Feb. 9, 1960 H. SCHIRMER ET AL **2,924,733**

WALL-STABILIZED ELECTRIC HIGH-PRESSURE GASEOUS DISCHARGE LAMP

Filed Sept. 11, 1958

Fig. 1.

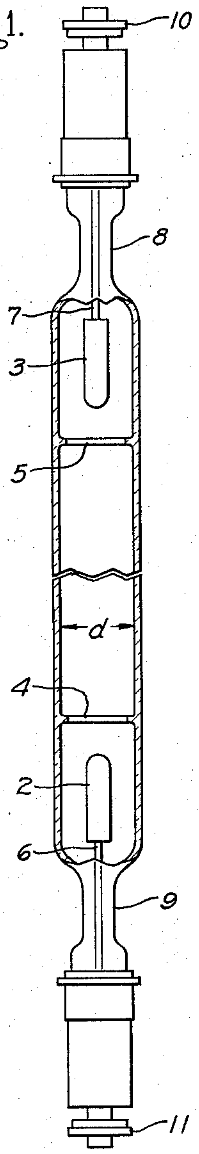
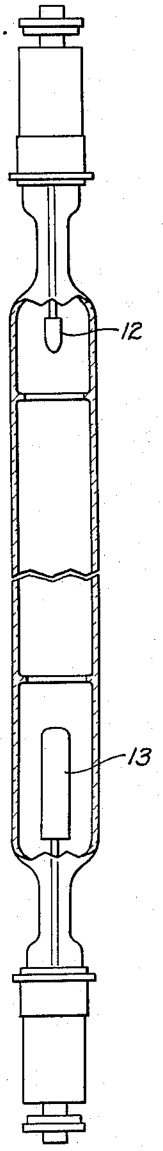


Fig. 2.



Inventors:
Herbert Schirmer,
Horst Grabner,
by Ernest W. Legree
Their Attorney.

United States Patent Office

2,924,733
Patented Feb. 9, 1960

2,924,733

WALL-STABILIZED ELECTRIC HIGH-PRESSURE GASEOUS DISCHARGE LAMP

Herbert Schirmer, Berlin-Charlottenburg, and Horst Grabner, Berlin-Zehlendorf, Germany, assignors to Patent-Treuhand-Gesellschaft fur elektrische Gluhlampen m.b.H.

Application September 11, 1958, Serial No. 760,404

Claims priority, application Germany
September 17, 1957

8 Claims. (Cl. 313—185)

This invention relates to high-pressure gaseous discharge lamps for continuous operation, as distinguished from pulsed operation. It relates more particularly to xenon discharge lamps, wherein the discharge arc is stabilized by the influence of the wall of the discharge envelope and the electrode distance amounts to a multiple of the envelope diameter.

An arc discharge may be designated as wall-stabilized if no convection effects appear. In such case the arc fills the whole cross section of the discharge envelope up to an edge zone determined by decrease of temperature of the plasma towards the tube wall. The data relative to the arc may then be calculated by integration of the Elenbass-Heller differential equation and with the aid of the theory of electrical conductivity, heat conductivity and radiation.

In practical realizations of wall-stabilized high-pressure gaseous long arc lamps, more particularly xenon lamps, for continuous operation there have been used up to now, for the purpose of obtaining a sufficiently high gas temperature for high luminus efficiency, very high high input concentrations in plasma and wall loading. These have been so high that only by means of artificial cooling, e.g., water cooling, could melting of the quartz glass used as the envelope material be prevented. Such xenon high-pressure gaseous discharge lamps are designated commercially as type XBF lamps; they show an efficiency of 35 lm./w. (lumens per watt) and burn silently. They may be built also as lamps of high wattage. The required water cooling, however, increases the cost of such lamps and restricts their utilization.

High-pressure gaseous discharge lamps as known hitherto which do not require any artificial cooling but only cooling by natural air convection have, up to the present, never been made as wall-stablized lamps of low filling or operating pressure. There are known for instance air-cooled short-arc lamps with a large bulb and, compared therewith, a very small arc diameter and in consequence thereof with high power concentration; because of the limited temperature resistance of the quartz glass it is impossible with such high power concentration to provide the bulb wall as near to the arc as is necessary for obtaining a stabilizing effect. There is also well know an elonagted xenon high-pressure discharge lamp without artificial cooling but with lower output, e.g., 1 kilowatt, in which the arc fills only a small part of the envelope cross section; it cannot be considered as wall-stabilized in the present sense but it has a convectional operation. Its cold pressure is proportionately high with 600 mm. Hg. In another design of an air-cooled xenon lamp stabilizing of the arc is obtained by several diaphragms each with a central aperture in the discharge path. In other cases stabilizing is obtained by externally applied magnetic fields. All these lamps without artificial cooling have, hitherto, been provided with a gas filling of proportionately high pressure in order to obtain a high electrical wattage per unit of volume and, thereby, as high a temperature and light output as possible.

High-pressure gaseous discharge lamps according to the present invention, the electrode distance of which amounts at least to double the inside tube diameter are wall-stabilized. This has been established theoretically and confirmed experimentally. Artificial cooling of the discharge tube being omitted, the lamps have an avearge input concentration in the discharge which lies between about 5 and 200 w./cm.^{3} (watts per cubic centimeter) only if quartz glass is used as the bulb material and have a filling pressure of the gas or gases reduced to a lamp without dead space between 5 and 350 mm. Hg.

The power concentration is lower by at least one order of magnitude (factor of 10) than with known artificially cooled lamps. This fact results from the lower heat radiation by the bulb surface in consequence of omitting any artificial cooling. An important feature in such lamps according to this invention consists in that with the required low input concentration, the pressure must be kept low so that the arc is not disturbed by convection effects but is wall-stabilized. Also the low pressure permits sufficiently high gas temperatures to be obtained. The importance of this fact may be understood when it is considered that the radiation power of an arc (with maintained temperature) decreases as the pressure is reduced because the number of radiating atoms decreases with reduced pressure at constant temperature. Thus the arc must have a higher temperature for an applied electrical wattage at low pressure than at higher pressure provided the arc diameter is so dimensioned that the increased heat conduction at low pressure does not make completely ineffective any temperature increase. Quantitative calculations have indicated these functional relations between input concentration, filling pressure, radiation power and heat losses whereas simple qualitative considerations have been unproductive of exact conclusions.

When such low filling pressures are used in the field of high-pressure gaseous discharge, e.g., with xenon, it might be feared that a thermal balance would no longer be achieved so that the discharge would not show any strong continuum and sufficient light output. This supposition is rather natural because of the small cross sections of action of xenon atoms in regards to probability of an electron impact. In fact, however, a thermal balance will be achieved with these pressures if sufficiently high current intensities are applied. A reason for this latter fact may be seen in the extensive coulomb fields of the ions which bring about the necessary coupling of the electron gas and the carrier gas.

Lamps according to the present invention with low input concentration are discharge lamps having real high-pressure characteristics, as evidenced by the strong continuum. This means the gas temperature is only a little less than the electron temperature. Even if lowest pressures are used, only a small difference (about 150°) exists between electron and gas temperature, as measurements have shown. By comparison, in the case of a low-pressure discharge, the electron temperature is higher than the temperature of the gas by a factor of 10 at least. The average gas temperature in a wall-stabilized continuous burning xenon high-pressure discharge amounts to about 6500 to 9000° K. whereas the electron temperature is about 100° higher. By comparison, the difference in a low-pressure discharge would be 1000 to 10,000°.

Consequently, lamps made according to the present invention represent a type of high-pressure discharge lamps which was unknown hitherto. The above-mentioned filling pressures relate, strictly speaking, to discharge envelopes without dead space, that is spaces into which the discharge does not spread, such as behind the electrodes. Any dead space must be taken into consideration when determining the filling pressure in order to obtain similar lamp characteristics, and especially, of course where the dead volume is a high percentage of the total volume. The real filling pressure p_F results, then, from the filling pressure reduced $p_{F\ \text{red.}}$ to a lamp without dead space with similar properties by means of the following proportion:

$$p_F=\left(1+\frac{1}{V_{ges}}\sum^{n}a_n(V_T)_n\right)p_{F\ \text{red}}$$

where V_{ges} is the volume of the total discharge envelope, $(V_T)_n$ the volume of the *n*th dead space, and the factor

$$a_n=\frac{T_E}{(T_T)_n}-1$$

The factor a_n takes into account the difference between the average temperature in the discharge T_E and the gas temperature in the specific dead space $(T_T)_n$ (all temperatures in ° K.).

With low filling pressures of less than 350 mm. Hg, preferably 20–200 mm. Hg, used in these lamps, the operating pressure lies between about 1/10 and 4 atmospheres dependent upon the difference between space and plasma temperature as found from the temperature distribution calculated per Elenbaas-Heller. With such low filling and operating pressures, the lamps are wall-stabilized. In case of higher pressures, the discharge arc is contracted; it no longer burns wall-stabilized but is subject to convection disturbances. Generally, the mode of operation of the lamp is, then, dependent on position. The upper pressure limit depends on the bulb diameter, and increases with decreasing diameter. The lower limit for wall-stabilized discharges is determined by the requirement of thermal balance in the plasma.

Within the pressure range used in lamps according to the present invention, under constant wall loading and other constant conditions, the luminous efficiency is quite independent of pressure throughout a wide range as experiments have shown. This follows from the fact of increasing plasma temperature with decreasing pressure previously described. Luminous efficiency would be improved thereby because the continuous radiation with increasing temperature increases more than line radiation which lies often outside the visible range. But, simultaneously, the coefficient of heat conduction increases with decreasing pressure and, thereby, the loss by heat conduction. By the working of both the aforesaid factors in opposite directions, luminous efficiency is almost independent of pressure over a wide range. The luminous efficiency with constant wall loading is in practice given by the arc output per centimeter of length. A certain arc output per centimeter may be obtained according to the above explanations:

(1) in the usual manner by means of high pressures: this entails high gradients, low current, small discharge cross section, high input concentration and stabilizing by additional means such as magnetic fields, diaphragms etc.; or

(2) as it is obtained in lamps according to the present invention, by means of low pressures: this entails low gradients, high current, large discharge cross sections, low input concentration, and wall stabilization.

Therefore, it follows from the present invention that it is not necessary in high-pressure gaseous discharges to use high pressures and outer stabilization. Nearly the same luminous efficiency may be obtained in opposite manner, i.e., with low pressures and wall stabilization; in such case however, contrary to higher pressure discharge, a higher current must be used and the arc diameter must be large.

A low filling pressure shows the advantage that in manufacture of the lamps, gas filling and sealing-off the exhaust tube may be made always with a pressure below atmospheric. By comparison with lamps used hitherto, consumption of expensive filling gas is much smaller. If low pressures are used, particularly if the operating pressure in the lamp is nearly equal to atmospheric, then the danger of breaking is, practically, eliminated and the wall thickness of the discharge tube may, therefore, be kept small.

As the gas filling there may also be used instead of xenon one of the other rare gases, e.g., krypton, argon, neon or helium or mixtures of several or of all rare gases. It is, however, known that the proportion of light radiation to heat losses is most favorable if xenon is used as the filling gas whereby also wall loading is the least. Also additions, e.g., of hydrogen, CO_2, metal vapours, halogens or nitrogen may be present in the rare gases.

The lamp operates especially favorably with regard to luminous efficiency at high wattages. Heat conduction takes place from the arc surface and is, at first, proportional to the surface area. If the arc diameter increases, heat losses increase almost proportionally to the diameter; whereas the output, under the assumption of constant current density and constant gradient, increases with the square of the diameter. Therefore as the diameter is increased, heat losses do not increase proportionally to the wattage but only with the root of the wattage. Thus the proportion of radiation percentage to heat loss is shifted with increasing discharge diameter, thereby increasing wattage in favor of the radiation whereby an upper limit for the luminous efficiency is given by the plasma temperature. Tube diameters of the lamps according to the present invention are generally chosen not less than one centimeter, and in most cases greater. The cross section is determined by the current used for the discharge. Lamps according to this invention may be manufactured for any high output and there is no upper limit in rating.

Lamps according to the invention may be operated with A.C. as well as with D.C. The shape and size of the lamp electrodes are determined by the current load and by the kind of operation, that is whether on D.C. or A.C. There may, suitably, also be provided diaphragms, for instance in the form of perforated quartz glass discs connected with the quartz glass envelope, in front of the electrodes as a protection against sputtering. By suitably lengthening the discharge path, for instance to 1 meter as it is possible in high-pressure discharge lamps according to the invention, such a high operating voltage is obtained that the electrode losses compared with the energy conversion in the arc become insignificant, thereby favorably influencing efficiency.

If compared with water-cooled lamps of similar output, lamps according to this invention show the advantages of simpler handling, less need of attendance, and greater safety in consequence of omitting the outer envelope and the water supply with the pipes. The plasma temperature of air-cooled, wall-stabilized lamps according to the present invention is just slightly lower than that of liquid-cooled lamps. Therefore, color temperature and color appearance differ only little from sunlight, just as is the case with liquid-cooled lamps.

The limit for non-artificial cooling of lamps is given by the surface load capacity of the envelope. The above-mentioned data about the maximum permissible input concentration relates to quartz glass used as the material for the discharge tube. In case of transparent material which may have a higher thermal load capacity than quartz glass, as for instance aluminum oxide (sapphire), magnesium oxide etc., the input concentration in the discharge may be higher whereby luminous efficiency would be furthermore increased. Input concentration could, of course, be further increased by using artificial cooling, e.g., by blowing-in an air-current, by liquid-cooling or the like.

Some examples of lamps according to the present invention are shown in Figs. 1 and 2.

Fig. 1 shows a lamp designed for A.C. operation. The lamps may be operated because of their positive characteristic either immediately on A.C. voltage of 220 volts or on a higher voltage, if desired, by connecting in series a choke coil. The tubular envelope **1** made from quartz glass and having an inside diameter *d* contains xenon as the filling gas. A central portion of the envelope has been broken out to shorten the figure. The cylindrical electrode bodies **2** and **3** of thoriated tungsten take about one third of the tube diameter. In front of the electrodes are mounted the perforated quartz glass discs **4** and **5** serving as protective diaphragms. The electrodes are supported on conductors **6**, **7** sealed through tube extensions **8**, **9** and connected to base terminals **10**, **11**.

Fig. 2 shows a lamp designed for D.C. operation and which may also be operated without series resistance. In this lamp the cathode **12** is made smaller than the anode **13**.

The following table I shows data on some wall-stabilized xenon high-pressure discharge lamps without artificial cooling made according to the present invention and designated XBL 3000, XBL 16000, and XBL 50000. The data are compared with corresponding data on a well known wall-stabilized liquid cooled xenon long-arc lamp designated XBF 6001.

Table I

	XBF 6001	XBL 3000	XBL 16000	XBL 50000
input .... kw..	6	3	16	50
operating voltage .... v..	170	110	220	220
current intensity .... a..	35	29	75	240
electrode distance .... cm..	11	40	125	130
tube diameter *d* .... cm..	0.7	2	3	5
gradient .... v./cm..	14.4	2.5	1.7	1.6
surface load .... w./cm^2..	230	11	13	23
input concentration .. w./cm.^{3}..	1,310	23	18	20
current density .... a./cm.^{2}..	91	9	11	12
luminous intensity .... cd..	18,000	5,400	38,000	140,000
luminous flux .... lm..	210,000	66,000	430,000	1,600,000
luminous efficiency .... lm./w..	35	22	27	32
filling pressure .... mm. Hg..	1,030	125	75	55
operating pressure .... atm..	24	2.5	1.4	0.8
plasma temperature ...... ° K..	7,800	7,000	7,150	7,300

The above table shows clearly that the input concentration in w./cm.^{3} of air-cooled lamps is smaller by one order of magnitude (factor of 10) when compared with that of liquid-cooled types. The input concentration of the above-mentioned air-cooled lamps lies below 100 w./cm.^{3} but that of the liquid-cooled XBF lamp amounts to more than 1000 w./cm.^{3}. A preferred range of input wattage concentration for xenon filled lamps in accordance with the invention is 10 to 80 watts per cubic centimeter. The electrical gradients and current densities of the air-cooled lamps are low when compared with those of liquid-cooled lamps. Also the filling pressure and, thereby, the operating pressure is low in the XBL lamps and the inside diameter of the discharge envelope is large by comparison with corresponding values of the XBF lamps.

The discharge tube of the lamp according to this invention is not restricted to the straight form but it may also be bent in order to meet special optical requirements. There may be chosen beside the circular tube cross sections shown in the accompanying drawings any other cross section form. It may be advantageous to operate A.C. lamps in threephase connection.

An additional increase in radiation in any desired spectral ranges may be obtained by means of a combination with a known fluorescent material or mixture. The intensity of light emission on one side of the discharge envelope may also be increased by providing a reflecting layer on a part of the discharge envelope.

Lamps as described in the present invention are quite suitable for illumination of large areas of all kinds, as for instance large rooms, railway yards, theaters, sport fields and factories, for coast lighting and landing ground illumination or the like.

The above described lamps proved particularly suitable for instance for fast color testing purposes as well as for aging plants. They are advantageous also for blueprinting purposes because for such purposes lamps of great length and of large diameter are desired in order to have uniform illumination of large areas. The lamps may be used also in large radiation plants, e.g., for light baths, for cultivation of plants or the like where all ranges of radiation may be utilized.

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

1. An electric high pressure gaseous discharge lamp for continuous operation comprising an elongated envelope of a radiation transmitting material having a temperature resistance similar to quartz, a pair of electrodes mounted in said envelope at a distance apart amounting to at least double the inside diameter of the envelope, and a gaseous ionizable filling within said envelope of an inert gas from the group consisting of xenon, krypton, argon, neon, helium and mixtures thereof at a filling pressure equivalent to a pressure in the range of 5 to 350 millimeters of mercury in a lamp without dead space, said lamp having an input wattage concentration in the range of 5 to 200 watts per cubic centimeter and being so proportioned with respect to distance apart of the electrodes and inside diameter of the envelope that with the said input concentration and with the said filling pressure in the absence of any artificial cooling a wall-stabilized discharge is achieved.

2. A wall-stabilized electric high pressure gaseous discharge lamp as defined in claim 1 whereof the envelope material is quartz and wherein the input wattage concentration in the discharge is in the range of approximately 10 to 80 watts per cubic centimeter.

3. A wall-stabilized electric high pressure gaseous discharge lamp as defined in claim 1 wherein the equivalent filling pressure in a lamp without dead space lies between 20 and 200 millimeters of mercury.

4. A wall-stabilized electric high pressure gaseous discharge lamp as defined in claim 1 wherein the rare gas filling contains a minor proportion of an additional gas from the group consisting of carbon dioxide, metal vapors, halogens, hydrogen, nitrogen and mixtures thereof.

5. A wall-stabilized electric high pressure gaseous discharge lamp as defined in claim 1 whereof the envelope consists of a radiation transmitting material having a higher temperature resistance than quartz.

6. An electric high pressure gaseous discharge lamp for continuous operation comprising an elongated tubular quartz envelope, a pair of electrodes mounted in said envelope at a distance apart amounting to at least double the inside diameter of the envelope, and a xenon filling within said envelope at a filling pressure equivalent to a pressure in the range of 20 to 200 millimeters of mercury in a lamp without dead space, said lamp having an input wattage concentration in the range of approximately 10 to 80 watts per cubic centimeter and being so proportioned with respect to distance apart of the electrodes and inside diameter of the envelope that with the said input concentration in the absence of any artificial cooling a wall-stabilized discharge is achieved.

7. A wall-stabilized electric high pressure gaseous discharge lamp as defined in claim 6 wherein said inside envelope diameter is not less than approximately 1 centimeter.

8. An electric high pressure gaseous discharge lamp for continuous operation comprising an elongated tubular

envelope of a radiation transmitting material having a temperature resistance similar to quartz, a pair of electrodes mounted in said envelope at a distance apart amounting to at least double the inside diameter of the envelope, and a gaseous ionizable filling within said envelope of an inert gas from the group consisting of xenon, krypton, argon, neon, helium and mixtures thereof at a filling pressure equivalent to a pressure in the range of 5 to 350 millimeters of mercury in a lamp without dead space said lamp having an input wattage concentration up to 1000 watts per cubic centimeter and being so proportioned with respect to distance apart of the electrodes and inside diameter of the envelope that with the said input concentration and with the said filling pressure in the presence of artificial cooling a wall-stabilized discharge is achieved.

References Cited in the file of this patent

UNITED STATES PATENTS

2,298,239	Stirnkorb	Oct. 6, 1942
2,367,595	Marden	Jan. 16, 1945
2,654,043	Freeman et al.	Sept. 29, 1953
2,761,086	Noel et al.	Aug. 28, 1956
2,774,013	Willoughby	Dec. 11, 1956