelope may be held to a minimum.

ALTERNATIVE OPERATING CIRCUITS

The luminous area of my double arc lamp is already large and suggests its suitability for applications where a wide luminous band is required as in projectors. However the arc area can be broadened further by various circuit modifications.

Referring to FIG. 4, an auxiliary single arc CB may be superposed on the double arc system whereby to fill the gap between the two arcs by applying a high-reactance voltage supply across a diagonally opposite pair of electrodes. As illustrated, a transformer 21 having its primary 22 connected across the AC supply 13 has its secondary winding 23 connected across a pair of diagonally opposite electrodes 8,10.

An auxiliary single arc may also be superposed on the double arc system by adjusting the turn ratio of the current splitting windings 15, 16 and 18, 19. For instance a three to four turns ratio in windings 15, 16 and a four to three turns ratio in windings 18, 19 will produce a substantial auxiliary single arc current CB.

Referring to FIG. 5, two transverse auxiliary arcs may be superposed on the double arc system. Transformer 21 now has two high-reactance secondary windings, 23 and 24 which are connected across a diagonally opposite electrode pairs, namely 9, 8 and 7, 10 respectively. Additive spreading or broadening results from this circuit because the current flows in the transverse auxiliary arcs are in opposite directions. The auxiliary transverse arcs therefore tend to repel each other with the result that the entire area between the main double arcs becomes luminous. Ballasting inductors or choke coils 27, 28, 29 and 30 are connected in series with electrodes 7, 8, 9 and 10 respectively to provide isolation between the two secondary windings 23 and 24 of transformer 21.

When it is desired to operate two or more double arc lamps in series, the windings of a current splitting core are interconnected between a pair of lamps, and a current splitting core is provided at each end of the series. This means that the number of current splitting cores required is equal to the number of lamps connected in series plus one.

OTHER MODIFICATIONS

FIG. 6 shows a modified lamp construction 31 wherein the electrodes 7 to 10 have their foil conductors 11 sealed through wide flattened pinches 32 at both ends of the lamp envelope. Such a lamp construction is more amenable to mass production.

Lamp 31 is intended for operation with one arc over the other in a vertical plane. This allows the gaseous filling to be exposed twice to the discharge before it is carried to the top of the envelope by convection, and permits a reduction in energy loss by convection. The convection energy loss may be reduced further by regulating the current in the upper arc to make it slightly less than in the lower arc so as to reduce the thermal gradient. Operating the lamp in this fashion helps to reduce the temperature at the seals. The turns ratios indicated in the drawing for the current splitting coils, 37/T in device 17 and 7/1.5T in device 20 may be used to achieve a broadened arc made up by the indicated current components.

APPLICATIONS TO RELATED FIELDS

It is an inherent characteristic of a double arc discharge in accordance with my invention to increase in stability with increase in arc current. This indicates that there is no upper limit to stability. Therefore by using a double arc discharge device having electrodes capable of withstanding the current, the loading may be raised beyond the level where kink instability would develop in a single arc discharge. Thus my invention presents a new approach to producing extremely high current discharges for such purposes as controlled thermonuclear fusion.

A double arc discharge also offers advantages in manufacturing processes such as welding. By passing materials through the middle of the parallel arcs, it is possible to control accurately the amount of heat applied to the materials. This follows from the fact that the presence of alien material in the middle of the discharge will not affect the power input to the double arc. This represents a great advantage over a conventional induction furnace used for welding wherein the power input changes considerably, depending upon the size and the conductivity of the materials.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination, a high-intensity multiple arc discharge device comprising an evacuated envelope, an ionizable filling therein, and pairs of electrodes sealed therein for supporting arc discharges in parallel paths spaced a short distance apart with mutual coupling causing inward bowing of the arc discharges when current flow is in the same direction in said paths, and an operating circuit connecting said device across an alternating current source comprising ballasting means for limiting the current through said device and a plurality of branch circuits, one for each arc path, connected across said ballasting means, each branch circuit comprising two current splitting windings connected in series with the arc path, one on each side thereof, the windings on each side being mutually inductively coupled such that the mutual reactance affecting a given arc path exceeds the negative resistance characteristic.

2. A combination as in claim 1 wherein the ionizable filling within the device includes an inert starting gas, mercury and a metal halide.

3. A combination as in claim 1 wherein the ionizable filling within the device includes argon, mercury and indium iodide.

4. A combination as in claim 1 wherein the electrodes are capable of withstanding a current greater than would develop kink instability in a single arc discharge.
5. In combination, a high-intensity double arc discharge lamp comprising an evacuated envelope, an ionizable filling therein, and two pairs of electrodes sealed therein for supporting arc discharges in parallel paths spaced a short distance apart with mutual coupling causing inward bowing of the arc discharges when current flow is in the same direction in said paths, and an operating circuit connecting said lamp across an alternating current source comprising ballasting means for limiting the current through said lamp and a pair of branch circuits, one for each arc path, connected across said ballasting means, each branch circuit comprising two current splitting windings connected in series with the arc path, one on each side thereof, the windings on each side being mutually inductively coupled such that the mutual reactance affecting a given arc path exceeds its negative resistance characteristic.

6. A combination as in claim 5 wherein the ionizable filling within the lamp includes an inert starting gas, mercury and a metal halide.

7. A combination as in claim 5 wherein the ionizable filling within the lamp includes argon, mercury and indium iodide.

8. A combination as in claim 5 comprising also a high-reactance voltage supply connected across a pair of diagonally opposite electrodes in order to broaden the arc.

9. A combination as in claim 5 comprising also two high-reactance voltage supplies connected across diagonally opposite pairs of electrodes in order to broaden the arc, and a reactance interposed between each electrode and its current splitting winding.

10. A combination as in claim 5 wherein the envelope is a quartz tube with foil conductors disposed side by side and pinch-sealed in its ends.