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The Concentrated-Arc Lamp

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DURING the war a new type of light source was developed under a contract issued through the Optics Division of the National Defense Research Committee. The new lamp, called the concentrated-arc lamp, is basically a direct-current arc lamp made with permanent, fixed electrodes which are sealed into a glass bulb filled with an inert gas. The name, "concentrated-arc," comes from a characteristic of the lamp which makes it possible to concentrate the arc activity upon a small portion of the electrode so as to produce a very high intensity light source in the form of a luminous circular spot which is fixed in position, sharply defined and uniformly brilliant.

The degree to which this concentration may be carried is illustrated by the 2-watt concentrated-arc lamp whose luminous spot is only 0.003 of an inch in diameter with a maximum brightness of 100 candles per sq. mm. Ordinary tungsten filament lamps operate at about 10 candles per square millimeter while the brightness of the crater of a carbon arc lamp is about 135 candles per square millimeter. The area of the spot formed increases with the current so that a 100-watt lamp has a spot 0.059 of an inch in diameter, while the spot of a 1500-watt lamp is 0.35 inch in diameter.

The source of the light is an incandescent spot which forms on the specially prepared negative electrode or cathode. This cathode is the unique element of the new lamp. It is made by packing zirconium oxide into a small cup or the open end of a tube which is made of tungsten, molybdenum, or tantalum, these metals being selected because of their high melting temperatures.

The positive electrode or anode, also made of a metal with a high melting point, consists of a simple sheet or plate which has sufficient radiating surface so that during operation it will reach no more than a dull red heat.

These two electrodes are mounted in the bulb so that the exposed oxide surface of the cathode is but a few hundredths of an inch from and directly behind a hole in the center of the anode. This hole is slightly larger in diameter than the cathode tube or cup and provides a window for the emergence of light from the cathode.

After the bulb has been evacuated, it is filled with an inert gas, usually argon, to almost atmospheric pressure. The cathode is then put through a "forming" process. To do this a high potential direct-current source, with suitable current limiting resistors in series, is connected to the electrodes so that an arc strikes between the anode and the metallic tube of the cathode. After a few seconds, the cathode tube becomes red hot and heats the zirconium oxide packed in it to a temperature where the oxide becomes electrically conductive. The arc then strikes between the anode and the oxide and ionic bombardment raises the temperature of the surface

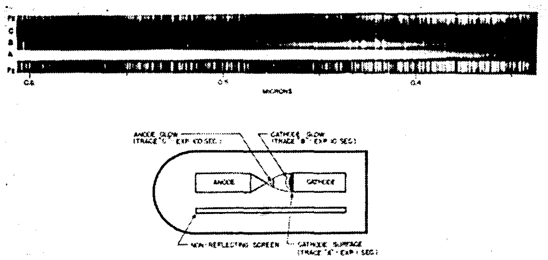

FIG. 1. Spectrogram of various regions of a concentrated arc.

of the oxide to or above its melting point of 3000° K. The molten oxide flows and bonds itself to the sides of the metal tube forming a smooth glassy surface.

The exact mechanism of the next phase of the forming sequence is not fully understood but it is thought that in the molten state and under the intense ionic bombardment of the arc, some of the zirconium oxide is reduced to metallic zirconium. The zirconium atoms form a thin surface layer in equilibrium with the molten oxide. The released oxygen migrates to the anode which always shows signs of oxidation.

Zirconium metal is apparently a better electron emitter at high temperatures than is the oxide and it also has a lower melting temperature; thus as soon as the zirconium surface layer is formed the temperature of the cathode drops slightly and the underlying oxide solidifies and supports the thin film of molten metal on its surface. It is this film of molten metal which is the chief source of the visible radiation from the lamps. The film, once formed during manufacture, remains to be heated and become incandescent whenever the lamp is relighted. It is so thin that surface tension holds it to the oxide backing so the lamps may be burned in any position.

Spectrograms of the portion of the arc stream very near the cathode always show zirconium lines. This indicates that some evaporation of free zirconium occurs. Very little zirconium is lost however since positive zirconium ions are produced by electron bombardment and are driven back to the cathode. If any metal atoms do escape from the cathode, they are replaced by reduction of the underlying oxide. As a result of these processes, the lamps have lives which are measured in hundreds of hours.

The cathode-current densities in the Concentrated-Arc Lamp vary from about 250 amperes per square centimeter for the 100-watt lamp to about 900 amperes per square centimeter for the 2-watt lamp. Assuming the electron emitter to be the thin zirconium layer at a temperature slightly below 3000° K, the melting point of the oxide, and using the constants commonly given for a zirconium filament in a vacuum, values of electron emission are obtained which are of the order of 500 amperes per square centimeter. This value is entirely in line with the actual current densities found in the lamps and seems to confirm the present belief that the arc is maintained entirely by thermionic emission, and that the active surface of the cathode consists of a thin layer of zirconium atoms at a temperature considerably above the normal melting point of the bulk metal.

The radiation from the concentrated-arc lamp appears to be divided into three parts as follows:

1. Continuous radiation from the molten cathode surface.
2. Line radiation from the excited gas and vapor.
3. Continuous radiation in the spectral region from at least 3500A to 5000A originating in the excited gas and vapor.

The existence of the three types of radiation is shown by the spectrograms in Fig. 1. The three exposures were made from the cathode spot, cathode glow, and anode glow portions of the arc of a specially constructed 100-watt lamp. The cathode spot is by far the brightest portion. Even though the exposure times for the three

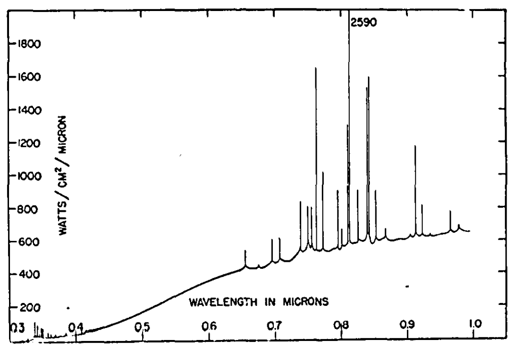

FIG. 2. Spectral distribution of radiation from a 100-watt concentrated-arc lamp.

traces varied in the ratio of 1:10:100, it is found that the trace of the cathode spot area is more than ten times as intense as that of the cathode glow area.

Thus the molten incandescent cathode surface or cathode spot furnishes the greatest amount of radiation from the arc. It is, in all probability, thermal radiation from the bound molecules and atoms present in the surface. The spectral distribution of this radiation is essentially that of a gray body.

The characteristic radiation of the rare gas filling and the zirconium vapor comes from the arc stream and in particular from the cathode glow region.

Spectrograms of 100-watt concentrated-arcs in argon show lines of excited and singly ionized argon and zirconium atoms and doubly ionized zirconium atoms (AI, ZrI, AII, ZrII, and ZrIII). The excited argon, AI, and the singly ionized zirconium, ZrII, atomic lines are the strongest and most numerous, only a few very weak AII and ZrIII lines appearing.

The continuum shown in the spectrogram of the cathode glow region seems to have its origin in this dense cloud of argon gas and zirconium ions which is very close to the molten cathode surface. Since special precautions were taken in constructing the lamp to make sure that scattered or reflected light from the molten cathode surface could not enter the spectrograph when the cathode glow was used as the source of radiation, it seems quite certain that this continuum has a different origin than that of the cathode spot.

Thus concentrated-arc lamps emit radiation from two main sources, the white hot zirconium cathode surface and the cloud of excited zirconium vapor and argon gas extending for a few thousandths of an inch from the cathode. The portion which originates from the cathode surface has a continuous spectral distribution. It extends in measurable amounts from 2500A in the ultraviolet, through the visible, reaching a maximum near 10,000A and on into the infrared. That portion of the radiation which comes from the cloud of excited vapor and gas shows three principal spectra, a continuum extending from the ultraviolet to about 5000A, the normal, singly and doubly ionized zirconium spectrum and the normal and singly ionized argon spectrum.

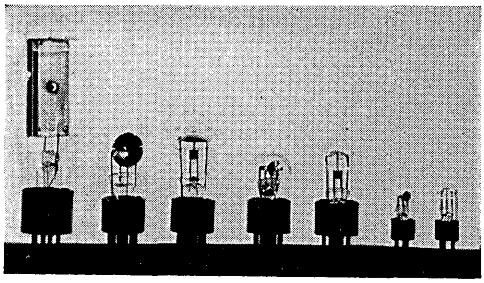

FIG. 3. 100-, 25-, 10-, and 2-watt concentrated-arc lamps.

The spectral distribution characteristic shown in Fig. 2 thus represents the combination or sum of these several individual spectra. Radiation shorter than 3000A or longer than 5 microns is not transmitted by the type of glass used for the bulbs of standard type lamps.

A line of standard size lamps has been developed in sizes ranging from 2 to 100 watts. Pictures of these lamps are shown in Fig. 3. Larger lamps are made but designs have not been standardized.

The diameter of the cathode spot of a given lamp depends upon the current. If the current is increased, the spot slowly grows larger, taking several seconds to adjust itself to the new condition. Figure 4 shows how the diameter of the light sources vary from 0.05 mm to 3.5 mm as the lamp currents are changed in the several standard sizes of lamps. While the lamps are designed to operate at a definite current value, it is possible to adjust the spot size by changing the current. The upper limit of this process is reached when the spot completely covers the activated zirconium oxide surface. If the current is increased further, the spot becomes brighter but not larger and the life of the lamp is shortened. When the current is very much less than normal, the spot becomes variable in size and position and the lamp is unstable.

One of the advantages of the concentrated arc is its high brightness. As shown by Fig. 5, the maximum brightness of standard lamps at their normal operating current varies between 40 and 100 candles per square millimeter.

To the eye, the cathode spot appears to have a uniform and constant brilliance. Measure-

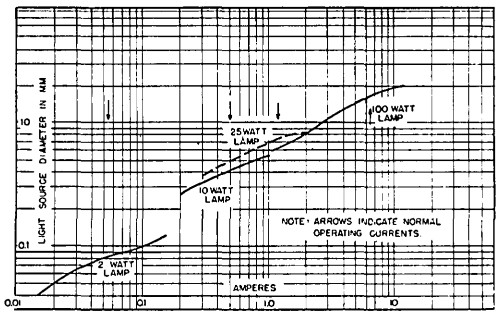

FIG. 4. Change of light source diameter with current of concentrated-arc lamp.

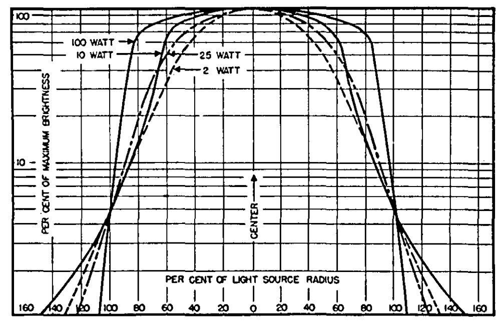

FIG. 6. Average cathode brightness distribution of concentrated-arc lamps.

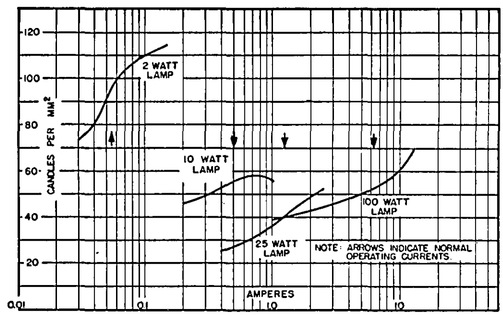

FIG. 5. Change of maximum brightness with current of concentrated-arc lamp.

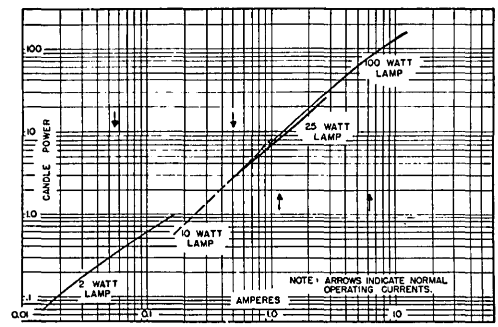

FIG. 7. Change of candlepower with current of concentrated-arc lamps.

ments show that the brightest part is near the center. The average brightness variation across the spot, for the several sizes of lamps, is shown in Fig. 6. Variations in the position taken by the arc stream and irregularities in the cathode surface may produce an unsymmetrical and changing brightness distribution. Also, the spot position may shift slowly during operation by an amount equal to a small percentage of its own diameter. These factors combine to produce variations of about ten percent in brightness and total emitted light.

The candlepower increases with the current, maintaining an almost linear relationship over a very wide range as shown by the curves of Fig. 7.

The efficiency of concentrated-arc lamps, as measured in candlepower per watt input to the lamp, varies between 0.15 for the 2-watt lamp to 0.8 for the 100-watt lamp. This characteristic is shown in Fig. 8. Comparable figures for tungsten filament lamps range from 0.54 for a 6-watt lamp to 1.29 for 100-watt lamps.

The spatial light distribution curve of Fig. 9 plots the light about the axis of the cathode and shows that concentrated-arc lamps have a cosine distribution.

The average changes in the major characteristics of a group of twenty-five 10-watt lamps during aging is shown by the curves of Fig. 10. These show that during the first few hours of running the candlepower and light spot diameter will decrease while the maximum brilliance increases. After about 100 hours of operation, these characteristics become reasonably stable around 80 percent of the initial candlepower, 75 percent of the initial light spot diameter, and 140 percent of the initial brilliance.

The mortality curve of Fig. 11 shows the average life of 2-watt lamps to be 175 hours. Similar data on larger lamps give 700, 800, and 1000 hours on 10-, 25-, and 100-watt lamps although individual lamps have shown lives up to 5000 hours. Failure is usually caused by loss or shrinkage of the cathode-filling material.

Concentrated-arc lamps have a negative volt-ampere characteristic as is shown by the curves of Fig. 12. Consideration must be given this fact in the design of their power supplies.

The lamps are started with a high voltage which breaks down the gap in the lamps. They are usually run from a rectifier or direct-current generator or battery with sufficient ballast resistance in series to limit the current to its normal value. Some lamps have been made with multiple anodes which permit their operation from an alternating current supply, in which case the lamps act as their own rectifiers.

Two-watt lamps require 1000 volts for starting and 130 volts or more for running. Larger lamps need up to 2000 volts for starting and may be run from sources supplying from 24 volts up, higher supply voltages resulting in more stable operation. The a.c. type of lamps are frequently started without the use of high voltages by the aid of an auxiliary tungsten filament which is built into these lamps to furnish the initial ionization required to break down the gap and establish the arc.

Power supplies, such as shown in Fig. 13, can be designed to operate from almost any power source and deliver the necessary starting and running voltages for any size lamp.

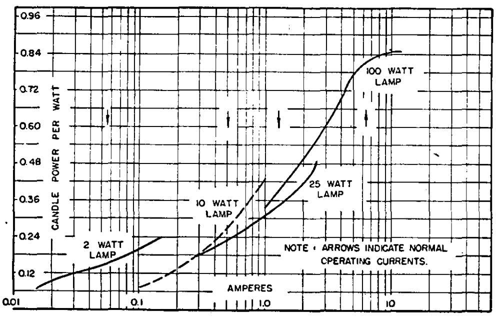

FIG. 8. Change of efficiency with current of concentrated-arc lamps.

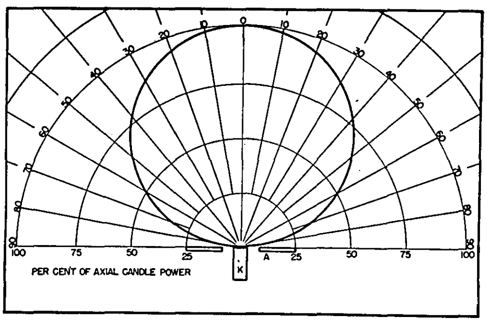

FIG. 9. Spatial distribution of radiation of concentrated-arc lamps.

The concentrated arc is therefore a new type of lamp which offers a unique combination of properties. The source of the radiation is a circular spot which is fixed in position, sharply defined, and uniformly brilliant. It is very bright, being several times brighter than tungsten filament lamps and almost as bright as the carbon arc. The source may be as small as 0.003 inch

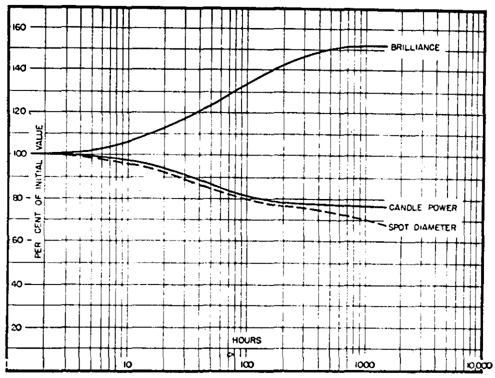

FIG. 10. Change of characteristics with age of 10-watt concentrated-arc lamps.

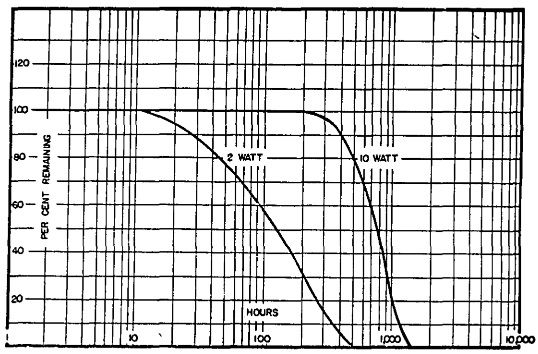

FIG. 11. Mortality curves for 2- and 4-watt concentrated-arc lamps.

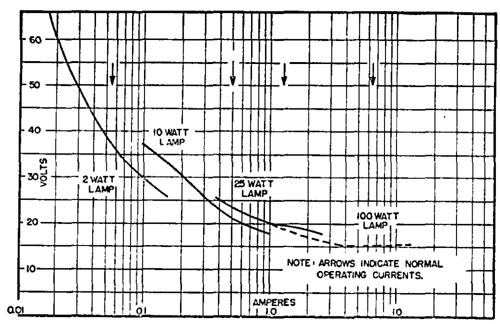

FIG. 12. Volt-ampere characteristics of concentrated-arc lamps.

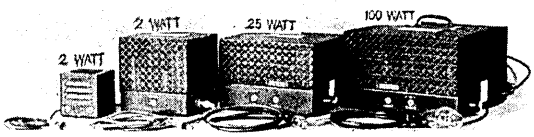

FIG. 13. A.c. operated power supplied for concentrated-arc lamps.

or as large as several tenths of an inch. The principle radiation is emitted as a continuum which extends well into the ultraviolet and infrared. The lamps start almost instantly and burn quietly without need of attention or adjustment. They may be burned in any position, are reasonably rugged and have lives which are measured in hundreds of hours. These properties make the concentrated-arc lamp useful for narrow beam and high intensity projection and illumination applications. It may also be used to furnish a high intensity continuum for absorption studies. In small sizes, the lamps are a close approach to a point source and have applications in optical testing and demonstrating, lensless projection and enlargement, photography, and in many entirely new devices which a brilliant point source will make possible.

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