HPS SERVICING GUIDE

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American Electric Lighting®

An Acuity Brands Company

American Electric Lighting™

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High Pressure Sodium Servicing Guide

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OVERVIEW

The information presented in the High Pressure Sodium (HPS) Servicing Guide is generic in nature. It can be applied to and used in troubleshooting and servicing all types of HPS systems regardless of the manufacturer. The servicing guide contains information, illustrations and data on these same topics:

- Safety practices and equipment used when servicing HPS and other High Intensity Discharge (HID) lighting systems.
- Basic construction and operation of HID lamps, and how they differ from incandescent lamps.
- Unique construction and operating features affecting servicing. Special attention is paid to starting circuits, ballasts and photocontrols.
- An in-depth look at the causes of the cycling ON and OFF of the HPS lamp, including end-of-life cycling.
- Test equipment for servicing HPS lamps and luminaires, including the drawbacks of voltmeters and neon lamp/luminaire testers. Details on constructing and using a highly effective, inexpensive piece of test equipment-the incandescent lamp luminous wattmeter tester (LWT).
- Troubleshooting the HPS luminaire in the field. Step-by-step guidelines for performing a 15-minute service call and making quick, cost-effective repair/replace decisions.
- Factors to consider and problems associated with the installation and use of mercury vapor to HPS conversion kits.

IMPORTANCE OF SAFETY

LIGHTING SAFETY TRAINING PROGRAM

HID lamp servicing requires close attention to safety. Working with electrical equipment at significant heights can be dangerous if proper preparations and precautions are not taken. The following is a general safety checklist. Always follow the exact safety procedures outlined by your company.

1. Park the lift truck at the safest possible location at the work site. Set up safety cones to direct traffic around the truck.
2. Before beginning, check the lift bucket of the truck to make certain it is secure. The pivot point mounting should be tight with no cracks or breaks. Also make certain the bucket is equipped with a fiberglass liner and that the liner is in good shape with no cracks or breaks.

   Although not a common problem, lamps have been known to shatter due to operational problems or when being turned into or out of the socket.
3. Make sure the boom strap is in place and secure.
4. Make certain the lanyard is in good shape, fastened and secure. The safety belt also must be in good condition.
5. Always strap on the safety belt before raising the bucket. Putting the safety belt on should be the first thing you do after stepping into the bucket.
6. Always use a properly secured safety belt when working from ladders.
7. Always wear a hard hat when servicing a luminaire in the field.
8. Wear work boots with non-slip insulating soles.
9. Always wear high-voltage gloves when servicing and replacing luminaires. Inspect the gloves at the start of each workday for holes and tears. Replace damaged gloves immediately. Keep your high-voltage gloves in the glove bag located in the bucket so they will always be available when needed.
10. Always wear proper eye protection whenever you work on luminaires or replace a lamp. Although not a common problem, lamps have been known to shatter due to operational problems or when being turned into or out of the socket.
11. Luminaires can be heavy. Position the bucket so you do not have to overreach or stretch while lifting or handling the luminaire. Always secure the luminaire, cover and any other items or tools inside the bucket so there is no danger of them falling to the ground.
12. Always be certain the luminaire is properly grounded. Use the grounding screw provided and run back to mechanical ground. If the luminaire is not properly grounded, it may become electrically "hot" if a component or wire inside the housing grounds itself to the housing. This can happen if wires become frayed, or ballasts or other components are damaged. The danger of electrical shock then exists when the service technician touches the housing and grounds another part of his or her body. The feeling of static electricity when you are near to, or brush lightly against a luminaire is a sign that it may be electrically "hot." De-energize the fixture immediately and inspect for a possible short to ground inside the housing.
13. If a lamp (light bulb) should break during installation or removal, de-energize the fixture and remove the broken lamp from the socket using a broken lamp base extractor.
14. Work carefully and use good judgment in all situations. Most accidents are the result of carelessness.

INTRODUCTION TO HID LIGHTING

HPS lighting systems are one of a group of systems classified as High Intensity Discharge lighting. The HID lamp group also includes all mercury vapor and metal halide lighting systems.

The HID lamp group is one of the three major lamp groups used in modern lighting; the others are incandescent and fluorescent. To better understand how HID lighting systems operate, a short review of incandescent and fluorescent lamp operation is helpful.

Incandescent Lamps

A conventional tungsten incandescent lamp has a tungsten filament enclosed in a glass bulb filled with inert gases (Figure 1). When electric current is passed through the filament, it offers resistance to the current flow. The filament heats up and glows, producing light. As the lamp operates, the tungsten filament evaporates and deposits as black patches on the inside of the bulb. The inert gases work to reduce this blackening, but cannot eliminate it. Light output diminishes as the filament evaporates, and the lamp eventually fails due to filament breakage.

Tungsten halogen lamps try to reduce filament evaporation by including small amounts of bromine, forcing the tungsten to redeposit on the filament. Halogen lamp life is about twice that of conventional incandescent lamps.

Incandescent lamps are available in wattages ranging from 2 to 1500 watts and above. In many cases, the light level generated by a particular luminaire can be increased or decreased simply by switching to different lamp wattage. This is because incandescent lamps are "resistance smart." The lamp's filament is designed and sized to offer a preset amount of resistance to current flow. This controls the amount of current passing through the lamp.

On the other hand, HID lamps are "amps dumb." They have no built-in resistance to current flow and the lamp must rely on an external ballast to limit current flow to the lamp. The wattage and voltage ratings of the HID lamp and its ballast must match exactly.

Fluorescent Lamps

Fluorescent lamps are low pressure or Low Intensity Discharge lamps. The lamp consists of a closed tube that contains two cathodes, an inert gas such as argon, and a small amount of mercury (Figure 2). When voltage is supplied to the lamp in the correct amount, an electrical arc strikes between the two cathodes. This arc emits energy that the phosphor coating on the lamp tube converts into usable light.

HID Lamps

The HID lamp group is by far the most important lamp group used in modern exterior and industrial lighting. HID light sources are highly regarded for their long life and high efficacy. The compactness of HID lamps also increases optical control and allows for a great deal of flexibility in the area of luminaire design.

HID systems are the most cost-effective method of lighting roadways, parking areas, sports fields, signs and buildings. HID systems also are ideally suited for interior applications such as sports arenas, warehouses, industrial plants and certain types of indirect office and commercial lighting.

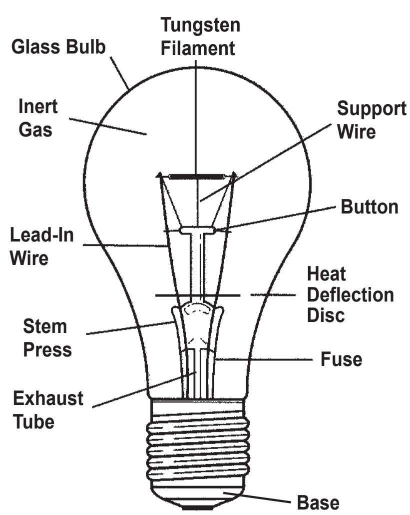


FIGURE 1. Typical incandescent lamp components.

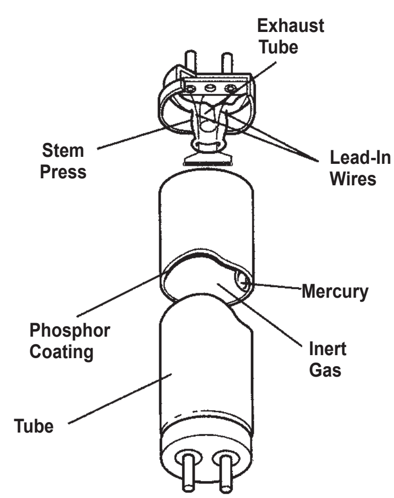


FIGURE 2. Typical fluorescent lamp components.

HID OPERATION AND CONSTRUCTION

All HID lamps share a number of design and operating features, but there are some important differences between mercury vapor, metal halide and HPS lamps (Figure 3).

All HID lamps contain a sealed arc tube mounted inside a glass bulb. In mercury vapor and metal halide lamps, the bulb is filled with hydrogen gas, which absorbs the ultraviolet radiation produced during operation. HPS lamps have a vacuum inside the bulb to isolate the arc tube from changes in ambient temperature.

As the arc tube is manufactured, small amounts of special arc metals, such as mercury, halide compounds or sodium, are sealed inside the tube. Starting gases, such as argon, neon or xenon, are placed inside the tube. The arc tube also houses the lamp's two main electrodes, plus the separate starting electrode used in mercury vapor and metal halide lamps.

An HID lamp produces light in much the same manner as a lightning bolt. But instead of a brief flash, the electric arc between the lamp's two main electrodes is continuous. The striking and maintaining of this continuous arc is made possible by the starting gases and arc metals sealed inside the arc tube. The proper start-up voltage also is needed to establish the arc. Lamp start-up is not the same for all HID lamps.

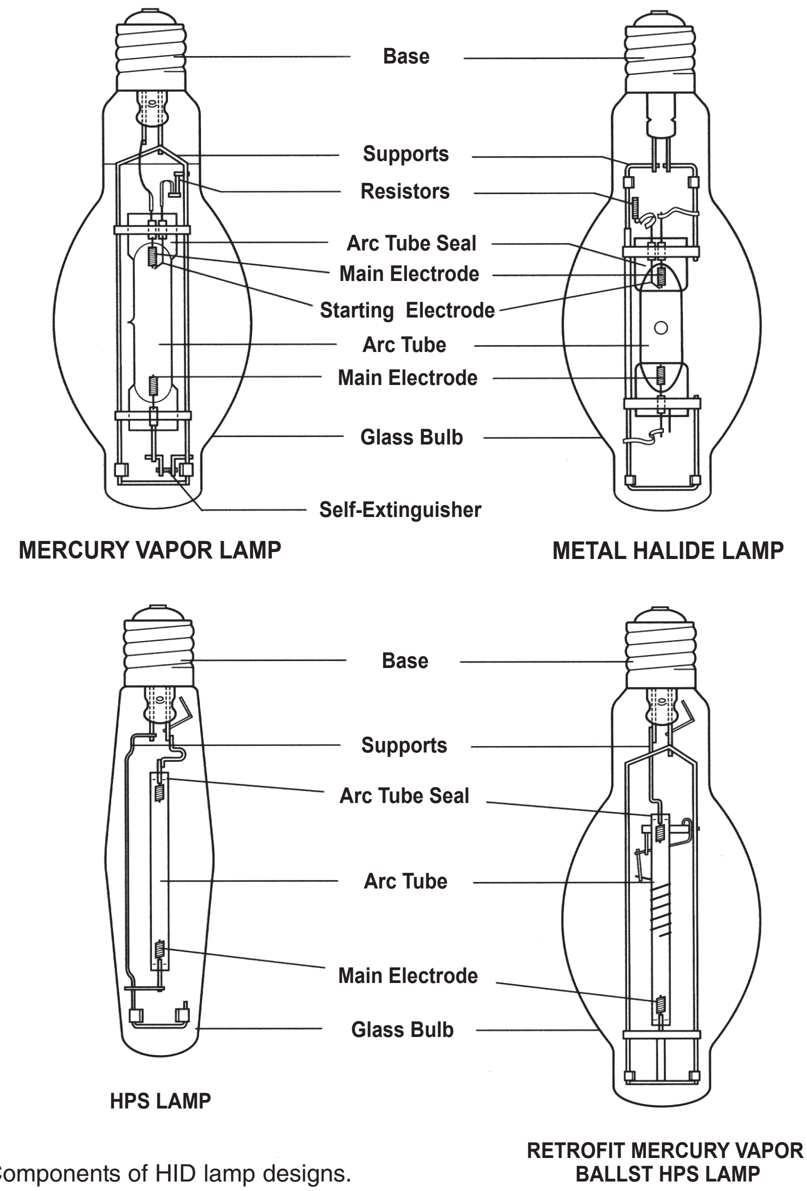


FIGURE 3. Components of HID lamp designs.

Mercury Vapor and Metal Halide Lamp Starting

As just mentioned, both mercury vapor and halide lamps use a separate starting electrode. This starting electrode is located next to one of the main electrodes inside the arc tube. The start-up electrode allows these lamps to be started using a much lower start-up voltage than required by HPS lamps.

When a mercury vapor or metal halide lamp is energized, an electrical field is generated between one of the main electrodes and the starting electrode next to it. This causes an emission of electrons that ionize the argon starting gas. The ionized argon particles create a diffused argon arc between the two main electrodes of the lamp (Figure 4).

The heat from this argon arc gradually vaporizes the arc metals in the arc tube. These ionized arc metal particles join the arc stream between the two main electrodes. When a sufficient number of ionized particles join the arc stream, the resistance between the main electrodes drops to a point where the start-up voltage supplied by the ballast can strike a current arc across the main electrodes. The arc current continues to increase until the current rating of the lamp is reached; a process that normally takes several minutes.

The HID arc consists of a very rapid flow of both electrons and charged arc metal ions. During this rapid movement, countless collisions occur between ions and electrons. As these particles collide, they release energy at a specific wavelength (Figure 5). This energy appears to us as light. Because the number of particles in the arc tube is so great and the occurrence of collisions so frequent, it appears that the entire arc path constantly generates light.

The color of the light is a characteristic of the light spectrum wavelength of the arc metals contained in the arc tube. For example, in a mercury vapor lamp, the mercury produces a distinct greenish white-blue light. Red, orange and yellow hues appear grayish.

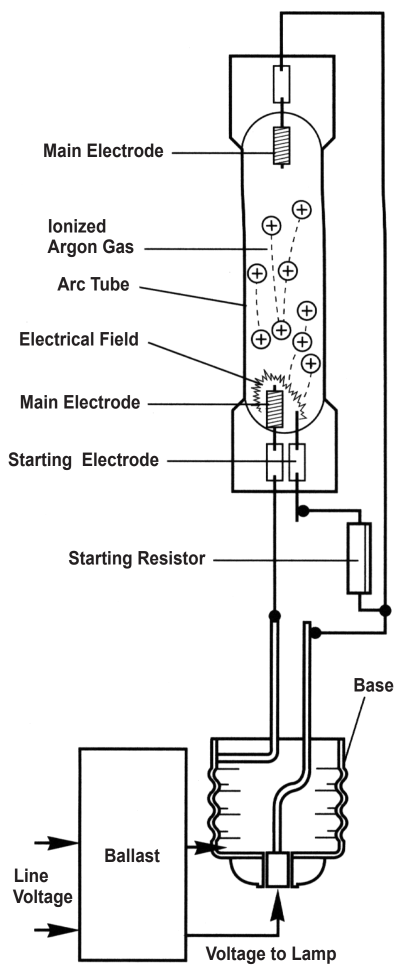


FIGURE 4. Mercury vapor or metal halide lamp

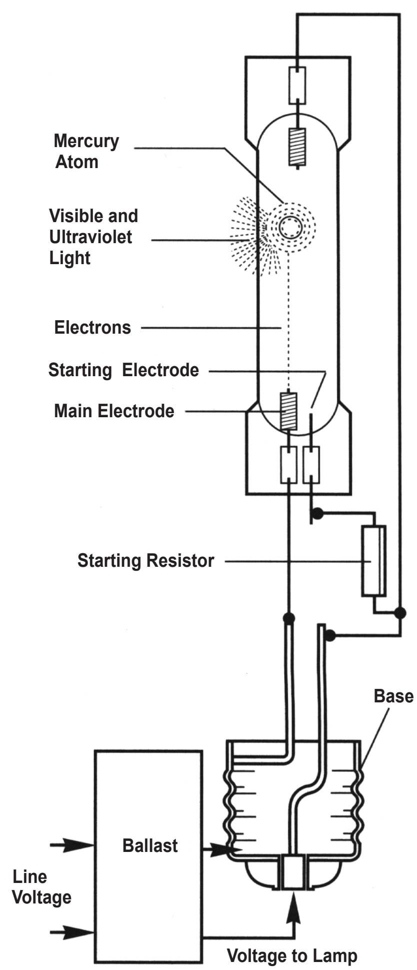


FIGURE 5. Light production in an HID lamp.

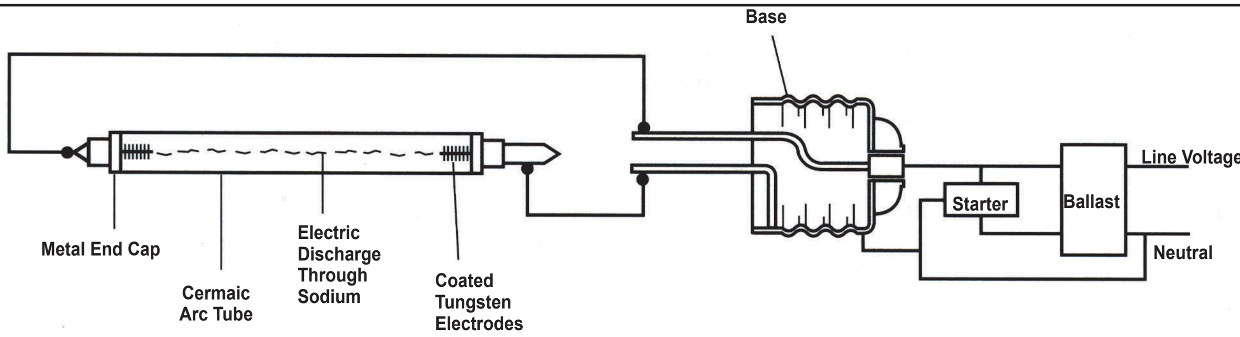


FIGURE 6. Components of HID lamp designs.

In a metal halide lamp, the arc discharges through the combined vapors of mercury and certain compounds of iodine. The halide compounds help strengthen yellows, greens and blues, so the overall color rendering of metal halide lamps is green-white. Reds and oranges appear dulled. Phosphor coatings on the bulbs of mercury vapor and metal halide lamps can improve color rendering and provide light diffusion.

Once a mercury vapor or metal halide lamp starts, voltage drops to lower operating voltage levels. A resistor or thermal switch in series with the starting electrode now blocks voltage to the starting electrode so it does not arc and burn out during normal lamp operation.

The arc tube of an HPS lamp is too narrow to house a separate starting electrode. Since there is no starting electrode in an HPS lamp, a much higher start-up voltage is required to establish an arc between the wide gaps of the main electrodes. This low-power, high-voltage spike ranges between 2500 and 4000 volts. This voltage spike or pulse is provided by a starter pulse circuit board separate from the ballast (Figure 6).

Note: Some lower wattage metal halide lamps (70-, 100- and 150-watt) also have arc tubes that are too narrow to house separate starting electrodes. These metal halide lamps now use an external starter board such as those used in HPS lamps.

When an HPS lamp is energized, the high-voltage pulse ionizes the xenon gas in the arc tube, and an arc is established between the main electrodes. As soon as this arc is established, the voltage pulse is switched off. Sodium and mercury arc metals quickly vaporize and join this arc stream, and the arc current increases and stabilizes.

HPS lamps generate a sodium-based light that is strongest in the yellow and orange range of the spectrum and weakest in the blue-green wavelengths. A small amount of mercury is added to the arc tube to help strengthen blues and greens, but the overall color rendering is still golden white, with both reds and blues appearing grayed.

Ballasts

All three types of HID lamps require the use of a ballast to assist in starting and limiting the current across the arc once the arc has been struck. Remember that HID lamps are negative resistance lamps. If a ballast were not used, the arc discharge would draw an unlimited amount of current and the lamp quickly would be destroyed. More complete ballast information can be found later in this manual.

Arc Tube Design

The arc tube of mercury vapor and metal halide lamps is shorter and wider in diameter than an HPS arc tube. This allows room for the starting electrode. Mercury vapor and metal halide arc tubes are thin-walled tubes made of high-quality quartz. The ends of the tube are sealed by flame forming. This one-piece, press-fit construction assures greater uniformity between lamps and also holds and protects the thin leads of the electrodes. As the two ends of the arc tube are heated and pressed together, the two main electrodes and thinner, starting electrode are imbedded in the molten glass. The arc metal and starting gas are fed into the tube through a glass straw welded into the arc tube. As the glass straw is heated to the melting point, the opening seals, trapping the gas and arc metal inside.

Both mercury vapor and metal halide arc tubes are filled with the exact amount of arc metal (commonly called amalgam) needed for operation. After an initial 100-hour burn-in time by the end user, mercury vapor and metal halide lamps reach a stabilized operating point at which all arc metal inside the tube is ionized during start-up and operation. At this point, lamp voltage

becomes relatively constant throughout the rest of the lamp's operating life. There is a very slight voltage rise, but it is not great enough to affect the life span of the lamp. The same is not true of HPS lamps.

The arc tube of an HPS lamp is a slender cylinder approximately 1/4" to 3/8" in diameter. Sodium cannot be contained in a glass tube. The sodium would etch the glass and further degrade light output. Sodium must be contained in a metal container. Most lamp manufacturers use a special ceramic material known as polycrystalline alumina (PCA) to construct the HPS arc tube. PCA is basically an aluminum oxide material virtually insensitive to sodium attack.

PCA tube materials do not lend themselves to the molten sealing method used in the construction of mercury vapor and metal halide arc tubes. Instead, PCA end caps, using either a wire-out end seal or a compound (shrink-fit and cemented) end seal, are epoxied or glued to the tube body using silicone glass. Each tube end cap contains an electrode. The sodium-mercury amalgam and starting gases are placed inside the arc tube before it is sealed closed.

Unlike mercury vapor and metal halide lamps, HPS lamps are excess amalgam lamps. This means there is more sodium and mercury arc metal placed inside the tube than can be vaporized during start-up and operation. The amount of amalgam that vaporizes depends on the total energy in the arc and the temperature of the amalgam. If the lamp becomes too hot, too much amalgam will vaporize, and operating voltage will increase.

When HPS lamps were first introduced, the amalgam not held in a vaporized state remained condensed in an external reservoir located in the coolest part of the lamp. If the lamp was vibrated by winds or passing traffic, amalgam from the reservoir would splash down onto the arc tube, causing a thermal shock that would extinguish the lamp. The lamp would then go through its start-up process and cycling would occur. Because of this thermal blink-out problem all but one of the major HPS lamp manufacturers have abandoned the external amalgam reservoir design in favor of internal reservoirs that do not create a thermal blink-out condition.

Experience has shown that during the first 20 minutes or so of HPS lamp operation, the lamp voltage may rise or fall from start to start, or even during continuous operation, as varying amounts of amalgam enter the arc stream.

Most HID lamps use a wire support frame to protect, cushion, and align the arc tube in the center of the bulb. The design and placement of this support frame is particularly important in HPS lamps, because it can affect the temperature of the arc tube and end caps. As we have seen, arc tube temperature has a direct effect on the amount of amalgam vaporized.

The construction and composition of the HPS main electrodes also are very critical. Material discharged from the electrodes during start-up and operation redeposits on the arc tube ends in much the same way the tungsten filament of an incandescent lamp evaporates and blackens the bulb. This blackening of the arc tube also will increase operating temperatures and voltage across the arc tube.

HPS End-of-Life Voltage

With a number of factors contributing to HPS lamp voltage rise, the increase in operating voltage over the life of the lamp becomes significant. The operating voltage of HPS lamps increases about 1-2 volts per 1000 hours operated. The life of an HPS lamp is dependent on the rate of lamp voltage rise. Lamp voltage will rise until it reaches the limit of the ballast voltage available. At this point, the HPS lamp will cycle ON and OFF, and its effective life will be over.

HID OPERATING CHARACTERISTICS

Certain operational characteristics are common to all HID lamps. With any HID lamp, sufficient starting current must be supplied to the lamp during the first half-minute or so of operation. Too little current results in the lamp never warming up properly, while too much current will reduce lamp life. Too little current can be caused by an improperly installed lamp, a bad connection or a bad capacitor, or use of the incorrect ballast or capacitor.

Due to manufacturing tolerances, individual HID lamps operate within a range of operating voltages. For example, as shown in Table 1, a 150-watt HPS lamp rated at 55 volts can have a lamp voltage range of 48 to 62 volts.

HID lamps will operate at their rated wattages only if the lamp and line voltages are nominal. Variations in lamp and line voltages can cause a lamp wattage variation of up to 20%.

HID lamps should not be operated at higher-than-rated wattages. This can be caused by using a capacitor with a rating too high for the fixture, or by installing a lamp with a lower wattage rating than the fixture. Although light output may increase, the excess wattage dramatically increases operating temperatures of electrodes, arc tubes and bulb walls. The arc tube may bulge and possibly shatter. Lumen maintenance and lamp life also are significantly decreased.

HID lamps also are sensitive to voltage interruptions. If the lamp circuit is turned OFF, a momentary power outage occurs, or the lamp voltage drops below the level needed to sustain the arc discharge, the ions in the arc tube deionize and light output stops. The lamp will not restart immediately. This is because the arc gases are now under pressure and the lamp must cool sufficiently to reduce the vapor pressure to a level where the arc will restrike at the available voltage. The time required to relight is strongly influenced by the design of the luminaire, since this will determine to a large extent the cooling rate of the lamp. In general, mercury vapor lamps will relight in 8 to 10 minutes, metal halide lamps in 10 to 45 minutes, and HPS lamps in 1 minute or less.

HID LAMP LUMEN MAINTENANCE

Light output from all types of HID lamps gradually declines over time. Lumen maintenance depends on a number of light loss factors. These include any physical changes in the lamp, such as electrode deterioration, blackening of the arc tube or bulb, shifts in the chemical balance of the arc metals, or changes in ballast performance. Longer burning cycles result in better lumen maintenance because there is less stress on lamp components due to frequent starting. Other factors affecting lumen depreciation are lamp watts and current, and the current waveform that is a function of the lamp and luminaire circuit. Ambient temperature does not have a great effect on the maintained light output of HID lamps.

TABLE 1: HPS LAMP DATA

ANSI Code	Lamp Watts	Rated Lamp Life[1]	Rated Voltage	Minimum Socket Voltage[3]	NEW Lamp Voltage Range (at 100 Hours)[2]	Nominal Lamp Amps	End-of-Life Lamp Voltage	Average Volts Increase Per 1,000 Hours Life
S76	35	16,000+ Hrs.	52	110	46-62	0.83	84	1.5
S68	50	24,000+ Hrs.	52	110	46-60	1.18	84	1.5
S62	70	24,000+ Hrs.	52	110	45-60	1.60	84	1.5
S54	100	24,000+ Hrs.	55	110	44-62	2.10	84	1.5
S55	150 (55 volts)	24,000+ Hrs.	55	110	48-62	3.20	88	1.5
S56	150 (100 volts)	24,000+ Hrs.	100	198	85-115	1.80	160	1.5
S66	200	24,000+ Hrs.	100	198	90-115	2.40	160	1.5
S50	250	24,000+ Hrs.	100	198	90-120	3.00	160	1.5
S57	310	24,000+ Hrs.	100	198	90-120	3.60	160	1.5
S51	400	24,000+ Hrs.	100	198	84-115	4.60	140	1.5
S52	1000	24,000+ Hrs.	250	456	210-275	4.70	350	1.5

[1] Rated lamp life is based on 50% survival.

[2] 100 hours is lamp manufacturer specification for stabilizing light output.

[3] Also called open circuit.

CAUTION: Disconnect starting lead not common to the lamp to eliminate the starting voltage when checking the minimum open circuit voltage. The starting voltage may damage your voltmeter.

HPS Lamps

HPS lamps have excellent lumen maintenance (Figure 7A). HPS lamps still are generating 90% of initial light output at the midpoint of their life span. Lumen maintenance at the end of life still is excellent at around 80%.

Mercury Vapor Lamps

The graph in Figure 7B covers the lumen depreciation curves for a range of mercury vapor lamp wattages. Maintenance of most types falls in the darkly shaded area. Frequent starting or lamp burning position has very little effect on mercury vapor lumen maintenance.

Metal Halide Lamps

As the graph in Figure 7C shows, the light output of metal halide lamps declines more rapidly than either HPS or mercury vapor lamps. Frequent starting will shorten metal halide lamp life.

HID LAMP LIFE

The rated average life of HID lamps is the life obtained from a large group of test lamps burned under controlled conditions at 10 or more burning hours per start. It is based on the survival of at least 50% of the lamps or groups of lamps and can vary considerably from the average. Factors affecting HID lamp life include: lamp operating wattage, lamp operating temperature, ballast characteristics, line voltage and burning hours per start. Lamp age, or the number of hours a lamp has operated, has very little effect on lamp startability, although metal halide lamps can require longer starting times as they age.

HPS Lamps

As shown in the lamp survival curve in Figure 8A, HPS lamps have a long average life span of 24,000 plus hours. Normal end of life occurs when the lamp begins to cycle on and off due to excessive lamp voltage rise.

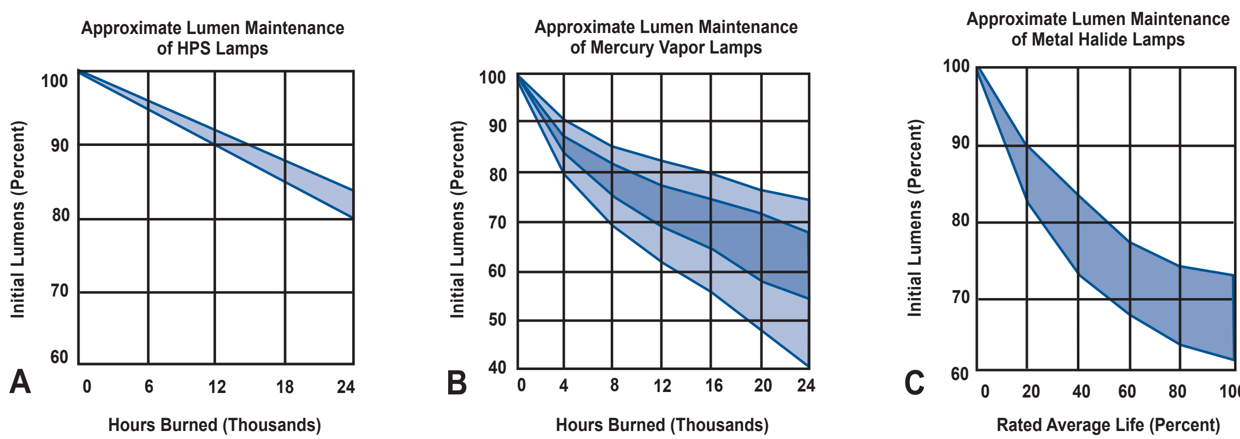


FIGURE 7. HID lamp lumens maintenance curves: (A) HPS, (B) mercury vapor, (C) metal halide.

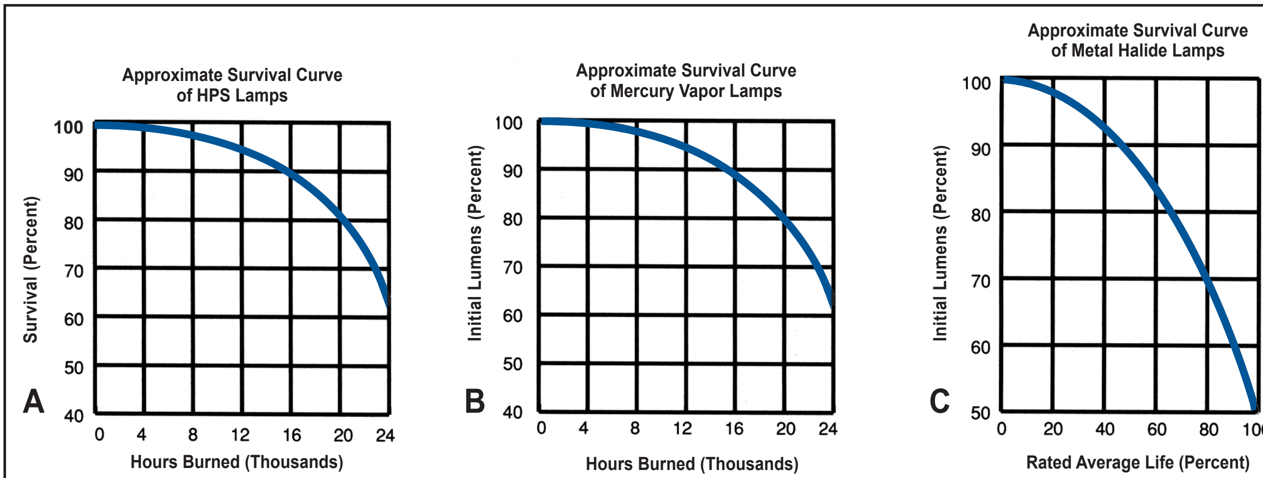


FIGURE 8. HID lamp life curves: (A) HPS, (B) mercury vapor, (C) metal halide.

More frequent starts will cause voltage to rise faster, as will overwattage operation. Slight underwattage operation will have no adverse effect on lamp life.

Mercury Vapor Lamps

Mercury vapor lamps have an extremely long-rated life, exceeding 24,000 hours (Figure 8B). Mercury lamps should be replaced before they burn out due to decreases in lumen output. Frequent starting does not adversely affect lamp life as significantly as other HID lamps. The normal mode of failure is the inability to start.

Metal Halide Lamps

Metal halide lamps have an average-rated life span of 3,000 to 20,000 hours, depending on lamp wattage. Lamp life generally is much shorter than HPS and mercury vapor due to poorer lumen maintenance and the presence of iodine compounds in the arc tube. The normal failure mode is the inability to start because of increased starting voltage requirements. Frequent starting also will adversely affect lamp life, as will overwattage operation.

THE HPS LUMINAIRE

Troubleshooting and repairing HPS lighting fixtures involve working with some components and operating principles not found in mercury vapor or metal halide fixtures. Now that you understand the primary differences between HPS, mercury vapor, and metal halide operation, it's time to discuss how these differences affect troubleshooting and repairing procedures.

HPS Lamp Starters

Inspection of an HPS luminaire will reveal an additional component not found in mercury vapor or metal halide fixtures—an external starter (Figure 9). This starter can be found as a printed electronic circuit board in some luminaires. The starter also may be packaged in a small plastic cube or can. Regardless of how they are packaged, external starters all perform the same function: they increase the 120 or 240 volts supplied to the lamp to the 2500 to 4000 volts needed to start the lamp.

Note: 1000-watt HPS lamps require a minimum starting voltage of 3000 volts and a maximum of 5000 volts. As explained earlier, this high-voltage spike is needed to bridge the wide gap between the HPS lamp's main electrodes.

The starter is used only during the first few moments of lamp start-up. Once the starting gas arc is struck between the main electrodes, the starter turns OFF and does not operate until it is needed again. Many service technicians unfamiliar with HPS starter operations are unaware of this fact. They automatically replace the starter when faced with an HPS lamp that cycles ON and OFF, particularly if the cycling is intermittent. The technician assumes the starter is at fault. In fact, it is operating repeatedly—it is turning the lamp ON not once, but many times.

The external starter must be properly matched to the lamp, luminaire and ballast. There are slight design and operating differences between starter manufacturers, and mixing starters could result in unreliable starts. There also are differences in the various wattage match-ups provided by the fixture manufacturers. Therefore, mixing various wattage ballasts with various starting circuits is not recommended as this also could result in unreliable starting.

Starter Operation

An HPS starter operates similarly to an automotive breaker point ignition system. The ignition system is made of two interconnected circuits: the primary (low-voltage) circuit and the secondary (high-voltage) circuit. When the ignition switch is turned ON, current flows to the ignition coil's primary winding, through the breaker points, to ground. This low-voltage current flow in the coil's primary winding creates a magnetic field. When the current flow is interrupted as the breaker points open, the magnetic field collapses, and a high-voltage surge is induced in the coil's secondary winding.

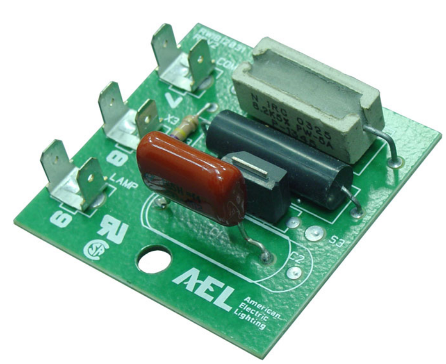


FIGURE 9. Starter circuit in typical HPS circuit.

The high-voltage surge from the secondary coil windings flows to the distributor via an ignition cable. From the distributor, high voltage is delivered through cables to the individual spark plugs, where it arcs across the plug electrodes to ignite the air/fuel mixture in the cylinder.

Opening and closing the points acts as a switch. Timing of the open/close switching is controlled by a camshaft in the distributor. As the camshaft turns, lobes on the shaft open and close the points. A condenser, which is actually a capacitor, promotes fast and complete breakdown of the magnetic field in the primary coil. This helps produce a strong induced voltage in the secondary coil.

An HPS lamp starter contains corresponding components. An electronic switch acts in place of the mechanical breaker points of the ignition system. The starter circuit contains a capacitor that corresponds to the ignition system condenser. The HPS ballast acts as the ignition system's primary and secondary coils. The electrodes in the arc tube correspond to the spark plug electrodes, and the starting gas acts as the combustible fuel.

The electronic switch of the starter is activated by the rise and fall of the voltage levels that occur in the 60-cycle alternating current (AC) used to power the lighting fixture. As you can see from the 120-volt AC waveform shown in Figure 10, the voltage cycles from 0 to 177 volts, to 0 to 177 volts again, 60 times per second. The average voltage is 120 volts. As the voltage rises and falls in each half cycle, the electronic switch opens and closes, just as the breaker points in the automotive distributor open and close when the distributor camshaft is rotated.

The capacitor also plays an important role in the operation of the starter. When the light fixture is turned ON, the capacitor is charged by the rise in voltage in the 60 cycle AC. When the voltage rises to the upper portion of the generated half cycle, the voltage level reaches a point that causes the electronic switch to close. Once the electronic switch closes, the charged capacitor is given a discharge path to the 10 to 12 winding turns of the tapped portion of the ballast (Figure 11). The ballast tap acts as a primary coil.

The high-voltage step-up in the ballast is accomplished in much the same way as in the automotive ignition coil previously described. Current from the charged capacitor passes through the 10 to 12 windings of the ballast tap, creating a magnetic field. When the starter's electronic switch opens, the capacitor's path to the ballast tap is momentarily broken and the magnetic field collapses inward toward the center of the ballast output coil. The magnetic lines of force that were created in the tap windings cut across the hundreds of turns of fine wire that make up the output coil. As a result, the electron balance in the output coil wire is upset and voltage is produced in the output coil windings.

The current flow from the output windings has high voltage because the output coil is made of hundreds of wire turns. As the magnetic field falls inward, it cuts across each turn of wire, generating a certain amount of voltage in each loop. Since the loops are connected in series, the voltage produced in one loop is added to the voltage produced in the succeeding loops. By the time the lines of force have fallen all the way to the center of the output coil, the necessary 2500- to 4000-volt starting pulse has been generated.

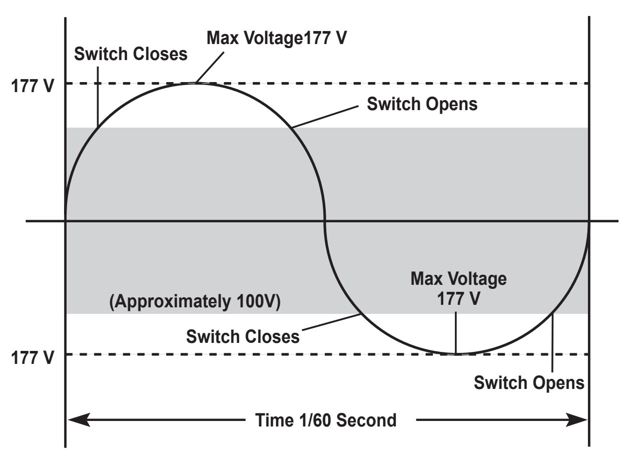


FIGURE 10. The electronic switch in the starter circuit closes every time voltage of 60 cycle AC power source rises above a certain level.

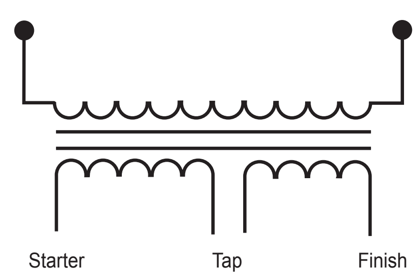


FIGURE 11. Ballast tap acts as a primary coil.

In effect, the ballast acts like a step-up transformer. For example, consider a ballast with 10 turns of wire in its tap coil and 300 turns of wire in its output coil. If the HPS starter capacitor charges to 100 volts and then discharges through the switch into the 10 turns of the ballast tap, the 100 volts would be divided over the 10 turns, and each turn would have 10 volts on it. When the magnetic field collapses, the 10 volts per tap turn would then be magnetically transferred to induce 10 volts on each of the 300 turns of the output coil. This would result in a total voltage output of 3000 volts (10 volts x 300 turns = 3000 volts). This example is a vast oversimplification. In actual transformer design, other considerations must be accounted for, such as wire and core losses. But the general operating principle is correct.

The HPS luminaire ballast also performs a number of other functions necessary in starting and operating the lamp. For example, the ballast allows a lower voltage to be placed on the arc tube electrodes during start-up and operation of the lamp. This lower voltage is the source of voltage needed to both start the lamp and then maintain and help in controlling the operation of the lamp.

For example, HPS lamps in the 35- to 150-watt range have an initial open circuit voltage of 110 to 120 volts. When the lamp starts, it pulls the ballast's secondary voltage down to approximately 15 volts. As the lamp warms up over the next several minutes, the lamp voltage rises to its rated operating level, which is usually between 44 and 62 volts. Operating voltage stabilizes at this time and the lamp operates at its rated light output and color rendering capabilities. See Table 1 for a complete summary of typical HPS lamp data.

The lower 44- to 62-volt operating voltage also keeps the HPS starter turned OFF. Remember, the electronic switch in the starter will close only when voltages in the neighborhood of 100 volts are applied to it. Once the lamp starts and the ballast decreases voltage to the 44- to 62-volt range, the electronic switch remains open and the charging and discharging of the capacitor cannot take place. The 2500- to 4000-volt starting pulse can no longer be produced until the lamp is turned OFF and the initial open circuit voltage of 110 to 120 volts is applied to the starter circuit.

Starter Variations

Since the commercial introduction of HPS lamps in the mid-1960s, very few changes have taken place in the starting principles of the lamp. Early starters used a transistor-type electronic switch that required additional electronic components to achieve the proper timing of the switching operation. Modern starter designs use a self-timing device that minimizes the number of electronic components. Fewer components have made modern starters more reliable.

Instant Restrike Starters

A standard HPS lamp starter requires that the lamp cool down for approximately one (1) minute before it can be restarted. Instant restrike devices that generate two to four times the normal maximum pulse voltage are available. This voltage is strong enough to overcome the gas pressure inside the arc tube and instantly reionize the gases, restarting the lamp. Instant restart devices usually are required in industrial applications where safety rules require the restoration of light within a short period of time after a power outage has occurred. Instant restrike starters are more expensive than standard starters.

Two-Lead Starters

One recent innovation in HPS starter technology is the two-lead starter (Figure 12). This HPS lamp starter contains its own ignition coil and does not rely on the ballast to provide voltage step-up. Some two-lead starters can be used with any manufacturer's ballasts.

In contrast, starters that use the ballast as an ignition coil are not readily interchangeable. The reason for this is that the turns ratio between the ballast tap and the output coil portion of the ballast varies from one manufacturer to another. This, coupled with differences in electronic component values between manufacturers, can lead to mismatch problems. A new lamp usually will start with a mismatched starter and ballast, but significantly reduced lamp life or premature ballast failure is likely.

Limited lamp life can occur when the mismatch does not allow the proper starting pulse to be produced. If the starting voltage pulse exceeds the lamp manufacturer's limits, the arc tube electrodes will erode away, causing premature lamp cycling or an outage. Excessive starting voltages also can short out the ballast, resulting in ballast burnout, or can break down the lamp socket or the lamp base internally. If the starting pulse is too low, then lamp starting will become unreliable early in lamp life.

The two-lead starter eliminates mismatching problems when used with various manufacturers' ballasts. The two-lead starter operates on the lamp socket voltage, which is an ANSI standard.

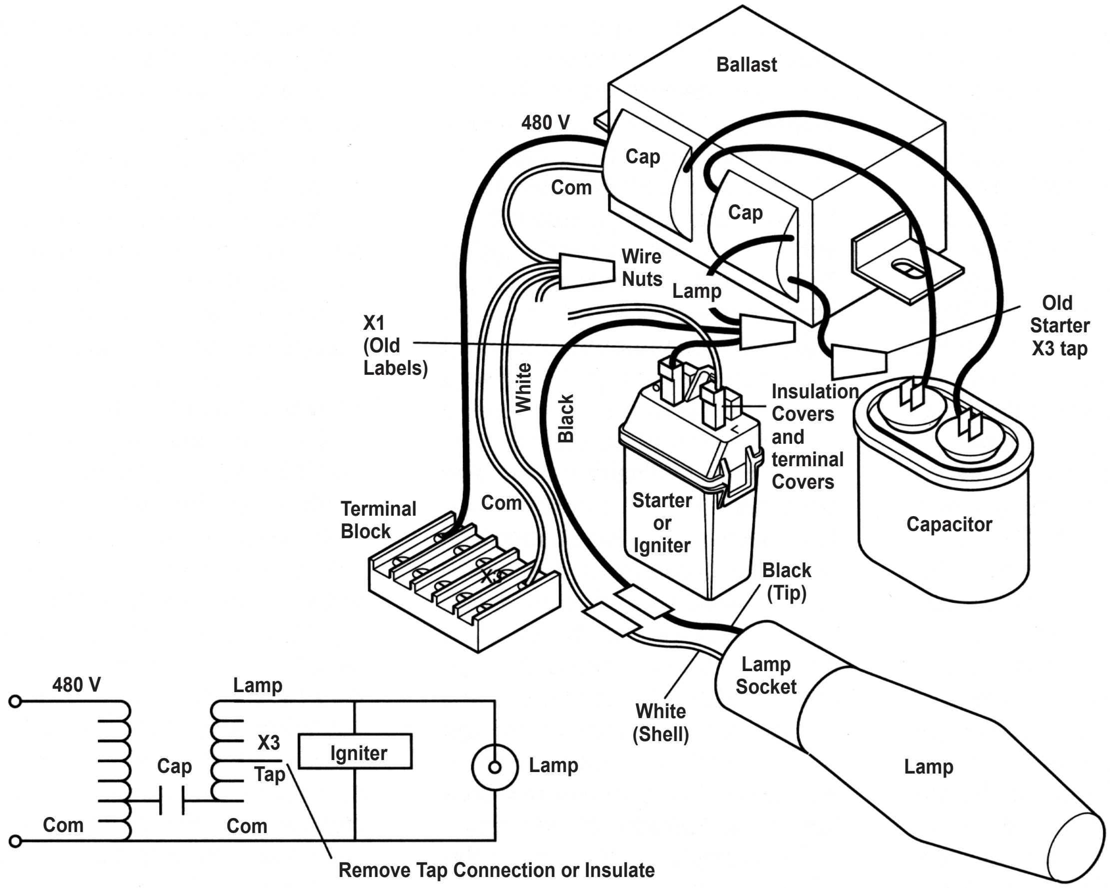


FIGURE 12. Two-lead starters have their own ignition coil.

It produces its own step-up voltage pulse and sends it to the lamp. When the two-lead starter is installed, the lead on the ballast that runs from the ballast tap to the starter is disconnected. This disables the starting function of the ballast, now handled by the two-lead starter. However, the ballast still can perform its other current and voltage regulation functions.

Two-lead starters are ideal for users that must maintain a wide range of luminaires built by different manufacturers. They also solve the problem of obtaining properly matched replacement parts.

HID LAMP BALLASTS

As we have discussed, the ballast performs a number of important functions in HID lamp operation. These include:

1. Providing the correct starting current.

2. Providing the correct starting voltage.

3. Limiting current to the lamp. The most basic function performed by a ballast is to limit the flow of current through the lamp. When the lamp starts and begins operation, it basically is operating as a short circuit across the electrodes. The ballast connected with the lamp acts to limit the current flowing to the lamp to keep it from destroying itself as resistance develops. Without the limiting capability of the ballast, the lamp would draw more and more current and eventually explode.

4. Providing the correct voltage to stabilize lamp operation. We also have discussed how a ballast can act as a transformer to step-up line voltage levels needed to start the lamp. Many mercury vapor and metal halide lamps are designed to start using approximately 240 volts. If this voltage is not available, transformers are used inside the ballast to change the available voltage into the 240 volts needed for start-up. For example, if 120 volts is applied to a 100-turn primary coil, a secondary output coil with 200 turns will produce the needed 240 volts for start-up.

By altering the ratio between the number of primary and secondary coil turns, and including the necessary switching circuitry, the ballast also can produce the 2500- to 4000-volt low energy voltage spike needed to start HPS lamps.

5. Regulating the flow of current through the arc discharge. As mentioned in our discussion of lamp operation, HID lamps reach a point of equilibrium several minutes after start-up. Changes that affect the temperature of the arc tube, such as changes in the voltage supplied to the lamp through the ballast, can produce significant variations in the lamp's wattage and light output. Ballasts act to reduce this variation by absorbing part of this varying voltage input.

   By subjecting the steel core of the ballast to high amounts of magnetic force, you also can change the ratio at which voltage is transferred between its primary and secondary coils. For example, a ballast can be designed to have a given voltage transfer ratio at a predetermined input voltage. However, if input voltage begins to increase from this value, the steel core of the ballast becomes overworked or saturated by magnetic force. The result is that increases in voltage in the primary coil are not transferred to the secondary coil, nor are they passed on to the lamp. Instead, the ballast continues to output voltage at the proper levels. This is the basic design principle used in all regulated ballasts. The secondary or lamp is isolated from changes in the primary or power supply.

6. Compensating for the low power factor characteristic of the arc discharge. Ballasts are classified as either *normal* or *high power factor*. A normal power factor ballast and HID lamp combination has a power factor of approximately 50%. This means that for a given wattage more than twice as much current is required to operate the HID lamp and ballast as would be needed to operate an ordinary incandescent lamp with the same wattage rating. Normal power factor ballasts are commonly used in reactor and high-reactance-type ballast circuits for both mercury vapor and HPS lamps. They commonly are used for lower wattage lamps of 150 watts or less.

   A high power factor ballast is one that draws within 10% of the minimum line voltage for a specific power consumption. This type of ballast is described as having a power factor of 90% or greater. High power factor ballasts allow the use of a large number of luminaires and high wattage lamps on each branch circuit.

The total power in any direct current (DC) circuit or in any AC circuit with only resistance loads, such as incandescent filament lamps, is expressed by the fundamental equation:

Total Watts = Volts x Amperes

In such circuits, the total watts are active in doing useful work, such as producing light. In an HID lamp circuit that requires a ballast, some of the current is not effective in operating the ballast or in producing light. So in an HID circuit, the product of volts and amperes does not equal the active watts as read by a wattmeter because such a meter measures only the active power used. It is, therefore, necessary to express the active watts in an HID lamp circuit as follows:

Total
Watts = Volts x Amperes x Power Factor
(Active)

$$\textbf{Amperes} = \frac{\textbf{Total Watts (Active)}}{\textbf{Volts x Power Factor}}$$

The power factor is the ratio of the active power as read on the wattmeter to the product of the volts and amperes as read on meters placed in the HID circuit. This ratio usually is expressed as a percentage:

$$\textbf{Power Factor} = \frac{\textbf{Total Watts (Active)}}{\textbf{Amperes x Volts}}$$

Using the equation **Total Watts = Volts x Amperes x Power Factor**, it is easy to see how the power factor of a ballast affects the total current in a circuit.

When the power factor is 100%, the current is at a minimum and the product of the amperes and volts is equal to the active watts as measured by a wattmeter. However, if the ballast has a power factor of 50%, the current in the circuit is doubled. If the ballast power factor is 90%, the current will be increased by only 10%. Failure to consider the effect of power factor on the current, especially when the circuits are heavily loaded, can result in overheated wires, excessive voltage drop, or interruptions caused by the operation of protective equipment.

TABLE 2: BALLAST CHARACTERISTICS FOR HID LIGHT SOURCES

Ballast Type	Reactor	Auto	Regulated Auto (CWA)	Mercury Vapor Constant Wattage (CW)	HPS Constant Voltage
Typical Line Voltage	240	120	**	**	**
% Lamp Wattage Change	±12%	±12%	±5%	±2-1/2%	±10%
% Input Voltage Change	±5%	±5%	±10%	±13%	±10%
Power Factor (P.F.)	50%	50%	90%	90%	90%
Capacitor	–*	–*	Std.	Std.	Std.
Mercury Vapor	X	X	X	X	–
Metal Additive	–	–	X***	–	–
Metal Additive (for approved mercury ballast)	–	–	X	X	–
HPS	X	X	X	–	X
HPS (no starting circuit, mercury ballasted)	X	X	–	–	–
Low-Pressure Sodium	–	X**	–	–	–

NOTE: X indicates equipment that is normally appropriate for a given source.
* Capacitor required for high power factor only.
** All voltages.
*** Specially designed CWA-type ballast for metal additive lamps.

Ballast Characteristics

Typical characteristics of ballasts used in HID lighting systems are summarized in Table 2. Figure 13 illustrates luminaire wiring diagrams for the various ballasts used in HID lighting systems. Other characteristics are as follows:

Ballast Efficiency: No ballast delivers all of the current passing through it to the lamp it serves. Some power always is lost in the form of resistance heat. A ballast that is 90% efficient delivers 90% of the power to the lamp. The remaining 10% is wasted in heating the ballast. The ballast watt losses add to the total power consumed.

Line Voltage: For some ballasts, the line voltage as the lamp starts is less than the final operating voltage. In these cases, fuses and circuit breaker ratings should be based on the operating voltage value. For other ballasts, the starting voltage is considerably higher than the final operating voltage, so circuit protection must be sized to accommodate starting voltage levels.

Line Voltage Regulation: Variations in line voltage can be caused by system demands and other factors. Newer power systems normally operate within ±5% of the rated system voltage, but in some older systems the daily voltage variation can be as high as 10%. The ballast selected must be able to accommodate these voltage fluctuations.

Extinction Voltage: All power systems are subject to dips in line voltage that normally are around 10%, but occasionally can reach 20% to 30%. The ballast should be capable of riding out these dips without extinguishing the lamp.

Reactor Ballasts

Reactors are the simplest type of ballast. They consist of a single coil or wire on a core of steel. Functionally, they act as current limiters and provide some lamp wattage regulation. Reactors are normal power factor ballasts, but a capacitor can be added to provide high power factor performance. The units are designed for ±5% input voltage variation and limit or regulate lamp wattage to a ±12% variation within that range. For example, in a 240-volt, 400-watt reactor ballast, voltage can vary from 228 to 252 volts (±5%) and wattage from 352 to 448 watts (± 12%). Characteristically, reactor ballasts require a higher start-up current than operating current. They only are used when the available line voltage is at least two times greater than the lamp-rated operating voltage.

An HPS reactor ballast contains a starting circuit that provides the proper pulse voltage for starting the lamp.

Lag Auto Ballasts

This type of ballast is known by several names: lag auto, lag or high reactance ballast. It is used when the line voltage is 120 volts and socket voltage is in the 240-volt range. This ballast consists of two coils on a core of steel. Together, the tap and output coils transform the line voltage into the required starting voltage.

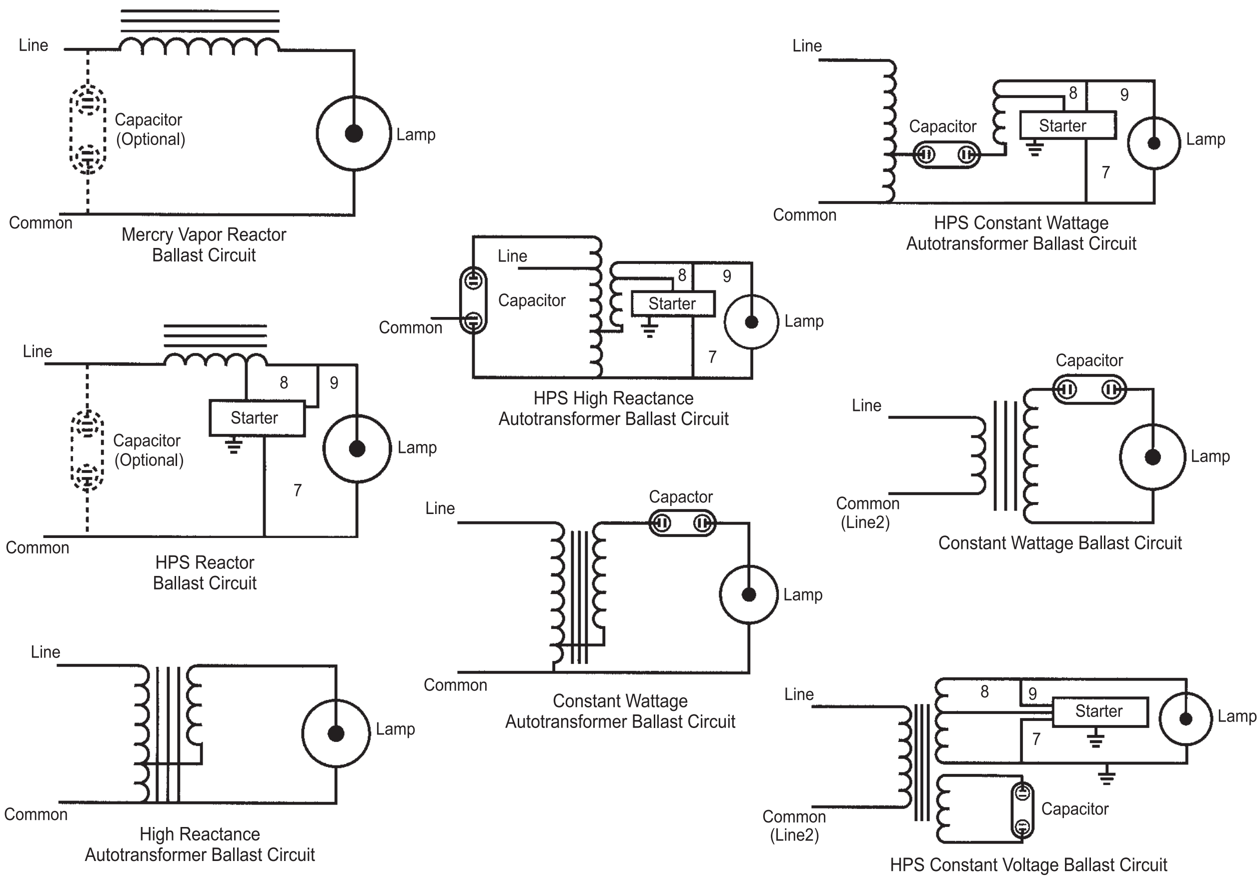


FIGURE 13. Circuit diagrams for various types of ballasts used in HID applications.

The ballast also limits lamp current. Lag auto ballasts have the same operating and performance characteristics as reactor ballasts. This type of ballast normally is used with mercury vapor and HPS lamps.

Constant Wattage Autotransformer Ballasts

These ballasts also are called regulated or autoregulator ballasts. The constant wattage autotransformer (CWA) ballast consists of two coils on a core of steel and a capacitor in series with the lamp. CWA ballasts perform the basic jobs of current limiting and voltage transformation. In addition, CWA ballasts are always high power factor ballasts. They have starting currents that are less than the operating current. In regard to voltage regulation, CWA ballasts offer significant improvements over reactor and lag auto designs. CWA ballasts are designed to handle a ±10% line voltage variation. Over this range, they will maintain lamp wattage within ±5%, a four-fold improvement over reactor and lag auto ballasts. They also can handle sudden dips in line voltage without lamp shutdown. This type of ballast is most commonly used in area, sports and indoor HID lighting.

Constant Wattage Ballasts

Also called isolated regulated-premium constant wattage ballasts, this ballast design limits current, performs voltage transformation and provides the best lamp wattage regulation available. They are designed to operate over a voltage range of ±13%, maintaining lamp wattage to within ±2.5%. Constant wattage (CW) ballasts have a high power factor and a lower starting current than operating current. These ballasts are similar in construction to CWA ballasts.

HPS Mag Reg

Also called reg lag, mag reg ballasts are used to meet HPS lamp wattage requirements on systems having a ±10% voltage variation. These are high power factor ballasts that have lower starting than operating current requirements. The mag reg transformer consists of three isolated coils on a core of steel.

Matching Lamp and Ballasts

It is very important to match lamp and ballast to attain proper lumen output and lamp life. HPS lamps rated at 55 volts can use a single coil reactor-type ballast having a separate starting circuit. A secondary coil is not needed in this case for voltage step-up, and the single-coil ballast generates less heat.

When installing replacement lamps, be sure the lamp voltage and wattage rating match the ratings of the fixture and ballast. For example, installing a 150-watt, 55-volt HPS light bulb in a fixture equipped with a 150-watt, 100-volt ballast will result in a dim burner. This is because the given ballast limits current to the lamp to 1.8 amperes. A 150-watt, 55-volt HPS lamp requires 3.2 amperes of current to reach full brightness. Ballast and lamp wattages must also match. Installing a 250-watt lamp in a 175-watt ballast fixture will result in a dim burning lamp. On the other hand, installing a 175-watt lamp in a 250-watt fixture will drastically reduce lamp life. A dim burner also can be caused by a shorted or incorrect capacitor.

PHOTOCONTROL OPERATION AND TROUBLESHOOTING

HID fixtures used in outdoor lighting applications such as roadway, area, site and security lighting can be equipped with photocontrol units that automatically turn the fixture on at dusk and off at dawn (Figure 14).

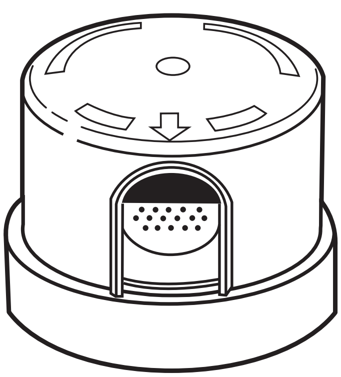


FIGURE 14. Typical photocontrol for HID luminaire.

The photocontrol, or photocell as it is sometimes called, consists of a small cadmium-sulfide cell wired in series with an electrical relay (Figure 15). Keep in mind that the cadmium-sulfide cell is not an energy-producing cell. It does not convert the sun's energy into a voltage.

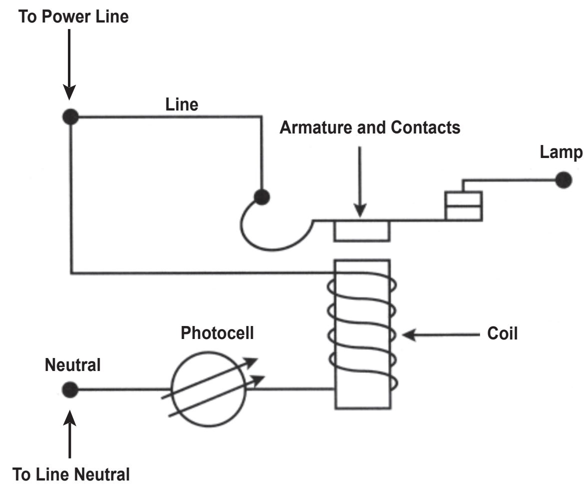


FIGURE 15. Photocontrol components and circuit.

The cell is a variable resistor, similar to those used to turn the volume of a radio up or down. The amount of light that strikes the cell increases or decreases the amount of electrical resistance in the cell.

During the day, when light strikes the photocell, resistance in the cell is very low. Current from the service drop can flow through the cell to the coil of the photocontrol relay. When the coil is energized, it creates a magnetic field that pulls in the armature of the relay. This armature movement opens the contacts to the fixture ballast. The lamp cannot operate with no line voltage supplied to the ballast.

As darkness falls, less and less light strikes the photocell and electrical resistance in the cell begins to increase. Less and less current passes through the relay coil and strength of the magnetic field generated by the coil drops. Finally, the magnetic field becomes so weak that it cannot hold in the armature, and the armature moves over to its open position. When the relay armature is in its open position, it closes the contacts to the ballast. Line voltage is applied to the ballast, and the lamp begins its start-up sequence. The lamp will operate until the light of sunrise again decreases resistance in the cell. This initiates current flow to the relay coil. The coil energizes and its magnetic field pulls the relay armature closed. This cuts line voltage to the ballast and the lamp turns OFF.

The photocontrol works because it uses a sensitive relay that operates on a very slow-changing voltage. The relay reacts to any voltage less than system voltage. An operational photocontrol will emit a soft, humming noise as it approaches its pull-in voltage. You will hear a slight click as the relay contacts close.

A defective or damaged photocontrol will emit a growling noise as it nears its pull-in voltage. This sound resembles a door bell buzzer and usually is caused by misaligned relay contacts. The photocontrol may continue to growl and never completely close its contacts. Or it may growl and then close its contacts. In either case, never use a photocontrol that can be made to growl or buzz during testing.

Test photocontrol operation by covering the photocell with your hand to simulate darkness (Figure 16). It should click open as you cover it and then click closed when you remove your hand. Repeat this test several times to center the relay armature. Now cover the cell completely and then very slowly uncover it in small stages to simulate sunrise. You should be able to trick the cell into humming lightly as it approaches its pull-in voltage. If you can trick the photocontrol into growling, replace it, or if it is new, do not use it.

FIGURE 16. Testing photocontrol operation. By gradually exposing the cell to light by moving your hand, you can trick the relay into closing.

A luminaire burning night and day is the most common indication of a failed photocontrol. A day burner is caused by the armature contacts of the photocontrol welding together due to an electrical heat buildup from "chattering" relay contacts. Coil circuit failure also can cause a day burner. Excessive heat also can pass from the photocontrol line twist lock connector pin through the photocontrol receptacle, weakening the photocontrol twist lock receptacle contacts. This is a common cause of early photocontrol failure. Heat also can deform the contact mounting in the photocontrol receptacle. Whenever you replace or inspect the photocontrol, also inspect the receptacle for signs of heat damage. Look for charred or deformed plastic or other signs of damage. Replace the fixture if the receptacle is damaged.

When installing a photocell into its receptacle, make sure it is locked into position and does not pull out. Make sure the receptacle mounting screws are fully tightened and holding. Otherwise, the springy nature of the gasket used to seal the photocell mounting surface will push the photocell upward and it will not be seated properly in its receptacle. Any vibration also will help push an improperly mounted photocell off its contacts. The contacts will then arc and burn, causing heat damage as just described.

HPS LAMP CYCLING

All HPS lamps experience voltage rise during their life and have a designed end-of-life voltage rating. When the voltage rise reaches the end-of-life voltage, the ballast cannot supply the needed operating voltage, the lamp goes out, and cycling begins. As the hot lamp cools, it restarts at a lower than end-of-life voltage. But as the lamp begins to heat up again, its operating voltage soon rises past its end-of-life voltage. The lamp turns OFF and the cycle repeats itself.

End-of-life cycling can occur in an HPS lamp at the time of installation, at six years, at end of life or at any time in between. A bad lamp can fail prematurely. In most cases, cycling is caused by a voltage rise due to increased lamp resistance, electrode wear, etc.

Equipment Mismatching

Using the wrong lamp in the fixture (Figure 17) can cause cycling. As shown in Table 1, 150-watt HPS lamps are manufactured in two voltage ratings: 55 volts and 100 volts. HPS 150-watt lamps will have their voltage rating stamped on the lamp body to avoid confusion when replacing these lamps. A 150-watt, 100-volt HPS lamp installed in a 150-watt, 55-volt fixture will cause cycling because the 55-volt ballast does not supply the necessary voltage required by the 100-volt lamp.

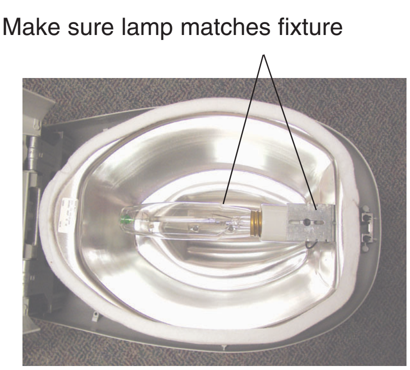


FIGURE 17. Checking the correct lamp.

Using a lower wattage HPS lamp in a higher wattage fixture, such as a 70-watt lamp in a 150-watt fixture, also may cause cycling.

Using the wrong or defective ballast or capacitor also can lead to cycling. Also be sure the ballast and capacitor are wired correctly.

Reignition Phenomenon

HPS and other HID lamps actually turn ON and OFF 120 times per second. Current is cut off for a millisecond or so at each midpoint, or zero crossing point, of the AC 60 Hertz cycle (Figure 18A). The lamp stays hot enough to automatically restrike after this very, very short outage. However, if several cycles of the AC power are lost or drop out due to loose wire connections or shorts, the lamp cools sufficiently to turn OFF and will not restrike immediately (Figure 18B).

To avoid dropouts due to poor connections, do not pull the wires tight when installing the luminaire or its internal components such as the ballast, photocontrol, starter or capacitor. The lamp must be screwed into the socket properly to make a good connection. The coil spring must be compressed completely to make proper contact at the base of the socket. All of the metal on the lamp's screw base should be hidden below the rim of the socket when the lamp is screwed in completely.

The lamp socket center contact and the tip of the lamp base must be in proper contact when the lamp is installed. If the center contact and lamp tip become misaligned due to a mismatch between the socket contact and the lamp tip, the lamp may not start due to poor or partial contact between the two. If this problem occurs, some service technicians may try turning the lamp out 1/2 turn or so. In some cases, the lamp may now light, but this is not an acceptable solution to the problem. The connection between the lamp and socket is not under full spring pressure, and electrical arcing will occur, drastically reducing lamp life or resulting in socket burnout.

Vibration Sensitivity

HPS lamps nearing the end of their service lives are very vibration sensitive. Vibration causes a rise in lamp current above the end-of-life voltage. HPS light color gives a good indication of relative lamp age. Older HPS lamps give off a whiter light. The color rendition they produce actually is better than new HPS lamps.

Vibration in the lamp due to wind or traffic can cause the lamp to cycle. Vibration-induced cycling is common in fixtures mounted on bridges. You can simulate this vibration in a burning lamp by striking the mounting pole with a short length of lumber, or by actually bumping the light fixture or light bulb with your hand. If the lamp turns OFF when the pole is struck, it is probably vibration sensitive.

The bump test also is a good way to check for intermittent open circuits and poor connections in the lamp and fixture.

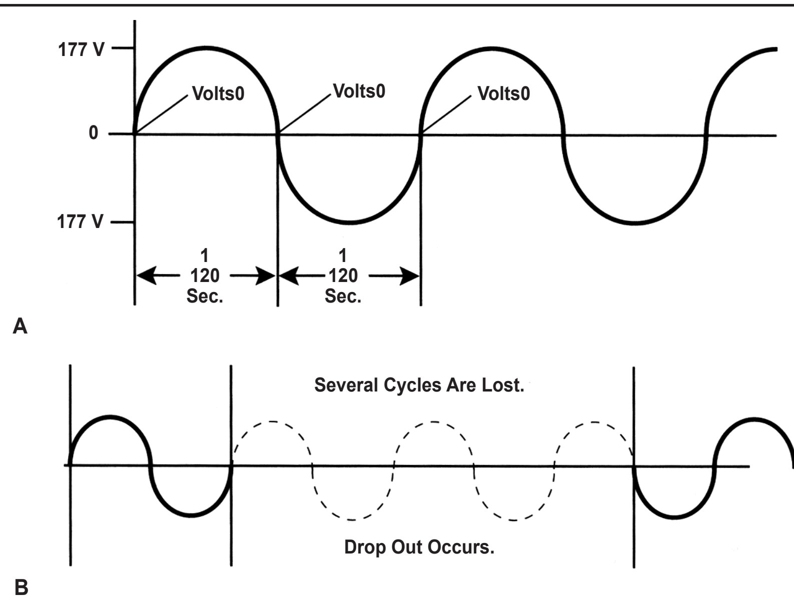


FIGURE 18. (A) Voltage actually is cut to the lamp every time alternating current changes direction. This happens 120 times per second with 60 Hertz AC power.
(B) When several cycles of AC current drop out or are lost, the lamp will turn OFF.

For example, the lamp's internal mounting frame is designed to allow the arc tube to move as it expands and contracts with changes in temperature. The metal mounting frame is stable, but the arc tube connects to the lamp base through the use of a flexible bond strap. Over time, the bond strap weld can fail, causing intermittent contact. A bump test often will detect this type of failure.

Keep in mind that normal end-of-life cycling is marked by a more or less predictable on/off pattern of a minute or so ON and a minute or so OFF. Cycling caused by open contacts or bad welds is much more unpredictable. The lamp may stay ON or OFF for several minutes or several hours.

When you field test a lamp with cycling problems, remember to test the photocontrol operation. As the lamp starts to come up, bump it to see if you can make it cycle OFF. You may even be able to see the slight electrical arcing at the bad connection. You also should bump test the lamp after it has started and stabilized.

Thermal Cycling

Thermal cycling is another vibration- or movement-induced problem that occurs in HPS lamps. Thermal blink-out is most common in exterior reservoir lamps operated in a position that places the amalgam reservoir above horizontal in the light fixture. However, severe vibration problems can cause thermal cycling in all types of HPS lamps. Vibration or movement due to wind, traffic or other reasons can cause excess amalgam to splash down onto the white-hot electrode, giving it a thermal shock. This thermal shock causes the lamp to drop out and cycle.

Bridge and viaduct installations are prone to thermal cycling problems. Thermal cycling can be avoided by selecting nonexternal reservoir-type lamps for high-vibration applications. In severe vibration conditions, thermal cycling could be fixture related. You can test for thermal cycling using the bump test.

Photocontrol-Induced Cycling

An overly sensitive photocontrol unit may cause cycling in an HPS or HID lamp installation. Light from the luminaire, or from other light sources around it, can trick the photocontrol causing it to turn OFF the luminaire. Aim the photocontrol away from strong light sources, or install shields to cut down on the level of ambient light entering the photocell (Figure 19). Seasonal changes can cause cycling problems due to reflective light differences between green leaves in spring and summer, and dead leaves and exposed tree bark in fall and winter.

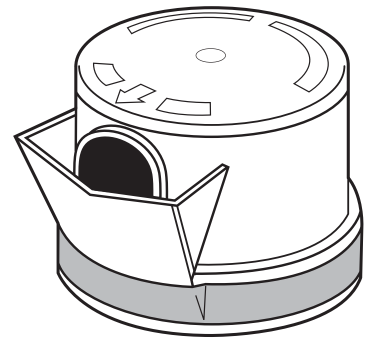


FIGURE 19. Shielding the photocontrol from high ambient light levels.

COST-EFFECTIVE SERVICING OF HPS LIGHTING SYSTEMS

When compared to mercury vapor and metal halide lamps, HPS lamps produce up to twice the amount of light per watt of power consumed. In terms of lumen maintenance, they outperform the other HID lamps by as much as three to one, and HPS lamp life is comparable to mercury vapor as the longest available in HID lighting. This all adds up to an extremely good lighting value. But HPS lighting offers another great value that often is overlooked—the ability to pretest and predetermine HPS lamp and luminaire performance before field installation.

Experience has shown that a short, easy-to-perform lamp voltage test can help eliminate potential early-failure HPS lamps and also can detect luminaires that could overdrive lamps and cause new good lamps to fail early in their rated life.

Spot (individual) lamp replacement is costly, and any unusually high failure rate due to defective equipment or components can be expensive, particularly when the replacements are being drawn from the same stock of lamps or luminaires that are failing in the first place. The time it takes to sample test 100 luminaires and lamps usually will be less than the time it would take a service technician to drive to a defective luminaire or outage, set up the bucket truck, change the lamp and/or luminaire, and drive to the next defective luminaire/lamp location.

Test Procedures

An HPS lamp can be pretested due to its voltage rise during its lifetime. For example, a new 100-watt HPS lamp is nominally rated at 55 volts, with an operating voltage range of 45 to 62 volts. This operating voltage usually stabilizes within 10 to 15 minutes after start-up. The 100-watt HPS lamp has an end-of-life voltage of 84 volts.

The projected life of the 100-watt HPS lamp is based on a lamp voltage rise from the 45- to 62-volt range to the 84-volt end-of-life voltage. This slow voltage rise usually takes about six years of normal operation. However, if a new HPS lamp tests higher than this 45- to 62-volt operating range, in the neighborhood of 70 volts for example, experience has shown that the rate of voltage increase will be significantly higher. The lamp will have a dramatically reduced life, and is a likely candidate for spot replacement if installed in the field.

Note: The above voltages are based on an ANSI standard where a nominal ballast is used on its nominal design voltage. Experience has shown that a slight 2- or 3-volt variation out of this range has not been detrimental to lamp life. For example, a lamp rated at 45 to 62 volts will operate satisfactorily in the 42- to 65-volt range.

Selecting the Test Group

In most cases, testing of 5% to 7% of the lamp or luminaire inventory is sufficient when testing for possible defective lamp or luminaire batches or runs. However, 100% pretesting may be more economical if the lamps and luminaires are to be installed in a high-cost maintenance location, such as a high-traffic roadway near a major airport. Spot lamp replacement in these areas can cost several hundred dollars for a single lamp.

If a 5% to 7% sampling is being used, be sure to select the lamps and luminaires from different batches or runs in your equipment inventory. Check the run or batch number that appears on the lamp or luminaire carton. This usually is either a code number or an actual run date indicating the day and time the unit was manufactured. Keep in mind that code numbers and/or dates that appear on the actual lamp or luminaire usually are warranty related and do not necessarily indicate the date and time of manufacture.

The reason you should select equipment from different batches or runs is simple: lamp and luminaire manufacturers usually make mistakes between batches, not between individual lamps or luminaires. Changes in raw materials, manufacturing methods or worker inspection can lead to a bad run of equipment before the problem is realized and corrected. These bad runs will have an inordinate percentage of defective units, whereas a good run may have only an occasional oddball defect. Your test group should contain units from all runs or batches in your inventory. If a bad unit is found, further testing of units in that batch may uncover a defective run that could play havoc with your spot replacement program.

Visual Inspection

Before performing any electrical tests, lamps and luminaires should visually be inspected for manufacturing defects and damage due to shipping and handling.

Lamps: Inspect all lamps for the following:

- Broken internal welds.
- Bent arc tube supports that allow an arc tube misalignment of more than 3°.
- Loose screw base.
- Broken arc tube mountings.
- Broken electrodes.
- Defective vacuum seal indicated by a white, chalk-like deposit inside the lamp envelope. (This condition may occur before or after the electrical test.)

Luminaires: Inspect all luminaires for the following:

- Broken refractors.
- Broken lamp sockets.
- Broken or bent luminaire housing.
- Loose or broken screws.
- Broken or damaged electrical components.
- Good optical assembly seal and alignment.
- Smooth, working housing hinges, hinge keepers and latches.
- Any loose electrical connections, kinked wire, abraded wire, stripped or overtight terminal block connections, etc.
- The presence of wildlife shields, fitter clamps and all equipment and options predescribed by the luminaire manufacturer's presubmitted sample.

Any damaged or missing component on the lamp or luminaire is reason for rejection. If it is apparent that shipping and/or handling damage has occurred, the source of the damage should be determined and the responsible parties notified.

Lamps and luminaires that pass visual and mechanical inspection are now ready for electrical testing. HPS lamps, photocontrols and luminaires can be pretested in one of three ways:

1. By using a test group of sample lamps and luminaires.
2. By testing lamps and luminaires using a special HPS lamp/luminaire test bench.
3. By testing photocontrols using the test bench.

TESTING HPS SYSTEMS IN THE FIELD

The high-voltage spike required to start an HPS lamp makes electrical testing of the luminaire somewhat of a problem. Testing for this very short duration voltage pulse normally would require the use of an oscilloscope. But an oscilloscope is not a practical piece of test equipment when testing a luminaire in the field. The quality and cost of the scope needed to accurately display this voltage pulse is quite high. Even when accurately displayed, the short duration spike is very hard to see on the scope screen, particularly in daylight or bright sun. Plus the oscilloscope is difficult to maneuver and set up in a truck bucket, and impossible to use from a stepladder or from climber's hooks.

Voltmeters

Voltmeters are of limited use when troubleshooting HPS luminaires. They can be used to check minimum open-circuit voltage at the lamp, but only after the starting circuit lead has been disconnected. Otherwise, the extremely high starting pulse voltage could damage the voltmeter.

Even if the voltmeter is protected against the high-voltage pulse, its voltage reading only will indicate that voltage is present. It cannot determine the load-carrying capability of the circuit being checked. For example, if the screw to the center contact of the socket becomes loose, the HPS light bulb may not light when screwed into the socket. However, if the leads of the voltmeter were placed across this connection, the meter would read voltage. A low-grade connection may allow the voltmeter to read a voltage, but limit the current to levels below those needed to operate the lamp.

Neon Lamp Testers

Various luminaire and lamp manufacturers also sell special neon testers designed to troubleshoot and test HPS systems. These testers may use from one to three neon lamps. The single-neon lamp type usually indicates socket voltage or spike voltage. The two- and three-neon lamp testers are designed to indicate the presence of *both* socket voltage and spike voltage. The two-lamp tester indicates a spike on one half cycle only, while the three-lamp tester supposedly indicates a spike voltage on both half cycles of the AC waveform.

Using these testers can be confusing and results are not always accurate. For example, the neon can be lit by stray voltages from various sources such as high-voltage transmission lines, transformers and other devices emitting static voltage. And like a voltmeter, a neon tester, even when operating correctly, indicates only the presence of a voltage. It cannot tell you if the circuit being tested has a load-carrying capability. The circuit being tested could have poor or marginal connections.

Also, some HPS lamp starters are designed to produce a starting spike on only one of the two AC current half cycles. Others are designed to produce spikes on both half cycles. A single luminaire manufacturer may use both systems, and there are no markings on the luminaire to indicate which system is being used. This means that if you test a one-half cycle starter with a three-neon lamp tester designed to signal the presence of spikes on both half cycles, the tester automatically would indicate a defective starter.

There also are several specifications that must be met in the starting voltage spike. The spike must be between the 2500- to 4000-volt ranges. It must be within ± 20 electrical degrees of the center of the half-cycle point, and its duration must be from 1 to 15 microseconds at 2150 volts. The neon tester does not indicate the spike's conformity to any of these parameters.

Luminous Wattmeters

One of the most reliable, meaningful and economical pieces of test equipment for HPS lamps is the incandescent lamp. A simple luminous wattmeter can be made using a 250-volt, 50-watt, rough service incandescent lamp equipped with a mogul-to-mogul lamp socket extender and fitted with a medium-to-mogul socket adapter (Figure 25). A 250-volt incandescent lamp is used because it can handle the minimum open circuit voltages of all HPS lamps, except the 1000-watt HPS lamp. The 50-watt lamp size produces a dimmer-burning bulb that will not blind you during testing. A 100-watt incandescent would be too bright. The 50-watt bulb also is smaller and cooler to handle. Finally, the rough-service-grade incandescent allows for testing in luminaires where high vibration is encountered without undue breakage of the lamp filament. It should be remembered, however, that these lamps are not indestructible. Tuffskin® coating for the lamp is advisable when the lamp is to be used in hazardous locations or adverse environments. Be sure your luminous wattmeter is using a known good lamp before taking it into the field.

Most HPS lamps and their corresponding luminaires are equipped with mogul bases and sockets. The 250-volt, 50-watt incandescent lamp only is available with a medium base. The mogul-to-mogul extender and medium-to-mogul adapter are needed to properly install the luminous wattmeter into the mogul base of the HPS fixture. Mogul sockets are equipped with lamp retainers and a locknut configuration that prevents the screwed-in lamp from vibrating out of the lamp socket.

When troubleshooting, it is desirable to mechanically stress the lamp socket by installing the lamp as tight as practical. A light lamp base-to-socket contact may not reveal problems at this connection. This causes some problems when adapting the incandescent lamp to the HPS mogul socket. If only a medium-to-mogul adapter were used, it would be difficult to install the incandescent tight enough to stress the connection. The weaker incandescent lamp medium base-to-medium socket connection at the adapter may become stressed and break, shattering the lamp. Usually, there is little problem screwing the adapter into the mogul socket. The problem is in safely removing it without breaking the incandescent.

The solution is to screw the incandescent into the medium-to-mogul adapter and then screw the mogul end of the adapter into one end of a mogul-to-mogul extender. The other end of the mogul-to-mogul extender is then screwed into the mogul socket of the HPS luminaire. It is possible to tightly grip the body of the extender without damaging or stressing the incandescent lamp or its base.

Note: While the medium-to-mogul adapter is a common piece of hardware, the mogul-to-mogul extender can be more difficult to find. One source for the extender is the Leviton Manufacturing Company Inc. Order through your electrical distributor.

Some lower-wattage HPS lamps and luminaires can be equipped with medium bases and sockets that match the incandescent lamp. The luminous wattmeter can be screwed directly into these sockets.

Advantages of the Luminous Wattmeter: The luminous wattmeter has several distinct advantages as an HPS troubleshooting tool. It does not require a starter for operation and it gives a visual indication of the circuit's ability to carry current. This makes it an excellent tool for determining the cause of luminaire outages in the field. The following is an example of how the luminous wattmeter can be used to troubleshoot an outage:

1. Begin by testing the photocontrol with the hand test explained earlier. Replace if defective.

2. If the outage is not corrected, replace the HPS lamp with a known good lamp.

3. If the known good lamp does not start, remove it and install the luminous wattmeter. As you install the luminous wattmeter, do not stop until the base is fully bottomed out in the socket and mechanically stressed. In some cases, the lamp may turn ON partway in and then turn OFF again when tightly installed. The lamp also may start to blink or turn ON and OFF. This could indicate a loose screw in the socket, or a bad base-to-socket connection or a shorting of the lamp socket connector to the lamp mounting bracket.

4. If the luminous wattmeter lights, it indicates that the luminaire has a good power system-to-fixture connection. Power is passing through the terminal board, through the ballast and out through the wiring and connections to the incandescent lamp. That quickly lets you know all these possible trouble spots are functioning correctly.

   Since the incandescent works and the HPS lamp does not, all evidence points to a defective starter. Replace the starter and install the HPS lamp. In the vast majority of cases, the lamp will now start. If it does not start, replace the entire luminaire if no other physical damage is found.

5. If the luminous wattmeter does not light when installed in step 3, it indicates other problems such as an open connection at a luminaire component, a blown line fuse, or no power to the luminaire. Check for burned or damaged fixture components and for loose or disconnected electrical connections. Use a voltmeter to check supply voltage. Is it the same as the fixture is rated for? Check for correct and functional photocontrol operation. You also should check for a missing or defective capacitor bleed resistor across the regulating capacitor when a two-coil regulating ballast is used.

   Note: In a rare case when the bleed resistor is open, the charge on the capacitor can cause the starter to remain in the OFF position and the lamp will not start.

When the luminous wattmeter does not burn, leave the luminous wattmeter in the luminaire and troubleshoot the problem until the incandescent can be made to light. If the problem cannot be found, replace the luminaire.

Two Problem Outages: Occasionally, two distinct problems could be the cause of the outage. For example, a given luminaire could have an intermittent power connection to the fixture. The arcing caused by the bad connection also could cause a starter circuit failure. When the known good HPS lamp is installed in such a situation, it will not start. When installed in its place, the luminous wattmeter also will not light.

When this condition occurs, leave the luminous wattmeter in the luminaire until it is made to burn. For example, repairing the bad connection would allow the luminous wattmeter to light. Then, it could be assumed the cause of the problem was the bad connection, but when the known good HPS lamp is reinstalled it does not start. Once reaching this point in the troubleshooting procedure, it becomes apparent that two problems exist. The fact that you were able to make the luminous wattmeter burn, but not the HPS lamp, indicates a possible defective starter. The important fact to remember is to leave the luminous wattmeter installed until it burns. Attempting to find intermittent connections and starter-related problems by only an HPS lamp could lead to considerable confusion and wasted time.

Special Problems: In rare cases, a luminaire ballast or capacitor failure may allow the luminous wattmeter to burn, but not allow the HPS lamp to ignite and operate even when a known good starter is installed. However, this is a very rare situation that most service technicians never will encounter.

Voltage Pulse Concerns: There is no need to be concerned over the possibility of the 2500- to 4000-volt starting pulse voltage spike damaging the luminous wattmeter or causing it to explode. The spike is of very short duration and very low current. The incandescent lamp harmlessly shorts out this starter output. The luminous wattmeter has been used to troubleshoot luminaires equipped with instant restrike devices producing 12,000 to 14,000 restrike voltage pulses or spikes with no harm to the incandescent bulb.

Caution: Always wear safely glasses when working with light bulbs of any type because there is always a possibility of a freak situation that may cause the lamp to explode.

Mercury Vapor Test Lamp: Since a mercury vapor lamp does not require a starter, it too can be used to troubleshoot an HPS luminaire, although not as effectively as an incandescent lamp. A mercury vapor lamp requires 240 volts at the socket for starting. HPS luminaires designed for 35- to 150-watt, 55-volt HPS lamps only will provide 120 volts. In this case, the mercury vapor lamp may start with 120 volts, provided the ambient temperature is not too cold. Unlike an incandescent luminous wattmeter, a mercury vapor test lamp will not readily show varying degrees of brightness. They also cannot be made to flicker when checking for intermittent connections. Instead, the mercury vapor lamp will drop out and cycle. For these reasons, it is highly recommended you use an incandescent luminous wattmeter to troubleshoot HPS fixtures.

SERVICING HPS LUMINAIRES AT AN INSTALLED LOCATION

After reaching a defective HPS luminaire location in the field, a properly trained service technician should be able to troubleshoot, repair or replace the defective fixture within a 10- to 15-minute time frame. This 15-minute service call relies on a consistent, logical approach to troubleshooting, an understanding of HPS operation and the proper use of test equipment. Make certain you take a known good HPS lamp, a luminous wattmeter and a voltmeter on all service calls.

The 15-minute service call is based on some very real economic facts of life. It takes time to travel to the job site and set up the lift truck or ladder. If the service technician then spends much more than 15 minutes servicing one particular luminaire, the cost of his or her time begins to approach or exceed the actual cost of the luminaire. If the problem cannot be pinpointed and corrected in this time frame, the luminaire should be removed and replaced.

The service technician also must take this opportunity to quickly inspect the entire luminaire. Look for potential future problems and repair them on this service call. Take a minute or two to look for charred or heat-damaged surfaces or photocontrol receptacle. Also check for pinched wires and hot spots on ballasts that may signal failure in the near future. Check the fixture mounting. The housing should be level and all mounting bolts and clamps should be present, tight and in good condition.

HPS Luminaire Failures

Following are common luminaire failures that may be encountered in the field.

Outages: An outage is the most common type of failure. The most common failed component is the lamp itself. Replace the lamp in the outage fixture with a known good HPS lamp. If the lamp does not come ON, remove it and install the luminous wattmeter. Troubleshoot using the luminous wattmeter as described in the previous section to pinpoint starter, wiring, or other power-supply-related problems. It should be noted that wiring problems are not as common as starter problems. Also check for a missing or defective capacitor bleed resistor (Figure 20). If line voltage to the lamp is good and if there appears to be no wiring or photocontrol-related problems, replace the fixture.

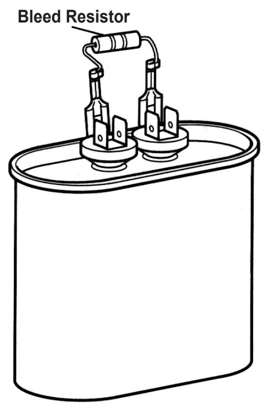


FIGURE 20. A missing or defective capacitor resistor can cause a no-start problem.

Cycling: Cycling is the normal, end-of-life failure mode for HPS lamps. To summarize, cycling can be caused by a normal, end-of-life HPS voltage rise, an intermittent electrical connection triggered by wind conditions or vibration from traffic, a manufacturing defect in the lamp, an overly sensitive photocontrol, heat damage to photocontrol receptacle contacts or high ambient light level tricking the control. A defective ballast or capacitor also can cause cycling.

Quite often, when the service technician arrives at the location of a cycler, the lamp will be operating properly. This is because the conditions that may have been causing the cycling, such as wind, traffic-induced vibration, or a slight variance in line voltage, are not occurring at the moment. If the lamp is no longer cycling, use the bump test described earlier to induce a vibration in the lamp and luminaire. With metal poles, it is possible to sufficiently shock the fixture by striking the pole while standing on the ground. When wood or concrete poles are used, it may be necessary to moderately strike the fixture mast arm.

If the lamp in question has reached its normal end-of-life, this bump test will cause the burning lamp to turn OFF. Reinstall a known good lamp and allow it to warm up for several minutes. Reshock the lamp. If it turns OFF, check the fixture wiring by probing with an insulated tool to locate opens and shorts. Check that the ballast and capacitor match the lamp rating, and be sure the capacitor is correctly wired. If this fails to isolate the problem, replace the luminaire.

If the vibration test of the suspect lamp does not cause it to cycle, turn the photocontrol to the area where it will receive the least amount of ambient light. Since a fixture's own light can sometimes reflect off of an object, such as a tree or building, and cause the fixture to turn OFF and then ON again after the lamp has cooled, be aware of nearby reflective surfaces and shield the photocontrol if necessary. Also, be sure the lamp is the correct lamp for the fixture by checking the lamp inscription label against that in the luminaire.

Dim Burners: A dim-burning or low-output fixture usually is caused by having the wrong wattage lamp installed in the fixture, such as a 55-volt lamp in a 100-volt fixture, or a 100-watt lamp used in a 50-watt fixture, or a 150-watt light bulb installed in a 70-or 100-watt fixture. Check and/or install a new correct size lamp.

Low supply voltage also can cause a dim burner. Measure the supply voltage across the terminals and make certain it matches the rating on the ballast voltage label. Improper wiring of a multi-tap ballast is another cause of low-light output. Check and correct any miswiring.

On regulated ballast fixtures, a disconnected or defective regulating capacitor also can cause a dim-burning fixture. Be sure the correct capacitor is used and that it is wired correctly.

Day Burners: A fixture that burns night and day usually has a defective photocontrol. Replace the photocontrol. If the problem persists, check for open wiring, usually the white wire from the photocontrol receptacle is open. If the problem still exists, replace the fixture. Also replace the fixture if there is evidence of heat damage to the photocontrol receptacle.

Short Life Lamps: If the lamp burns out shortly after being installed, check for proper match-up of lamp, ballast and capacitor ratings. Check a similar, properly operating luminaire for the correct capacitor size or refer to manufacturer's specifications. Finally, check the wiring diagram against the actual wiring to ensure the fixture has not been miswired.

Unknown problems: If the exact nature of the problem is unknown, troubleshoot the fixture as if it were an outage. Cover the photocontrol and listen for a sharp click when the control operates. Change the control if it growls. If the lamp does not come ON, substitute a known good HPS lamp. If this lamp does not operate, test and troubleshoot using the luminous wattmeter.

If the known good HPS lamp does light, test for cycling problems. If this is the first service call on this luminaire, replace the lamp and photocontrol. If it is the second call, remove and replace the fixture.

GLOSSARY OF ELECTRICAL TERMS

The following definitions are offered to develop a practical understanding of the electrical principles involved in lighting. In some cases, the definition may contain a slight technical error to make the definition more straightforward and convey the general meaning of the term. Many electrical principles are compared to familiar mechanical actions to more clearly present an idea or concept.

Ballast Short Circuit Current. This is current measured in the HID lamp circuit with the ballast energized and the lamp socket shorted out (socket shell-to-socket center contact.)

Conductor. A material such as copper or aluminum that supports the flow of current. It is important to remember that your body is an excellent conductor of electricity. Water also is a great conductor. Air and insulating materials such as rubber and plastics are poor conductors.

Current. Electricity in motion. It is the flow of electrons through a conductor. Voltage is the force, or pressure, that drives the current through the conductor. Current flows only between points having a difference of potential. The ampere, or amp, is the unit of current measurement.

Electric Circuit. A path or a group of interconnected paths capable of carrying electric current.

Electron. A single, microscopic particle with an electrical charge. It can be compared to a drop of water in a water pipe. In atoms, electrons orbit around the nucleus. Current flow occurs when electrons break free of their orbits and jump from atom to atom.

Fixture. See "Luminaire."

Frequency. In lighting applications powered by alternating current, voltage and current vary rapidly over a very short period of time. A cycle occurs each time a pattern of variation completes. The number of times a cycle occurs each second is the frequency (Hertz) of the voltage and current. Voltage and current in the United States and most of the world completes 60 cycles each second. Direct current, such as that generated by storage batteries, is not cyclical.

Ion. An atom or molecule that has an electrical charge.

Lamp. The actual assembly that includes the glass bulb, arc tube, screw base, etc. It should not be confused with the luminaire (see below). The lamp is commonly referred to as the light bulb.

Luminaire. The complete lighting unit. Its metal housing contains the lamp, socket, wiring, starter, ballast, photocontrol receptacle, optical assembly and all other components needed to generate lumen output. Many times the luminaire simply is referred to as the fixture.

Ohm's Law. The basic law of electricity. It states that **Voltage =Current x Resistance**. This equation can be used to find any unknown variable when the other two variables are known.

Open Circuit. A break or disconnection in the wiring or at a connection. Current does not flow in an open circuit. It is commonly expressed as voltage measured at the lamp socket without a lamp in the socket.

Power. The rate at which electrical energy is used. The watt is the unit of power measurement. Power requires voltage and current; that is, electric pressure accompanied by a flow of electrons. Power can be calculated using the following equation: **Power = Voltage x Current**. Wattage results in heat and light.

Power Factor. The time difference between the presence of voltage and the flow of current. It can be compared to air in the water line of a pumping system. You turn on the faucet and there is pressure (voltage), but a burst of air is all that comes out before the water (current) begins to flow. Power factor is high (90 % or better) when there is almost no delay in the current flow. Power factor is normal (about 50%) when current flow is delayed. See point N in Figure 21.

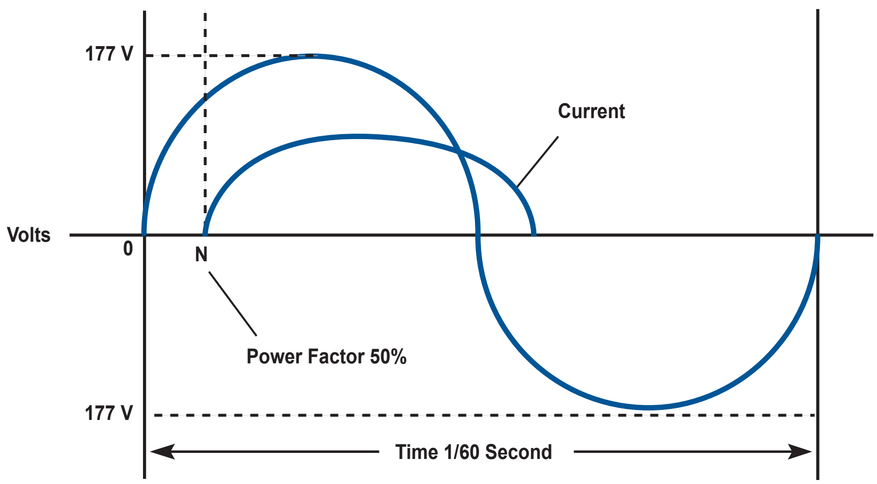
Resistance. Resistance limits or controls the flow of current. All conductors offer some resistance to current flow. Resistance can be compared to the amount of friction between the flowing water and the pipe walls in a plumbing system.

Secondary. The customer side of a power company's distribution transformer where the service drop for the luminaire is connected.

Short Circuit. An accidental path of low resistance that passes an abnormally large amount of current. A short often occurs as a result of improper wiring or broken insulation.

Voltage. Voltage is electric pressure. It can be compared to water pressure in a plumbing system. It also is a force, referred to as electromotive force (emf). Other terms used for voltage are potential and potential difference. The volt is the unit of electric pressure.

Watts Loss. The difference between the amount of power supplied to a luminaire (ballast and lamp) and the amount of power actually used by the lamp itself.



This illustration represents a 120-volt waveform.
The voltage ranges from zero to 177 volts to zero to 177 to zero 60 times a second.
The average voltage is 120 volts.

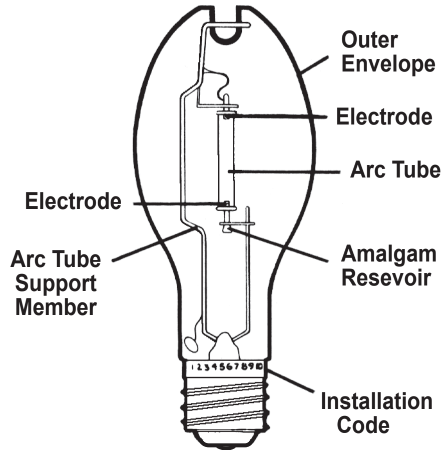
FIGURE 21. Graphic representation of normal power factor ballast.

APPENDIX A: TYPICAL LAMP MANUFACTURER'S BALLAST AND LUMINAIRE REQUIREMENTS FOR 150-WATT, 55-VOLT HPS LAMPS

This requirement is for lag circuit (regulated or non-regulated) ballast designs:

I. LAMP PHYSICAL CHARACTERISTICS

Base .... Mogul Screw
Bulb .... E23-1/2 Borosilicate Type 772
Maximum Overall Length 197mm
Maximum Diameter .... 76.48mm (3.011")
Light Center Length .... 123 ± 3mm
Arc Length .... 37 ± 1mm
Maximum Bulb Temperature .... 400° C[1]
Maximum Base Temperature .... 210° C[1]



II. LAMP ELECTRICAL CHARACTERISTICS (RMS Values)

A. Wattage

Rated Watts .... 150 watts
Permitted Operating Range for Rated Lamp Life .... Min. 112.5 watts (Max. 175 watts)

B. Voltage[2]

Rated Lamp Voltage (Design Center) .... 55 volts at 150 watts
Initial Lamp Voltage Range at 100 Hours .... 48-62 volts at 150 watts
Maximum Lamp Voltage[3] .... 88 volts

C. Current

Operating Current .... 3.2 amperes nominal

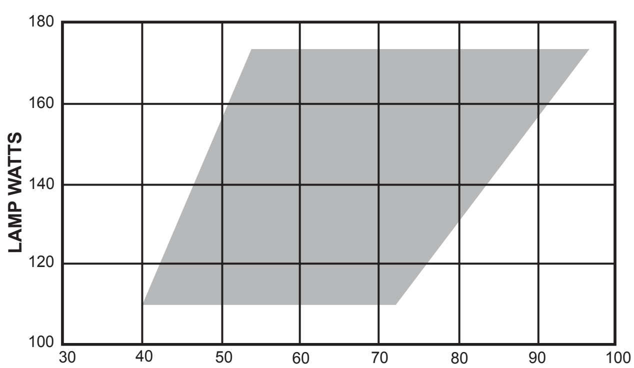
D. Operating Limits

The trapezoid shown below illustrates lamp voltage-wattage limits. For a ballast to meet the *lamp operating requirements*, its characteristic curve must intersect each of the lamp voltage limit lines at points between the wattage limit lines and must remain between these wattage limit lines throughout the full range of the lamp voltage.

1 Maximum temperatures allowed under conditions where published performance ratings apply.

2 Lamp voltage is determined by operating the lamp on a linear inductor of approximately 31 ohms for one hour, with the line voltage adjusted to maintain the lamp at 150 watts.

3 Lamp voltage may rise reaching 88 volts near the end of life.



TRAPEZOID — 150W HPS, 55V Lamp

III. BALLAST REQUIREMENTS

The required ballast characteristics must be provided with the ballast operating over the full range of line voltage for which it is designed.

A. Minimum Ballast Open-Circuit Voltage (O.C.V.): 110 Volts (RMS)[4]

B. Starting Pulse Requirements

1. Pulse peak voltage:

   Min. 2500 volts

   Arc-over in the lamp structure will not occur at peak voltage less than 4,000 volts.

2. Pulse width measured at 2250 volts:

   Min. 1 microsecond

3. Pulse repetition rate:

   Min. 50 per second

4. Pulse peak current:

   Min. 0.2 amp

5. The starting pulse should be located within 20 electrical degrees of the peak of the open circuit voltage for the most reliable lamp starting.

6. Lamp starting is not affected by ambient temperature.

C. Lamp Current During Warm-Up

Min. 3.2 amp (RMS)

Max. 4.8 amp (RMS)

D. Maximum Current Crest Factor: 1.8

E. Ballast Marking

The ballast should be clearly labeled to indicate the range of line voltage for which it is designed, as *published lamp performance ratings do not apply when the line voltage is outside these limits.*

F. Short-Circuit and Open-Circuit Current

To protect the ballast against unusual lamp failure modes, the ballast should be capable of operation under either an open or short circuited condition for extended periods.

NOTE: Starting pulses are not required and are not desirable after a stable arc has been established.

G. Other Considerations

1. High Pressure Sodium lamps, like other discharge lamps, exhibit reignition phenomena that are influenced by ballast design. Certain ballast designs can lead to distinctive effects such as:

   a. Strong visual lamp flicker.

   b. High lamp reiginition voltage.

   c. Lamp extinction and/or unusual sensitivity to line voltage fluctuations.

   d. Pulse voltage required to start lamps in excess of the minimum starting-pulse requirements.

NOTE: Any such observations should be cause for concern as the system life and performance may be adversely affected.

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2. Published lamp performance ratings do not apply when High Pressure Sodium lamps are operated on direct current or at frequencies other than 50-60 hertz.

IV. LUMINAIRE REQUIREMENTS

A. Lamp Voltage Rise Limits

The evacuated outer bulb of the lamp makes the lamp insensitive to ambient temperature. However, care must be used in luminaire design to avoid reflecting energy to the arc tube appendage (always at the lower end for both base-up and base-down lamps). This affects the temperature of the sodium-mercury amalgam and results in a change in lamp characteristics. The lamp voltage of new lamps (48-62 volts at 150 watts) must not increase more than 4 volts when going from stabilized bare-lamp operation to stabilized operation in the luminaire. Fixture effects are best evaluated by operating the lamp on a linear reactor of approximately 31 ohms with the line voltage adjusted to maintain the lamp at 150 watts. Additional information is available upon request.

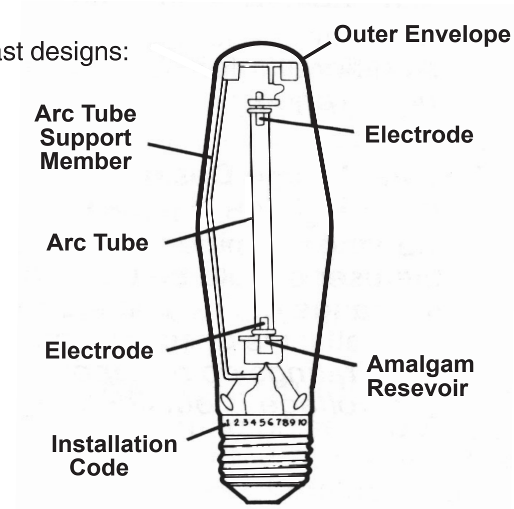
B. Line Voltage Designation

For integral-ballasted luminaires, labeling prominently displayed for the user should be used to indicate the range of line voltage for which the ballast is designed, as *published lamp ratings do not apply when the line voltage is outside these limits.*

4 Minimum value required for stable lamp operation throughout life. When designing the ballast, consideration must be given to avoiding lamp extinction with sudden line-voltage dips.

APPENDIX B: TYPICAL LAMP MANUFACTURER'S BALLAST AND LUMINAIRE REQUIREMENTS FOR 400-WATT, 100-VOLT HPS LAMPS

This requirement is for lag circuit (regulated or non-regulated) ballast designs:



I. LAMP PHYSICAL CHARACTERISTICS

Base .... Mogul Screw
Bulb .... E18 Borosilicate Lead Glass
Overall Length .... 244 ± 4mm (9-5/8" Maximum)
Diameter ....57 ± 1mm (2-1/4" Approx.)
Light Center Length .... 146 ± 3mm (5-3/4" Approx.)
Arc Length ....87 ± 2mm (3-3/8" Approx.)
Maximum Bulb Temperature ....400° C
Maximum Base Temperature ....210° C

II. LAMP ELECTRICAL CHARACTERISTICS (RMS Values)

A. Wattage

Rated Watts .... 400 watts
Permitted Operating Range for Rated Lamp Life .... Min. 300 watts (Max. 475 watts)

B. Characteristic Voltage[1]

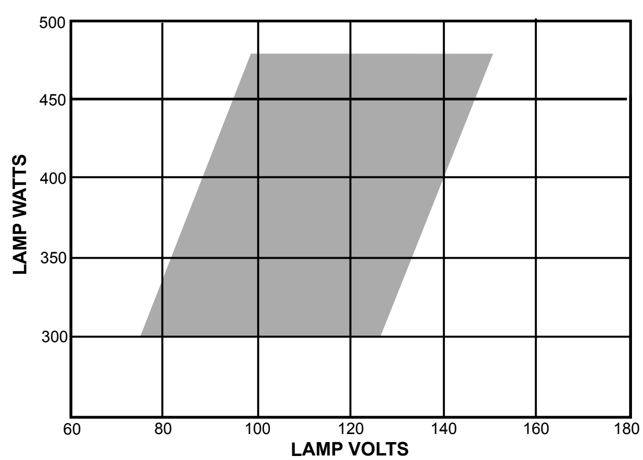
Rated Voltage (Design Center) .... 100 volts @ 400 watts
Voltage Range at 100 Hours .... 90-115 volts @ 400 watts
Maximum Lamp Voltage[2] .... 140 volts

C. Current

Operating Current (RMS) .... 4.7 amperes nominal
Current During Warm-Up (RMS) .... Min. 4.7 amperes (Max. 7.0 amperes)
Current Crest Factor .... Max. 1.8

D. Operating Limits

The trapezoid shown below illustrates lamp voltage-wattage limits. For a ballast to meet the *lamp operating requirements*, its characteristic curve must intersect each of the lamp voltage limit lines at points between the wattage limit lines and must remain between these wattage limit lines throughout the full range of lamp voltage.



TRAPEZOID – 400W HPS, 100V Lamp

1 Lamp voltage is determined after operating the lamp on a linear inductor for one hour. The line voltage is adjusted to control the lamp wattage. The *lamp characteristic curve* is the volt-watt curve for the equilibrated lamp. The *characteristic voltage* is the lamp voltage at rated watts.

2 Lamp characteristic voltage may rise reaching 140 volts near the end of life.

III. BALLAST REQUIREMENTS

The required ballast characteristics must be provided with the ballast operating over the full range of line voltage for which it is designed.

A. Minimum Ballast Open Circuit Voltage (O.C.V.): 195 Volts (RMS)

This is the minimum value required for stable lamp operation throughout life. When designing the ballast O.C.V., consideration must be given to avoid lamp extinction with sudden line-voltage dips. A ballast lamp testing procedure (measurement of ballast drop-out point for High Pressure Sodium ballasts) is available from the OEM fixture liaison and technical services section.

B. Starting Pulse Requirements

Measured across the socket terminals using a high frequency scope and high impedance probe.

1. Pulse Peak voltage:

   Min. 2500 volts

   Max. 4000 volts
2. The 4kv maximum is set to prevent internal arc-over. the starting circuit shall limit the pulse to a maximum of 4kv. If the starting circuit is turned on at the high point on the power distribution voltage wave, an abnormal transient can occur. The starting circuit must limit high transients.
3. Pulse width measured at 2250 volts:

   Min. 1 microsecond

   Max. 15 microseconds
4. Pulse repetition rate:

   Min. 1 per cycle
5. Pulse peak current:

   Min. 0.2 amperes
6. Pulse position: For near sine-wave O.C.V. within 20 electrical degrees of the center of the half cycle for reliable starting.
7. The pulse must be applied to the center terminal of the lamp base.
8. Starting pulses are not required after the arc has been established. To avoid radio frequency interference and sub-standard lamp performance, it is recommended that the pulsing circuit be de-energized during operation.
9. Lamp starting is not affected by ambient temperature.

C. Ballast Marking

The ballast should be clearly labeled to indicate the range of line voltage for which it is designed as *published lamp performance ratings do not apply when the line voltage is outside these limits.*

D. Short-Circuit and Open-Circuit Current

To protect the ballast against unusual lamp failure modes, the ballast should be capable of operation with an open or short circuit condition for extended periods.

E. Other Considerations

1. High Pressure Sodium lamps, like other discharge lamps, exhibit reignition phenomena that are influenced by ballast design. Certain ballast designs can lead to distinctive effects such as:
   a. Strong visual lamp flicker.
   b. High lamp reiginition voltage.
   c. Lamp extinction and/or unusual sensitivity to line voltage fluctuations.
   d. Pulse voltage required to start lamps in excess of the minimum starting-pulse requirements (Section 3B).

NOTE: Any such observations should be cause for concern as the system life and performance may be adversely affected.

2. Published lamp performance ratings apply only when High Pressure Sodium lamps are operated on 50-60 hertz.

IV. LUMINAIRE REQUIREMENTS

A. Lamp Voltage Rise Limits

The evacuated outer bulb of the lamp makes the lamp insensitive to ambient temperature. However, care must be used in luminaire design to avoid reflecting energy on the arc tube appendages. This affects the sodium-mercury amalgam and results in a change in lamp characteristics. The lamp voltage of new lamps (90-115 volts at 400 watts) must not increase more than 10 volts when going from stabilized bare-lamp operation to stabilized operation in the luminaire.

B. Line Voltage Designation

For integral-ballasted luminaires, labeling prominently displayed for the user should be used to indicate the range of line voltage for which the ballast is designed, as *published lamp ratings do not apply when the line voltage is outside these limits.*

V. SOCKET REQUIREMENTS

A. Breakdown Voltage

The internal clearances of typical mogul sockets are such that if an arc-over occurs, a destructive power arc will be sustained by ballasts meeting the criteria stated below. For this reason, the internal breakdown voltage of the socket should provide an adequate margin of safety, under the environmental conditions anticipated.

This can be measured by applying a 50 to 60 Hz sinusoidal voltage wave form between the center pin and shell terminations of the socket *with a dummy 400-watt High Pressure Sodium ceramic base inserted.* The voltage should be increased from zero at a rate of no more than 4kv/min. until breakdown occurs. The peak voltage at the point of breakdown should be 7kv. This test is equivalent to a 5000 volt (RMS) high pot test. Perform the test on the socket separately.

American Electric Lighting
Acuity Lighting Group, Inc.
1335 Industrial Boulevard, Conyers, GA 30012
Phone: 800-754-0463, Fax: 770-860-3255
www.AmericanElectricLighting.com