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GENERAL ILLUMINATION COURSE

WESTINGHOUSE LAMP COMPANY

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point source of light would be required but this is a physical impossibility. However, in some types of projection lamps the coiled filament is even coiled upon itself in order to obtain a maximum concentration.

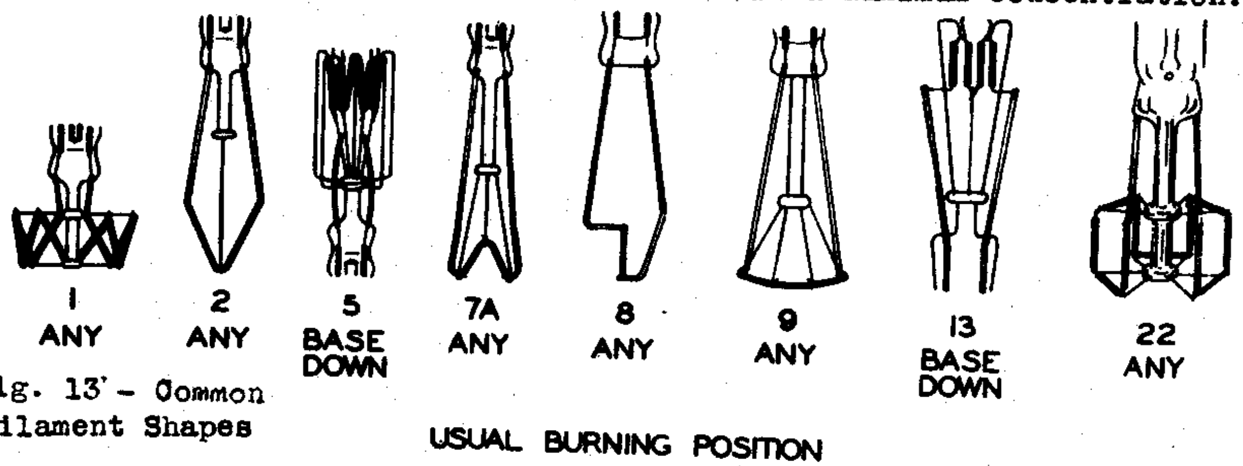

Fig. 13 - Common Filament Shapes

While most lamps are designed to be burned in any position, some are restricted in burning position in order to gain greater efficiency or filament concentration. For example, certain street lighting lamps are designed for either base up or base down burning, because by so doing the bottom filament supports may be eliminated with a resultant gain of 7 to 15 percent in efficiency.

DESIGN CHARACTERISTICS

LIFE

Incandescent lamps may be designed for any life desired but an exceptionally long life is secured only at the expense of efficiency, and conversely, a high efficiency lamp can be secured only at the expense of life. Since lamps are burned to secure light, their efficiency or light producing capacity must be given equal consideration with life.

An incandescent lamp is a device for transforming electrical energy into light. Its inherent worth is measured by how well it performs that function (efficiency) and how long it continues to perform that function (life). The first factor governs the amount of energy required per unit of light and the second governs the number of lamps required over a given period of time.

A 100 watt Mazda lamp costs only 35 cents, yet, during its average life of 1000 hours it consumes 100 kilowatt hours of electricity. At five cents per KWH this would cost $5.00, over fourteen times the cost of the lamp. In general it may be said that current cost is 10 to 15 times lamp cost.

For general service lamps, a life of 1000 hours has become accepted as a balance between lamp cost and current cost. Lamps designed for special services may have a longer or shorter life than those for general service. Their life may be governed by such considerations as inaccessibility in the case of sign and street series lamps or maximum wattage with minimum bulb size as in projection lamps.

The rated average life of lamps for several classes of service is given in the following table:

Lighting Service	Rated Average Life Hours	Lighting Service	Rated Average Life Hours
Projection	50	Floodlight	800
Airport floodlight	100	General	1000
Spotlight	200	Street Series	1350
Headlight	500	Sign	1500
Decorative	750	Street Railway	1500

It must be remembered that when "life" is mentioned, it implies "average life" of a group of lamps. It is impossible to guarantee what any individual lamp will do. But by continuous testing the average performance of any particular type of lamp may be predicted. The curve shown in Fig. 14 is known as a mortality curve, and indicates the rate at which burnouts may be expected if a quantity of lamps are installed for service and allowed to burn completely

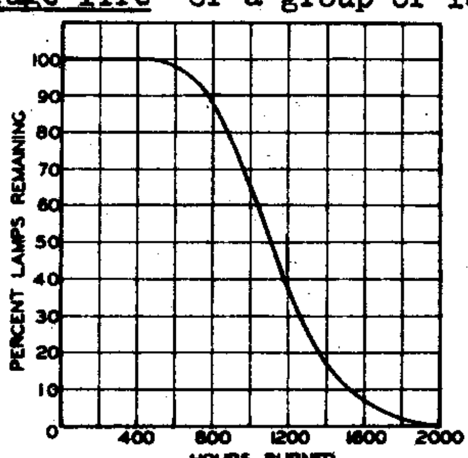

Fig. 14

until all are burned out. Naturally the consumer does not do this, but replaces them as they burn out.

The following formula will give the number of lamp renewals which may be expected in a given installation over a given period of time, provided there are no adverse operating conditions affecting the average life of the lamps.

$$\text{Expected number of lamp renewals per year} = \frac{\text{No. of lamps in installation} \times \text{Average hours actually burned per year}}{\text{Rated life of lamps in hours}}$$

EFFICIENCY

As mentioned in Assignment 1, the efficiency of incandescent lamps is expressed in terms of lumens per watt. The efficiency of vacuum lamps varies from 6 to 10 lumens per watt and that of gas-filled lamps from 10 to 30 lumens per watt. In general, lamp efficiencies increase with the rated wattage. This is because of a decreasing heat loss in percentage of the total wattage of the lamp, and also because of the ability of thicker filaments to withstand higher operating temperatures.

For this reason, to obtain a given quantity of light, without reference to distribution, glare, or other illumination principles, a high wattage lamp is more economical than a number of smaller lamps. This is evident from the following illustration.

It is desired to obtain approximately 20,000 lumens of light for a period of 1000 hours.

The 1000 watt 115 volt, general lighting service lamp has an efficiency of 21 lumens per watt. Therefore it will give:

1000 (watts) x 21 (lumens per watt) = 21,000 lumens.

The efficiency of a 200 watt lamp is only 17 lumens per watt. If an equivalent wattage is used, five lamps will give:

5 x 200 (watts) x 17 (lumens per watt) = 17,000 lumens.

This would not be enough light. Six 200 watt lamps will give:

6 x 200 (watts) x 17 (lumens per watt) = 20,400 lumens.

This is approximately the same as the 21,000 lumens from a 1000 watt lamp. But it would be necessary to use 200 watts more electric energy to obtain this light, costing, at a 5 cent rate, ten dollars more for the 1000 hour period.

Lumen Maintenance:- In the design of a lighting installation, it is important not only to know the initial lumen output of the lamps involved but also how nearly they maintain this value throughout their life.

Lamps that are operated on constant voltage circuits fall off gradually in their total lumen output during life. This is due mainly to two reasons:

(1) The burning of the filament causes it to evaporate slowly, become smaller in diameter and increase gradually in resistance. This greater resistance allows less current to pass through the wire, thereby producing less light.

(2) The evaporated filament material is deposited on the inside of the bulb and interferes with the transmission of light by the bulb. This deposit absorbs a considerable amount of light, depending upon its thickness within the bulb.

The lumen maintenance of a lamp is the average lumens throughout life expressed as a percentage of its initial lumens.

The lumen maintenance of gas-filled lamps is much better than that of vacuum lamps. The gas not only retards evaporation but also carries the evaporated tungsten to the upper part of the bulb. When a gas-filled lamp is burned base up, the blackening is deposited in the neck of the bulb and has practically no harmful effect. Its lumen maintenance is best when it is burned in this position.

Street series lamps maintain a higher percentage of their initial lumens than do multiple lamps because a constant current flows through the filaments. Therefore, as they grow thinner, more energy is required which in turn produces more light. In some sizes of street series lamps this compensates for the loss due to bulb blackening.

Efficiency Maintenance:- Closely allied with lumen maintenance is the efficiency which a lamp maintains throughout life. Just as initial efficiency of a lamp is expressed in terms of lumens per watt, so its efficiency maintenance is expressed in terms of the average lumens per watt throughout life in percent of initial lumens per watt.

It is evident that both lumen maintenance and efficiency maintenance should approach as near as possible to 100 percent. A large share of the research and development work in the Mazda lamp industry has been directed toward this problem.

OPERATING CHARACTERISTICS

The life and efficiency obtained from a lamp in actual service are dependent largely upon the conditions under which the lamp is operated. When a lamp is burned under good operating conditions, normal life and efficiency may be expected; but some operating conditions may adversely affect the life of the filament, while others may affect its efficiency.

VIBRATION AND SHOCK

When new, the filament of an incandescent lamp is tough and will stand quite rough handling. After it has burned, however, the filament undergoes a crystallization which makes it more fragile. It is not to be inferred from this that an incandescent lamp is an object to be handled only with "kid gloves" but merely that there are limits of rough handling and vibration to which it can be subjected without injury.

When lamps are used for general lighting service in locations subject to severe vibration, it is advisable to provide them with suspensions that absorb the vibration. Sometimes these take the form of spring sockets or socket adaptors, sometimes semi-rigid hangers and, in very severe cases, spring suspended hangers. For local lighting where the lamp and its reflector may be fastened directly on a machine and it is impossible to provide vibration absorbing devices, a lamp listed as a limited service lamp is specially provided. This is the 50 watt, 115 volt, P-19 bulb lamp.

Lamps that are used on extension cords such as in garages are subject to rough handling (distinguishing shocks from vibration). For this purpose a special 50 watt, 115 volt A-19 bulb rough service lamp has been developed.

Neither the 50 watt P-19 lamp nor the rough service lamp are as efficient as an ordinary 50 watt lamp and each costs slightly more. Therefore their use should be restricted to locations where severe operating conditions prevail.

UNDER-VOLTAGE BURNING

In the definition of voltage, it was described as the electrical pressure at which lamps are burned. It is very important that the voltage supplied at the socket be, as near as possible, the voltage indicated on the lamp.

The reason for this is that voltage is directly related to the efficiency and life of a lamp and therefore to the cost of light (as indicated under LIFE on page 26). Lamps are designed so that the cost of light is an economic balance between cost of current and cost of lamps. By burning them at an incorrect voltage, this economic balance is upset.

When lamps are burned under-voltage (that is, a lower voltage at the socket than indicated on the lamp), three things are affected:

Wattage: With less electrical pressure forcing current through the lamp, electricity is consumed at a lower rate.

Life: This smaller consumption of electricity does not heat the filament to as high a temperature as that for which it was designed. This materially reduces the rate of evaporation of the filament and in consequence the lamp lasts longer.

Light: Because the filament is not heated to its normal working temperature, it gives off a much smaller amount of light.

The first two items indicate a saving in money spent, while the third indicates a loss. It is because this third factor far overbalances the other two that under voltage burning increases the unit cost of light as shown by the following table:

THE EFFECT OF VOLTAGE UPON LAMP PERFORMANCE

Socket Voltage in % of Rated Lamp Voltage	Watts Consumed in % of Rated Watts	Lumens of Light in % of Normal	Lamp Cost per 1000 Hours in % of Normal	Unit Cost of Light* in % of Normal
90 %	85 %	70 %	24 %	115 %
92	88	75.5	33	111
94	91	81	44	108
95	92.5	84	50	106.5
96	94	87	59	105
98	97	93	77	102.5
100	100	100	100	100
102	103	107	130	98.2
104	106.5	114	162	97
105	108	118	185	96.4
106	109.5	122	208	95.8
108	113	129	266	95.7
110	116	137	328	96

*Applies only to 200 watt 115 volt lamps at a list price of $.80 and energy at $.05 per KWH. For other lamps and other energy rates the costs would be slightly different.

No attempt has been made to include all of the factors entering into lighting costs, such as interest and depreciation on wiring and fixtures, etc., as they are, for the most part, fixed costs independent of socket voltage. Roughly, the table shows that for every 1 percent drop in voltage, the wattage is reduced 1½ percent and the amount of light over 3 percent. While lamp life increases (and therefore lamp costs decrease), this factor is so small in comparison with current costs (increasingly so under-under voltage conditions) that it does not alter the upward course of the unit cost of light.

Example:- Suppose a 200 watt 115 volt lamp (which costs 80 cents) is burned 5 percent under-voltage (approximately 109 volts). What is the increased cost of light for 1000 hours under these conditions with current costing 5¢ per kilowatt hour?

Under normal conditions the cost is:

$\frac{200}{1000}$ (KW) x 1000 (hrs.) x \$.05 (current rate)	\$10.00
Lamp Cost	.80
Total Cost	10.80

At 5 percent under voltage, the cost is:

$\frac{200 \times .925}{1000}$ (KW) x 1000 (Hrs) x \$.05 (current rate)	\$ 9.25
Lamp Cost \$.80 x .50 (from table)	.40
Total Cost	9.65

But for this \$9.65 less light has been obtained than under normal conditions. Therefore, it is necessary to multiply this cost by a ratio that will put both costs on the same light basis (3400 lumens). This ratio is $\frac{1.00}{.84}$ and gives as the correct answer

$$\frac{1.00}{.84} \times \$9.65 = \$11.50$$

Here is a loss of \$0.70 (an increase of 6.5 percent in the unit cost of light). From the standpoint of a single lamp during 1000 hours of burning, it may seem small, but with hundreds of millions of dollars being spent annually for lighting, under voltage operation of lamps is costing the people of the United States \$150,000 per day - over \$100 per minute!

Eliminating Under Voltage Operation:- There are two general ways in which under voltage may be eliminated by the consumer:

(1) Use of Proper Voltage Lamps by the Consumer. Due to lack of knowledge many lamps are purchased of a voltage differing from the central station voltage in the locality where they are to be used. This often occurs when a consumer purchases lamps in one community for use in another where the existing voltage may be different. For example, New York City has a voltage of 120, whereas most New Jersey communities have a voltage of 115. Therefore, a New Jersey resident, purchasing lamps in New York City for home use, would be operating them at five volts under their rating.

Sometimes dealers sell lamps of a voltage rating higher than the central station voltage simply because an occasional customer complains that his lamps do not last long enough. This is a poor policy since it results in the customer paying more for light. If the consumer is actually getting short lamp life, the adverse operating conditions should be ascertained and corrected rather than adopt the wasteful expedient of higher voltage lamps.

(2) Wiring. The central station is responsible only for the voltage delivered at the meter. But the consumer is responsible for the wires leading from the meter to the sockets. These wires should be sufficiently large to give a full load voltage drop of not over two percent from the customer's meter to the most distant socket.

City ordinances and fire underwriters' rules specify minimum sizes of wire for safety but not necessarily adequate for economic operation. For example, #14 wire is safe for 15 amperes, yet in a run of fifty feet (100 feet of wire) a voltage drop of four volts results. Thus #14 wire would be inadequate for good lighting practice.

A factor in the rental of buildings is their ability to provide services comparable with those of newer buildings that are constantly being erected. The adequacy of the original wiring in meeting the increased demands of tenants is an important element of these services. A survey covering any period of years in the electrical industry indicates that the demand for electric service - due to better lighting and additional power and heat applications - increased yearly. With increased demand comes increased voltage loss in the wiring. Therefore, the wiring of new buildings should provide a factor of safety against obsolescence.

OVER-VOLTAGE BURNING

Over-voltage burning of lamps is not as frequently found in practice as under-voltage burning. When it is present, however, it shows itself very quickly in the excessive demand for lamp replacements. While over voltage increases the light output of a lamp, this gain is outweighed in most cases by the item of lamp replacement costs, which must be considered as a third factor of the cost of light when excessive over-voltage conditions are present. The table given under UNDER-VOLTAGE BURNING (Page 32) contains also data on over-voltage burning.

INCORRECT BURNING POSITIONS

Most incandescent lamps are made for universal burning, i.e., operation in any position. This does not mean that their light output will be as good but that there will be no serious harm in using them in any position. Every gas-filled lamp while it is lighted has a flow of gas inside the bulb which carries with it the slowly evaporated black tungsten. If the lamp is burned base up, the tungsten particles will be deposited in the neck of the bulb and will interfere very little with light output. If, however, the lamp is burned base down, the tungsten particles will rise to the bowl of the bulb and, being deposited, will blacken it and absorb light throughout the remaining life of the lamp.

Some lamps are designed to be burned only in certain positions. For example, incorrect positions of burning may cause early failure due to concentration of heat upon parts of a lamp not designed to withstand it. Another result is damage to the filament which may be unsupported in certain directions.