

[54] **HEAVILY LOADED METAL HALIDE DISCHARGE LAMP**

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[58] Field of Search .... **313/184, 225, 229, 227**

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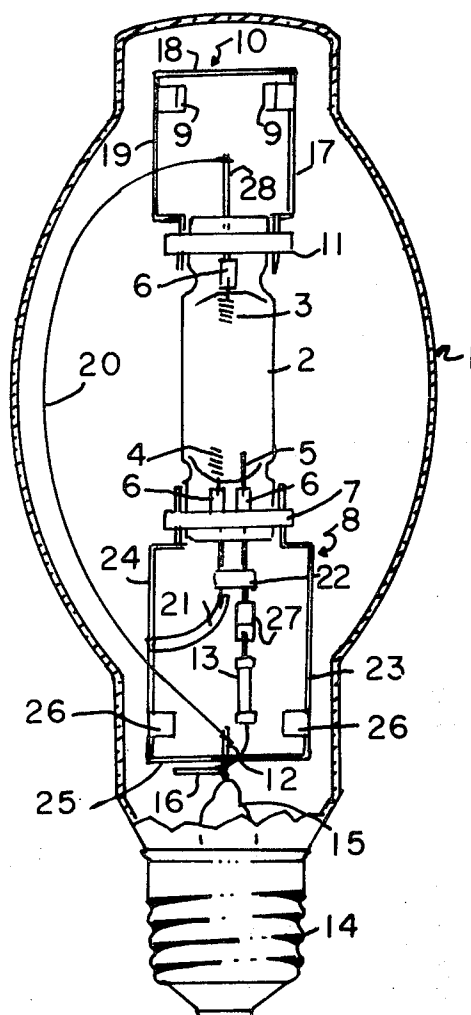
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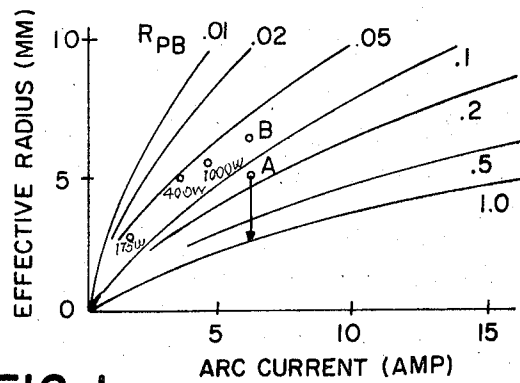
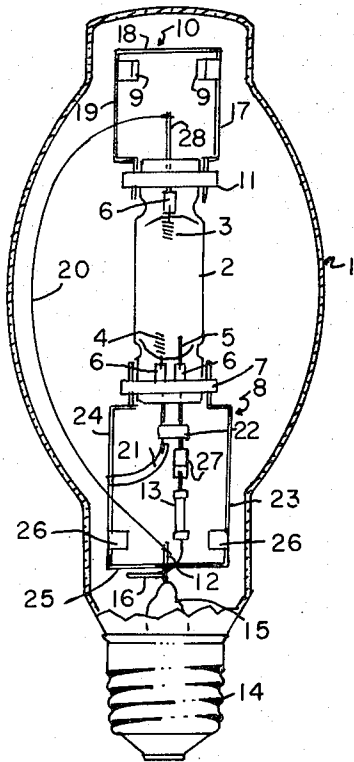
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**ABSTRACT**

A metal halide lamp is operated at higher than its normal rated wattage in order to increase its light output and efficacy, i.e., lumens per watt. But the quantity of fill in the arc tube must be less than a critical amount in order to prevent constriction of the arc discharge. The critical amount of fill is that which results in a value of 0.1 for the ratio of arc discharge pinch force to arc discharge buoyant force.

**2 Claims, 2 Drawing Figures**





# HEAVILY LOADED METAL HALIDE DISCHARGE LAMP

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

This invention is in the field of metal halide lamps. Such lamps include an arc tube having electrodes therein and containing a fill comprising mercury, an inert gas and one or more metal additives which can be added to the arc tube either as the metal or the halide but which, during normal lamp operation, is present in the vapor state in halide form.

### 2. Description of the Prior Art

Metal halide lamps of the type with which this invention is concerned are disclosed in the following U.S. Pat. Nos. 3,153,169, 3,226,597, 3,234,421, 3,250,934, 3,279,877, 3,285,725, 3,313,974, 3,324,332, 3,325,662, 3,331,982, 3,333,132, 3,334,261, 3,351,798, 3,363,132, 3,364,375, 3,374,377, 3,379,916, 3,384,775, 3,385,645, 3,405,303, 3,407,327, 3,424,935, 3,427,087, 3,450,925, 3,452,238, 3,484,640, 3,512,110, 3,569,766, 3,575,630, 3,590,306.

There are presently three ratings of metal halide lamps in general use, namely, 175 watts, 400 watts and 1000 watts. The arc tube volumes for each of these lamp ratings are about 3.5 cc, 14.5 cc and 35 cc respectively, and the inside arc tube diameters about 13, 20 and 22 mm. The respective arc lengths are about 25 mm, 45 mm and 90 mm. The loading on all three lamps is about 10 to 14 watts per square centimeter of arc tube wall area.

It has recently become desirable to operate some of these lamps at higher than their normal rated wattages. The advantages of increased light output and efficacy (lumens per watt) resulting from such overloading outweighs, in some applications, the disadvantage of a marked reduction in lamp life. One such application is in the lighting of sports stadiums.

One approach to the problem of overloading metal halide lamps is shown in an article entitled "A Highly Loaded Metal Halide Lamp And Its Applications" by W. E. Ishler and R. L. Paugh, appearing in the January 1971 issue of *Illuminating Engineering* at page 56.

We have found, however, that mere overloading of existing lamps, that is, say, operating a 1000 watt lamp at 1500 watts, does not yield desirable results. Under such conditions the lamp life is much too short and there is a severe problem with arc tube shattering.

A major cause of such short life and arc tube failure is a local constriction of the arc at some point along its length and consequent local overheating of the arc tube surface to a temperature for greater than the average increase in power, if distributed uniformly, would warrant.

Accordingly a major purpose of the invention is to reduce, minimize or eliminate the excessive constriction of the arc that results when metal halide lamps are operated under overload conditions, that is, at power inputs substantially in excess of 10 to 14 watts/cm<sup>2</sup>.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 shows curves of constant ratio of pinch force to buoyant force ( $R_{PB}$ ) on a plane of arc discharge radius versus arc discharge current.

FIG. 2 is a drawing of a metal halide lamp in accordance with this invention.

## THE INVENTION

We have found that increasing the loading of a metal halide arc discharge lamp above its normal rated loading can result in portions of the arc discharge displaying constricted sections. These sections usually occur approximately one third of the distance from either electrode. Increasing wattage increases the severity of the constrictions. In some cases the discharge becomes segmented, that is, alternate large diameter discharge portions followed by constricted areas. As already pointed out, this results in overheating of and damage to the arc tube; it can also result in a serious drop in luminous efficacy. It has been determined that this constriction results in part from the increased magnetic fields generated by higher arc current, e.g. 6.1 amperes for a 1000 watt lamp operated at 1500 watts versus the normal current of 4.2 amperes at 1000 watts.

An axial discharge current generates an azimuthal magnetic field which, according to electromagnetic theory, exerts a force on the current-carrying electrons at right angles to the direction of travel of the electrons and at right angles to the magnetic field itself, that is, in the radial direction. The direction of force is radially inward regardless of the direction of current flow, since the current-generated magnetic field reverses in phase with the current. This radial inward force, exerting a compression on the arc, leads to a constriction or "pinching" of the arc.

The "pinch effect," so called, is known, for example, in thermonuclear fusion reactors in which it is an object to compress a deuterium plasma into the smallest possible cross section thereby increasing the temperature and promoting fusion of deuterium nuclei to form helium with the liberation of energy.

In the present instance the existence of a pinching mechanism is clearly undesirable and must be avoided even at the higher arc currents associated with over wattage operation. As will be shown in the mathematical analysis to follow, the pinch mechanism is fundamentally unstable, since the pinching force *increases* as the arc radius decreases while the ability of the arc to resist such pinching *decreases* as arc radius decreases. Thus, once arc operation extends into the domain where pinch forces exceed a critical value, they quickly become dominant and the arc is pinched to a very small cross section.

The important parameter to consider, therefore, is the ratio of the magnitudes of pinch force to those of other forces on the arc. When the pinch force reaches a value which is no longer insignificant in comparison to other forces determining the arc cross section and position in the arc tube, an unstable condition is set up; any local perturbation in additive pressure which results in a slightly smaller radius to the arc leads to an increase in pinch force which leads to a further decrease in arc radius, a further increase in pinch force and so on.

For the purposes of comparison we choose the upward buoyant force of convection on an arc in a horizontally-operating arc tube. This is an easily-calculated force which leads to a measurable displacement of the arc upward from its normal axial location in the cylindrical arc tube. When other forces on the arc, such as those due to externally-imposed magnetic

fields, or when the pinch magnetic fields become comparable with the buoyant force, they must clearly effect comparable displacements and distortions of the arc geometry. As already mentioned, however, because of the unstable nature of the pinch mechanism, we expect to find that the critical ratio of pinch force to buoyant force above which pinch force becomes dominant is still substantially less than one.

In what follows, we shall first calculate the pinching force per unit length as a function of arc current and radius, then the buoyant force per unit length as a function of arc radius, and finally determine the ratio of the two.

The pinch force per unit length of arc can be calculated by assuming a relatively simple model for the current density distribution as a function of radius, which we have taken to be Gaussian.

The current density distribution, in amperes per square meter, can be expressed as follows:

$$j(r) = i/\pi r_o^2 e^{-(r/r_o)^2} \text{ amp/m}^2 \quad (1)$$

where  $j(r)$  is current density in amp/square meter,  $i$  is arc current in amperes,  $r$  is the variable radius in meters, and  $r_o$  is the effective radius of the arc. According to Gauss's theory the azimuthal magnetic field at radius  $r$  is given by

$$B(r) = \frac{\int_0^r j(r) 2\pi r dr}{2\pi r} = \frac{\mu_o i}{2\pi r} [1 - e^{-(r/r_o)^2}] \quad (2)$$

where  $B(r)$  is the magnetic field in Gauss,  $\mu$  is the permeability of free space and  $i$  is the current in amperes. The pinch force per unit volume is the vector cross product of  $j(r) \times B(r)$ , and the total force per unit length is the integral of this over the radius

$$P_1 = \int_0^\infty 2\pi r j(r) B(r) dr = \frac{0.52 \mu_o i^2}{2\pi r_o} \text{ newtons/meter.} \quad (3)$$

In eq. 3, all units are in the MKS rationalized system;  $\mu_o = 4\pi \times 10^{-7}$   $i$  is in amperes and  $r_o$  is in meters.

We follow the procedure of Elenbaas ("The High Pressure Mercury Vapor Discharge," North-Holland Publishing Co., Amsterdam 1951, p. 86), regarding the arc column as a cylinder of high temperature, low density gas at a temperature of about 5000°K immersed in an annular cylinder of lower-temperature higher-density gas at about 1000°K to calculate the buoyant force according to the following equation:

$$F_B = \pi r_o^2 (\rho_{\text{gas}} - \rho_{\text{arc}}) g \quad (4)$$

where  $F_B$  is force in newtons/meter,  $\rho$  gas is density of gas,  $\rho$  arc is density of arc in kilograms/cubic meter and  $g$  is a constant. In a typical metal halide lamp at about 3 atmospheres total pressure, the gas is 90 percent mercury vapor, so, with small error, we may use in equation 4 the densities of mercury vapor at 3 atmospheres pressure, and 1000°K and 5000°K;

$$\rho_{\text{Hg}} = P_{\text{atm}} \times .2 \text{ Kg/mol} / 2.24 \times 10^{-2} \text{ m}^3 \text{ atm/mol} \times 273/T^\circ \text{K}$$

Substituting in (4)

$$F_B = 80,000 \pi r_o^2 (1/1000^\circ \text{K} - 1/5000^\circ \text{K}),$$

$$F_B = 64 \pi r_o^2 \text{ newtons/meter.} \quad (5)$$

From Eqs. 3 and 5 we obtain the ratio of pinch force to buoyant force:

$$R_{PB} = 0.52 \mu_o i^2 / 2\pi r_o / 64 \pi r_o^2 \quad (6)$$

Substituting the value for  $\mu_o$ , at three atmospheres pressure, yields

$$R_{PB} = 0.52 i^2 / r_o^3 \quad (7)$$

Equation 7 is plotted in FIG. 1 in the form of contours of constant  $R_{PB}$  on the  $r_o - i$  plane.

Also shown on this plot are the values of effective radius and current for several different metal halide lamps of comparable vapor composition, 175 watt, 400 watt, 1000 watt, and two different 1500 watt lamps A and B; lamp A being a 1000 watt prior art lamp operated at 1500 watts and lamp B being a lamp in accordance with this invention. Note that the values of arc radius here are those of "effective radius," about two-thirds the extreme radius of the luminous arc. It is clear that the points for the three lower wattage lamps cluster about the  $R_{PB} = 0.05$  curve, but the point for 1500 watt lamp A lies between the curves for  $R_{PB} = 0.1$  and 0.2. Once the arc constricts for any reason, the point for lamp A will move in the direction indicated by the arrow, toward ever more rapidly increasing values of the pinch-force-to-buoyant-force ratio.

The point for 1500 watt lamp B, however, lies above the curve for  $R_{PB} = 0.1$ , and this lamp is stable, and shows little or no tendency to pinch. Other experiments carried out in still higher wattage lamps have indicated that the curve for  $R_{PB} = 0.1$  is indeed a critical boundary. Arcs whose radius-current points lie below and to the right of the curve for  $R_{PB} = 0.1$  show a pronounced tendency to pinch, while those above and to the left do not.

Although the calculation has been carried out for strictly horizontal lamps, pinch effects are observed in vertical operation as well as in operation at 45° angles. The choice of the horizontal attitude for calculations is dictated primarily by the fact that this is the only position for which convective forces are easy to calculate. The basic logic is, of course, that convective forces move the arc, and we therefore expect magnetic forces to move the arc when they become comparable with convective forces.

A wall-stabilized arc in a mercury-metal-halide vapor lamp at constant pressure will increase in radius as power input is increased. With the additive blends normally employed in these lamps, the radius will decrease as the additive pressure increases. If one uses the same quantity of additives and same size arc tube for a 1500 watt lamp as for a 1000 watt lamp, the pressure of additive in the vapor phase is higher at 1500 watts. Thus these two effects tend to cancel one another, and in

equilibrium the arc at 1500 watts would be slightly smaller in radius than the arc at 1000 watts.

If no change is made in additive blend or content, the reduced radius together with the higher arc current at 1500 watts result in  $r_0 - i$  points in the unstable range, i.e., having  $R_{PB}$  less than 0.1.

This effect can be overcome by reducing the quantity of additive dispensed into the arc tube. The actual pressure of additive vapors in the arc of a metal halide lamp has been shown to depend on both the quantity of additive and the wall temperature; presumably this result is obtained because the vaporization process is speeded up by hot gases from the arc convecting past the condensate film, vaporizing additive faster than the wall temperature itself would allow. Thus the total rate of vaporization, and hence additive pressure, depend on the surface area of the condensate film, i.e., the quantity of additive, as well as on the wall temperature.

Thus in order to increase the equilibrium radius of the arc in the 1500 watt lamp the additive quantity is reduced. The radius-current point for such a lamp is shown as B in FIG. 1. A substantial reduction of additive content is required, for example, from 1.2 mg of additive per cc of arc tube volume to 0.5 mg/cc. As would be expected from FIG. 1, this technique produces an arc which is stable and fills the arc tube. Luminous efficacy from lamps made with this technique are as high as 118 lumens per watt.

FIG. 2 shows a metal halide lamp in accordance with this invention. The lamp includes a generally tubular outer bulbous envelope 1 having a bulbous central portion and a conventional metal base 14 attached to the bottom thereof. Extending inwardly from base 14 and inside of the envelope 1 is a mount 15 having a pair of stiff lead-in wires 12 and 16 in electrical conducting relation with base 14. Disposed upon one of the stiff lead-in wires 12 is a lower, U-shaped support 8 welded thereto. The U-shaped support 8 comprises a pair of vertical wires 23 and 24 rising from a horizontal wire 25. The upper ends of lower U-shaped support 8 are welded together with a lower strap 7 which in turn supports an arc tube 2. Preferably, lower strap 7 includes two sections abutting against either side of the arc tube 2, thereby holding it firmly in place. They touch only the press seal of the arc tube and not the body. Generally, both sides of lower strap 7 can be of identical construction. A pair of bumpers 26 are welded to lower U-shaped support 8 and abut against the tubular portion of walls of the outer-bulbous envelope 1, thereby stabilizing the structure within the lamp. Preferably, these bumpers are made of a resilient material so that if the lamp is jarred they will absorb much of the shock.

Since lower U-shaped support 8 is electrically connected to stiff lead-in wire 12, support 8 forms part of the circuit in the device. Current passes from base 14 into lower U-shaped support 8 and thence to lead-in wire 21 which in turn is connected to an electrode 4 in the arc tube. It is sometimes desirable to place an insulating shield about lead-in wire 21 to prevent arcing within the lamp and between the various elements. Current passes from lead-in wire 21 to electrode 4 through an intermediary molybdenum foil section 6.

The other side of the circuit is formed through stiff lead-in wire 16 which is preferably bent out of place so that parts on one side of the line are insulated from those on the other side. A resistor 13 is attached to stiff lead-in wire 16 through a lead-in wire associated there-

with and thence to a connector 27 which in turn leads through molybdenum foil section 6 to a starting probe 5. A bimetal 22 is disposed between lead-in 21 attached to the electrode 4 and lead-in wire 27 which is attached to starting probe 5. Bimetal 22 is biased open when the lamp is off but when the lamp starts, it biases closed against the lead-in wires to probe 5, thereby establishing the same current potential at probe 5 and electrode 4. Such closing prevents electrolysis between probe 5 and electrode 4.

At the other end of arc tube 2, an upper support 10 is mounted within the tubular portion of bulbous envelope 1. Support frame 10 includes a horizontal section 18 having vertical wires 17 and 19 extending downwardly therefrom and attached at the free ends to an upper strap 11 which surrounds the press seal of arc tube 2 and rigidly holds it in place. Preferably, the construction and disposition of upper strap 11 is similar to lower strap 7. A pair of upper bumpers 9 are mounted upon vertical wires 17 and 19 of upper support 10 and resiliently abut against the sides of the tubular portion of bulbous envelope 1. Such disposition prevents breakage of the lamp if the arc tube is shaken or dropped.

A lead-in wire 28 extends to the outside of arc tube 2 and is attached at its inner end to a molybdenum foil section 6 and thence to an electrode 3. An electrical connection is made between stiff lead-in wire 16 and lead-in wire 28 through a thin conducting lead 20 which may be of any suitable conducting material. Preferably, conducting lead 20 is distantly removed from the arc tube 2.

In one example of a lamp (lamp B) in accordance with this invention, arc tube 2 contained an additive consisting of 14.4 mg sodium iodide, 3.6 mg scandium iodide and 0.5 mg thorium for an additive content of 0.5 mg per cc of arc tube volume. Arc tube 2 also contained 160 mg mercury and a starting gas (argon, at 20 mm absolute pressure). Arc length was 91 mm and the inside diameter of arc tube 2 was 22 mm. At 1500 watt operation, the wall loading was about 20 watts per square centimeter, the lamp had an efficacy of 103 lumens per watt and a rated life of 1500 hours. The pinch force to buoyant force ratio was 0.07.

A lamp having the same physical dimensions as the above example, but designed for 1000 watt operation (lamp A), had an additive content of 44 mg or 1.2 mg per cc, more than double that of the above example. The wall loading was about 13.5 watts per square centimeter and the lamp had an efficacy of 100 lumens per watt and a rated life of 7500 hours.

The additives may be added as the metal or as the halide, but when added as the metal, the fill must contain sufficient halogen or halide (such as mercury halide) to permit reaction thereof with the additive metals to form the metal halide. As used herein total additives includes halogens and all metal halides added to the arc tube but excludes mercury added as the metal.

We claim:

1. A heavily loaded metal halide arc discharge lamp of the type normally used for general illumination comprising a sealed light transparent arc tube having electrodes disposed therein and containing a fill including mercury and an additive, said additive including a metal halide, the quantity of additive being such that the ratio of arc discharge pinch force to arc discharge buoyant force, during normal lamp operation is less than 0.1, the wall loading at normal lamp operation being in excess of 14 watts per square centimeter of arc tube wall area.

2. The lamp of claim 1 wherein said additive includes scandium and sodium and wherein the total additive content is about 0.5 mg per cc of arc tube volume.

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