Characteristics of 400-Watt and 250-Watt Type H Mercury Lamps

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Alternating-current arcs between oxide-coated tungsten electrodes in mercury vapor at pressures of one-half to one atmosphere have recently been developed as light sources, characterized by high luminous efficiency, long life, compact dimensions, and a high degree of simplicity in application. A 400-watt and a 250-watt lamp, designated as type H1 and type H2 respectively, are commercially available. The essential elements of the lamps and their operating equipment are described. The electrical starting and operating characteristics are explained. Wave forms showing the cyclic variation of arc voltage, current, and light output are discussed. Life, lumen maintenance, and efficiency ratings are defined.

GENERAL CHARACTERISTICS

THE high luminous efficiency, compact dimensions, and long useful life of the arc discharge in mercury vapor at a pressure of the order of one atmosphere have long been known to illuminating engineers. Light sources of this type were extensively used for industrial lighting in this country[1] and in Europe for several years prior to the time when the gas-filled tungsten lamp was made commercially available.

Application to the high-pressure mercury arc of comparatively recent improvements in oxide-coated tungsten cathodes has led to the development of alternating-current arc lamps that have a degree of simplicity and convenience in application surpassing that of previous commercial discharge lamps. Because it combines high efficiency, long life, and high lumen maintenance with simplicity and reliability in operation, the alternating-current arc in mercury vapor, at a pressure of about one atmosphere, has been extensively applied in industrial lighting since the time of its commercial introduction in this country in March, 1934.

In mercury vapor, at pressures of the order of one atmosphere, the arc discharge is constricted to a narrow tubular path between

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the electrodes. Commercial lamps, in which the light source is the constricted mercury arc, have been designated as type H mercury lamps. At the present time there are available two different type H mercury lamps. The 400-watt type H1 lamp, illustrated in Fig. 1, consists of the discharge tube mounted within a sealed glass tube of larger diameter known as the jacket. The jacket is fitted with a standard mogul screw base. The 250-watt type H2 also illustrated in Fig. 1, consists of the arc tube only, and is fitted with a medium screw base which is separated from the arc tube by an opal glass extension sleeve. The glass sleeve serves to insulate the base from the high temperature of the arc tube, and also provides a housing for the resistor which is connected in the starting circuit of the tube.

The 250-watt lamp is designed for burning in any position, in contrast with the 400-watt lamp, which is restricted to the vertical position. Because the jacket is not an integral part, the 250-watt lamp must be burned in an enclosing fixture to protect it from the cooling effect of air currents.

The candlepower distribution curves of the bare 400-watt lamp and of the bare 250-watt lamp are shown in Fig. 2. The spectral energy distribution and the color of the light have been previously described.[2,3] Essential technical data and dimensions of the two lamps are given in Table I.

DESCRIPTION OF ESSENTIAL ELEMENTS

The type H lamps consist of three essential component parts: the arc tube *A* (Fig. 3); the ballasting reactor *X*, or the high reactance transformer *T* (Fig. 4); and the heat insulating jacket *J*, which surrounds the arc tube, and may be a part of the lamp or part of the fixture.

The discharge tube *A* has a smooth contour, so shaped that it may be uniformly heated by the arc discharge, which is maintained between the arc energized, oxide coated, tungsten electrodes *E*. Argon gas and a small accurately measured quantity of mercury are introduced into the arc envelope before it is finally sealed.

A circuit diagram for the arc tube and associated apparatus is shown in Fig. 3. The voltage drop in the discharge tube is less than the applied voltage of the line. In order that the current in the tube may not increase without limit, the reactor *X* is connected in series with the discharge tube. The reactor is of the iron core type with air gap to prevent saturation of the iron. This type of ballast

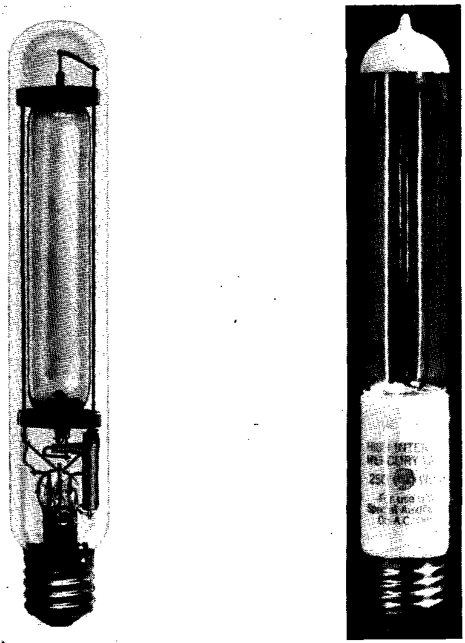


FIG. 1—400-watt type H1 mercury lamp, (left), and 250-watt type H2 (right).

TABLE I—ESSENTIAL TECHNICAL DATA ON TYPE H MERCURY LAMPS

	Type	
	400-Watt Type H1	250-Watt Type H2
Bulb	T-16	T-9
Base	Mogul Screw	Medium Screw
Maximum Overall Length, Inches	13	8
Light Center Length, Inches	$7\frac{3}{4}$	5
Length of Light Source, Inches	6	$4\frac{1}{8}$
Burning Position	Vertical	Any
Finish	Clear	Clear
Life (Average)	2000 hr.	20[illegible]0 hr.
Lumens per Watt (Initial)	40	30
Lumens per Watt at 70 Per cent of Rated Life	33	25

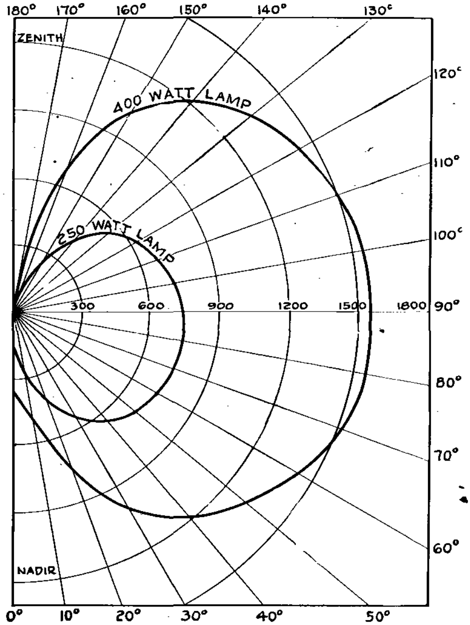
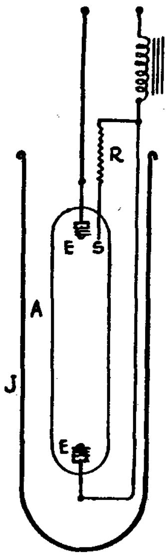


FIG. 2—Candlepower distribution curve of bare 400-watt lamp, and bare 250-watt lamp.

not only limits the discharge current, but with low losses, stabilizes the arc and minimizes the flicker in the light output.

The high reactance transformer of Fig. 4 transforms the line voltage from 120 to the terminal voltage of the lamp. By means of magnetic shunts between the primary and secondary coils, the necessary ballast reactance is provided. Such a transformer, when properly designed, has a reactance equivalent in all respects to that of the iron core air gap reactor. The high reactance transformer frequently performs a third function of supplying a leading current, at relatively high voltage, from an extension of the primary winding to the power factor correcting capacitor, *C*.

Efficient and stable operation of type H lamps is dependent on complete vaporization of the small quantity of mercury in the arc tube. The glass temperature of the arc tube must rise, as a result of the energy supplied to the arc, from room temperature to a point well over 350 degrees C. In order to insure that the necessary rise shall take place in a reasonable time, the arc tube is enclosed by



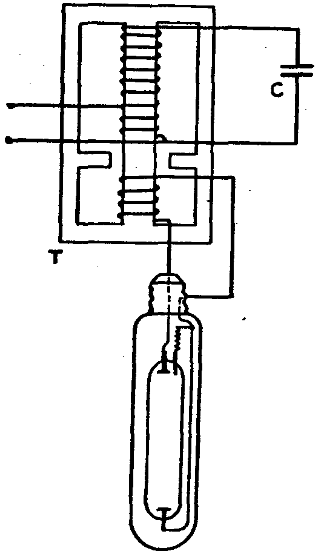


FIG. 3—(Left) Circuit diagram of lamp and series reactor.
FIG. 4—(Right) Circuit diagram of lamp and high reactance transformer.

a glass envelope or jacket. The arc tube is thus effectively surrounded by still air, and protected from the direct cooling effect of drafts. The temperature of jacketed arc tubes becomes sufficiently high to vaporize all the mercury in from 6 to 8 minutes. Under the same conditions an unjacketed arc tube might never reach a temperature sufficiently high. The coolest spot on the arc tube surface in commercial lamps reaches an equilibrium temperature considerably higher than necessary to just vaporize the mercury.

OPERATING CHARACTERISTICS

1—Starting Process

Starting of the type H lamp takes place immediately on application of the line voltage. Initiation of the discharge at low voltage is a unique feature of this type of mercury lamp which contributes in a large measure to the simplicity of the lamp and associated apparatus. Previous hot cathode lamps of the low-pressure type[4] consisted of long narrow tubes which required special starting circuits to provide a high voltage impulse to ionize the gas and initiate the discharge.

The low breakdown or starting voltage of type H mercury lamps is a result of three important factors in the design of the arc tube. In the first place the tube has a relatively small ratio of length to diameter. This low ratio of length to diameter is permissible only in a tube which is capable of building up pressure and voltage gradient after the discharge has been initiated.

A second important factor is the low work function of the surface of the alkaline earth oxide coated electrodes. These electrodes are capable of emitting electrons when cold and at the same time resist the erosive action of the arc.

The third important factor comprises the filling of argon gas and the mercury vapor which is present in the arc tube at ordinary temperatures, together with the auxiliary starting electrode *S* (Fig. 3). Upon application of voltage to the lamp a glow discharge is initiated between the auxiliary electrode *S* and the adjacent main electrode *E*. The current in this auxiliary circuit is limited to a small value by means of the resistor *R*. Resonance radiation of argon atoms excited by means of this auxiliary discharge is capable of traveling the length of the tube,[5] producing excited argon atoms throughout the tube. Some of these excited argon atoms may lose enough energy through elastic collisions to put them in the metastable state. The metastable argon atoms have relatively long lives (10^{-4} sec) and the probability is correspondingly greater of their meeting and transferring their energy to mercury atoms. By this means positive ions of mercury are produced in the space between the two main electrodes at the applied potential of the line. Under the influence of the voltage gradient between the electrodes cumulative ionization by collision takes place between the electrodes *E E*. The establishment of this glow discharge is undoubtedly facilitated by the fact that electron emission from the electrode *E* adjacent to *S*, is augmented by the auxiliary discharge. Under the influence of the glow discharge between electrodes *E E*, the electrodes are heated, their electron emission increases, and almost immediately the low current glow discharge transfers to an arc characterized by low cathode fall and high current; the current being limited by the reactor.

2—*Arc Characteristic with Liquid Mercury in Arc Tube*

We consider the case illustrated in Fig. 3 where the mercury arc in series with its ballast reactor, is connected to a constant potential

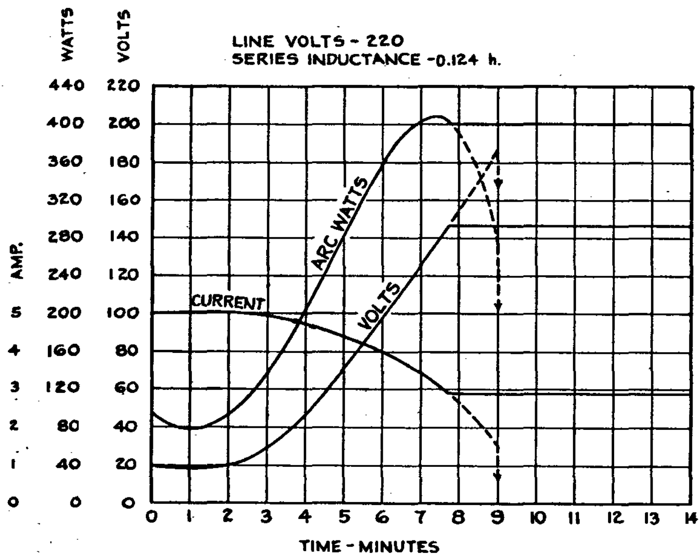


FIG. 5—Electrical characteristics of 400-watt arc between time of starting and complete vaporization of mercury.

source of alternating current. The arc tube is initially at room temperature, and the mercury is nearly all in the liquid state. There is, of course, a small amount of mercury in the vapor state at a pressure of .0018 mm corresponding to a temperature of 25 degrees C. The inductance of the ballast unit and the applied voltage are assumed constant quantities and the only variable factor is the pressure of the mercury vapor in the arc tube.

Immediately after starting (zero time in Fig. 5), the arc current of the 400-watt lamp has a value of 5 amperes, practically the short circuit current of the reactor on 220 volts. The voltage drop in the arc is 17 volts and the power input to the arc is 80 watts. The temperature of the arc tube increases slowly at first, due to the relatively small amount of energy initially supplied to the arc. The arc drop and wattage at first decrease slightly as the mercury pressure increases. After a few minutes, the voltage and wattage increase rapidly. During this period of rapidly increasing pressure the arc constricts. The wattage passes through a maximum but the voltage increases with time as long as any liquid mercury remains in the tube. After about 7 minutes all the mercury is vaporized, and the electrical

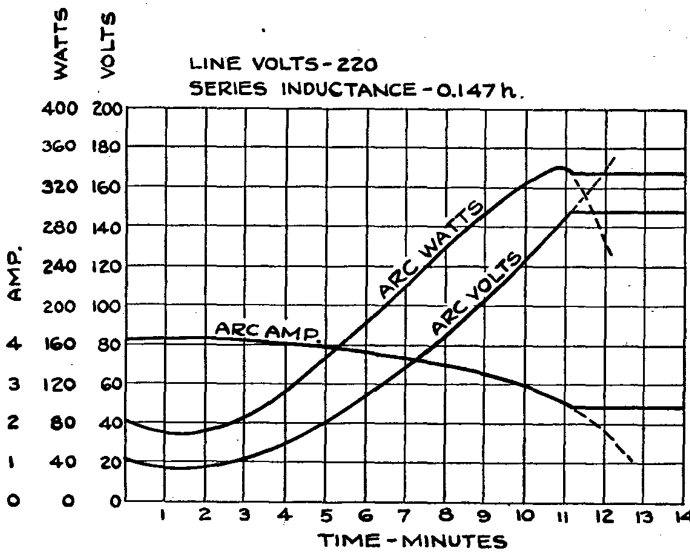


FIG. 6—Electrical characteristics of 400-watt arc with series reactance 18 per cent higher than standard.

characteristics alter their course and are thereafter constant. If the mercury were not limited in amount, then the course of these characteristic curves would continue as indicated by the dotted lines in Fig. 5.

It should be emphasized that the shape of these characteristic curves is influenced by the value of the series inductance, by the value of the line voltage, and by the design details of the arc tube. In Fig. 6 is shown the effect of increasing by 18 per cent the value of series inductance on the length of time required for complete vaporization of mercury. The minimum arc wattage is 68 watts instead of 80 watts. The final steady value of arc watts is only 340 instead of 400 and the time required to attain this steady condition of arc watts and volts has been increased from 7 minutes to 11 minutes.

By a slight change in electrode location within the arc tube, it is possible to design a lamp in which the mercury will not completely vaporize under ordinary conditions. In such a tube, equilibrium is attained between the energy input and the output, with some part of the arc tube wall at a temperature too low to vaporize all the mercury.

It is likewise possible to so construct the arc tube that equilibrium is attained with liquid mercury at the temperature corresponding to any desired mercury vapor pressure. The standard arc tube of the 400-watt mercury lamp may contain a larger amount of mercury and be sealed off with a longer tip than is usual. After proper adjustment of the size of the appendage formed by the seal-off tip, the lamp will heat up and vaporize only enough mercury to produce the desired arc volts and watts. The unvaporized portion of the mercury will be found in the appendage at a temperature of 350 degrees C corresponding to a pressure of 700 mm for the 400-watt lamp.

Mercury lamps which are designed to operate at their rated wattage with liquid mercury in the arc tube have undesirable characteristics. In the first place, they must be relatively slow in heating up to the operating temperature, since this is a final equilibrium temperature. Secondly, changes in the immediate surroundings such as confinement in fixtures and reflectors of different kinds result in changes in the equilibrium temperature, arc volts, and watts. The equilibrium temperature and arc volts may easily be raised to a point too high for stable operation so that the arc is extinguished. Another difficulty with saturated pressure lamps is that each lamp requires an individual critical adjustment of the appendage in which the excess mercury is intended to condense.

3—Control of Arc Wattage Input

The power input to the arc depends on three controlling factors, the arc voltage, the value of the ballasting inductance, and the applied voltage. Arc watts are shown as a function of the root mean square value of arc voltage for the 400-watt lamp and for the 250-watt lamp in Fig. 7. In both of these lamps the arc voltage is practically independent of arc current for the range of current values that may occur. The arc voltage depends only on the quantity of mercury vaporized in the tube. This quantity is so controlled that when completely vaporized, the arc voltage is between 140 and 154 in the 400-watt lamp and between 65 and 75 in the 250-watt lamp. Fig. 7 shows graphically the spread in lamp wattage which normally results from the spread in arc voltage between different lamps. This spread in arc voltage is a result of manufacturing tolerances in arc tube dimensions and mercury quantity. The arc current is also plotted in Fig. 7.

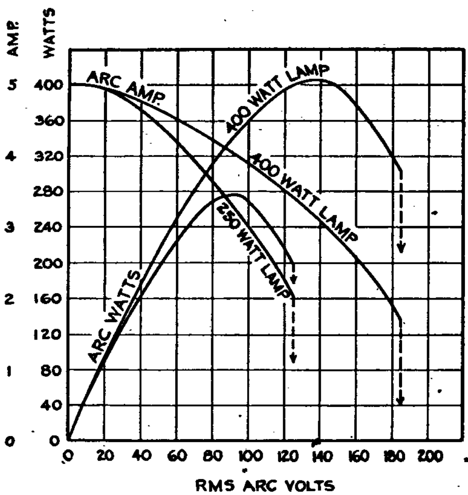


FIG. 7—Arc watts and current in 400-watt lamp and in 250-watt lamp as function of arc voltage.

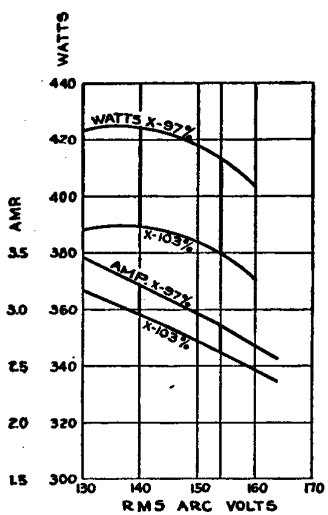


FIG. 8

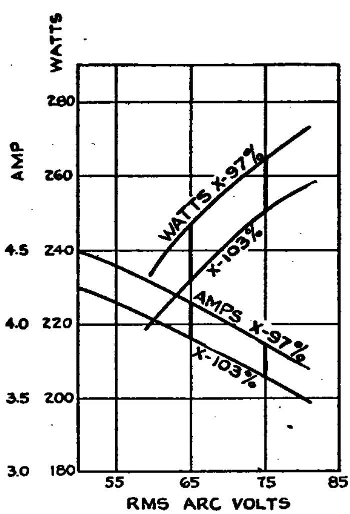


FIG. 9

FIG. 8—(Left) Effect of manufacturing tolerances on arc watts and current of 400-watt lamp.
FIG. 9—(Right) Effect of manufacturing tolerances on arc watts and current of 250-watt lamp.

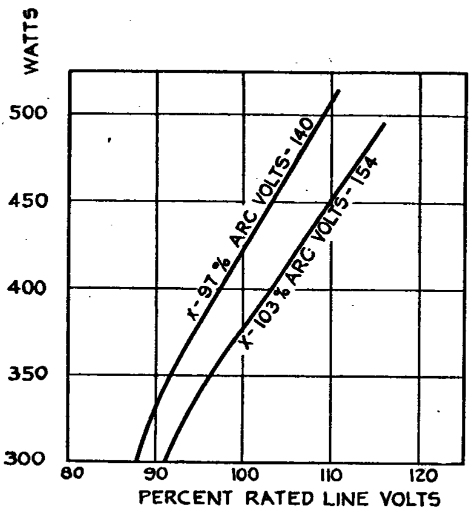


FIG. 10—Arc wattage input to 400-watt lamp as function of line voltage.

In addition to the manufacturing tolerance on arc voltage there is a tolerance in the reactance value of the reactor or transformer which may amount to ±3 per cent. In Figs. 8 and 9 arc watts and amperes are plotted against arc volts, in the normal range of arc volts, with values of series inductance equal to 103 per cent and 97 per cent of the mean specified values. The enclosed parallelograms cover the spread in arc wattage and current caused by all manufacturing tolerances.

In obtaining the data for Figs. 8 and 9 the line voltage was held constant and equal to the marked voltage of the taps on the reactor or transformer. The effect on arc input wattage of variations in line voltage from the marked voltage of the taps is shown in Fig. 10. Extreme values of arc voltage and ballast reactance were chosen so that the upper line in Fig. 10 traces the course of the arc wattage for a 140-volt arc and a ballast reactance 3 per cent below the mean specified value. The lower lines trace the course for a 154-volt arc and a ballast reactance which is 3 per cent high. For any value of line voltage, the arc input will be somewhere between the two parallel lines thus obtained, depending on the exact value of ballast reactance and arc voltage.

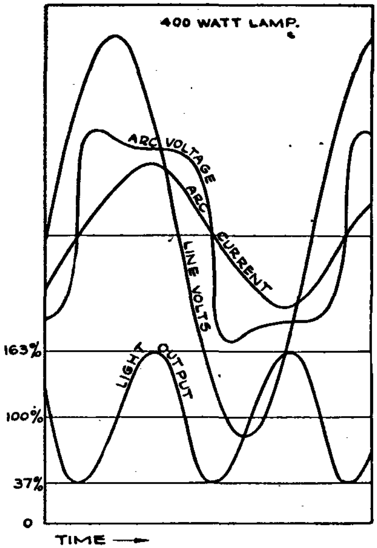


FIG. 11—Wave forms and phase relation of electrical characteristics and light output of 400-watt lamp.

4—Cyclic Variation of Light

The intensity of light output from alternating-current arc discharges follows rather closely the instantaneous values of arc current. The light output from alternating-current discharge lamps operated on 60-cycle circuits is modulated at 120 cycles. In Fig. 11 are plotted the cyclic variation in arc voltage, current, and light intensity for the 400-watt lamp. The crests and troughs of the light-output curve correspond with the maximum and zero values of arc current. The light output does not go to zero but has a value equal to 37 per cent of the average when the current passes through zero. It has been shown by Elenbaas[6] that the temperature of the constricted high-pressure arc in mercury vapor is of the order of 5000 degrees C to 7000 degrees C. The relatively high light output at zero current can be explained by assuming that the heat capacity of the arc is sufficient that the temperature remains high enough to cause thermal excitation of the mercury atoms.

The wave forms of Fig. 11 are characteristic of the inductance ballasted 400-watt arc. The inductance consisted of a standard iron core reactor with air gap to prevent magnetic saturation of the core at all values of arc current up to the maximum. With this type of ballast, the arc current lags the applied voltage. At current zero, the instantaneous value of applied voltage is sufficiently high, and is in the right direction for immediate restarting of the arc. After each current zero, the arc voltage rises very rapidly, the rate of rise being retarded only by the distributed capacitance of the reactor. As a result of this rapid rise of arc voltage, the arc is established in the reverse direction before the arc can cool off and become de-ionized.

If the applied voltage is reduced, the arc current and arc temperature are thereby reduced. The angle of lag of arc current and the voltage available for re-establishment of the arc are also reduced. If the applied voltage is reduced below a critical value, the arc de-ionizes before the voltage can rise sufficiently high to re-establish the arc in the reverse direction. The arc is then extinguished.

The per cent reduction in applied voltage necessary to cause extinction of the arc is a measure of the stability of the arc. The arc stability is greater and the cyclic flicker in light output is less when non-saturating reactors, rather than when saturating reactors or resistors, are used for ballast.

5—Power Factor

Fig. 11 shows that the arc current and arc voltage, although they are in phase, are non-sinusoidal. The ratio of arc watts to rms volt-amperes is for the 400-watt lamp 0.94 and for the 250-watt lamp 0.92. The line current has the same wave form as the arc current, and lags the line voltage as shown in Fig. 11. This angle of lag is about 43 degrees for the 400-watt lamp and 60 degrees for the 250-watt lamp. By connecting a suitable value of capacitance across the line, the sixty-cycle frequency component of line current may be brought in phase with the line voltage and reduced in magnitude. By this means the overall power factor of the type H lamps may be increased to a maximum value of 94 per cent. The overall uncorrected power factor of the 400-watt lamp, with series reactor and high reactance transformer ballast, is 65 per cent and 70 per cent respectively. The overall uncorrected power factor of the 250-watt lamp is about 50 per cent.

Where type H mercury lamps are operated from high-reactance transformers on 120-volt lines, the primary winding is extended to

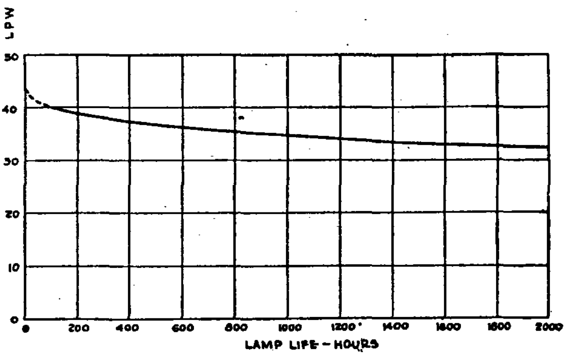


FIG. 12—Typical lumen maintenance curve of 400-watt lamp.

step up the voltage to about 600 volts to supply current to a 3 mfd capacitor for power-factor correction. Approximately 75 microfarads connected across the 120-volt line would be required to draw the amount of leading current required to raise the power factor of the lamp to the desired value. The use of the extended primary winding and smaller value of capacitance effects a substantial saving in space and cost.

6—Life-Lumen Maintenance-Efficiency

The rated average life of the 400-watt and the 250-watt mercury lamps is 2000 hours. The initial efficiency is defined as the efficiency in lumens per arc watt measured after 100 hours burning. The initial efficiency is so defined because the initial light output, although high, is quite variable. More consistent photometric measurements can be made after the 100-hour seasoning period. A typical lumen maintenance curve for the 400-watt lamp is shown in Fig. 12. The maintenance curve for the 250-watt lamp is similar in form to that for the 400-watt lamp. The rated initial efficiencies of the 400-watt and the 250-watt lamp are 40 lpw and 30 lpw respectively. The rated efficiencies at 70 per cent of rated life are, respectively, 33 lpw and 25 lpw.

The rated efficiencies take no account of the inevitable power losses in ballast equipment. These losses are different in the different types of equipment. Reactor losses are usually lower than transformer losses, and reactors or transformers of the same type made by different manufacturers may have different losses. Transformer losses are usually about 50 watts, so that the overall initial efficiencies of the 400-watt and the 250-watt lamp are about 35.6 lpw and 25 lpw, respectively.

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