

XENON BULB FAILURE ANALYSIS

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There are two things that are always true regarding xenon bulbs: they are expensive, and they will eventually require replacement . . . hopefully, not on a Saturday night when you have a full house! There are various reasons why a bulb requires replacement; it doesn't operate, it operates poorly, or it simply gets old.

The bulb doesn't work anymore! That's a broad statement defining a problem. It's like saying your car doesn't run! Is it out of gas? Are the tires flat? Did someone steal your engine? One must first be more definitive when describing the problem; this will save much time and eliminate unnecessary and costly mistakes. The easiest thing in the world for a bulb or lamphouse manufacturer to do is blame the other guy. Both believe that they make the perfect product, and if there's a problem, that it can't be their fault. They are both correct to an extent: there are such things as bad xenon bulbs, and there are also bad lamphouses and power supplies. Obviously they are not consistently bad, or the manufacturers would be out of business.

Let's start by defining the common bulb failure modes. Then we'll get into what can cause them – both within the bulb itself, and in the lamphouse/rectifier system. Once we've analyzed the symptoms, it's much easier to find the problem.

Contaminated Bulb Envelope. This is indicated by a blackened or dark envelope. It is usually most prominent around the anode (+) side of the envelope.

Failure to Ignite. This is indicated by the bulb's refusal to establish a maintained arc, either from the automatic or manual ignition system of the lamphouse.

Explosion. Or as bulb manufacturer's call it, "catastrophic failure." It requires little explanation once you've encountered your first one.

Leaker. This is indicated by a bluish-white color of the envelope when the bulb is operating. The real "tell-tale" of a leaker is high amperage and low voltage during bulb operation.

Low Light Output. Usually occurring on older bulbs, and is indicated by poor screen foot-lambert readings.

Unstable Arc or Flicker. Indicated by the bright spot on the screen jumping around. This is especially noticeable on bright sky scenes.

Contaminated Bulb

The contaminated bulb is one of the harder ones for a bulb manufacturer to blame on the lamp-house manufacturer. It is usually caused by poor quality tungsten and/or tungsten processing. In a many cases, it is evident by excessive pitting on the face of the anode electrode. It can also be caused by an inadequate vacuum prior to filling the bulb with xenon. Sometimes the bulb manufacturer will blame the rectifier, saying that it has **excessive current ripple**. Be certain to examine both electrodes prior to returning the bulb for credit. Excessive current ripple destroys cathodes much sooner than anodes. This would be evident by excessive cathode disconfiguration with lengthwise slits in the cathode head.

If you suspect the power supply is producing excessive current ripple, don't call your local electrician. He probably won't know how to measure it. Talk to your equipment dealer. If you've done what all bulb and lamphouse manufacturers recommend and kept good records of each system, you'll be able to tell right away if you're experiencing short bulb life in a specific system. If that's the case, attack the problem. Ask your dealer to contact the manufacturer or a trained service technician.

Failure to Ignite

Failure to ignite is by far the most complex problem to diagnose. However, as with all bulb problems, if you've kept good records, the solution is much easier to establish. One must know what it takes to start a xenon bulb, and the components used to accomplish that desired result.

First, the lamphouse contains an igniter which is similar to an ignition coil on an older car. This device uses either 115 volts AC or 230 volts AC input and converts it into 40,000 volts RF which is used to break down the arc gap, or the space between the anode and cathode electrodes. This is accomplished by means of (a) a high voltage transformer that takes the 115 or 230 volt input up to approximately 5,000 volts, (b) a spark gap which breaks down and passes current at approximately 5,000 volts, (c) a few doorknob-type capacitors, and (d) an RF transformer which takes that 5,000 volts and steps it up to approximately 40,000 volts. This high voltage is then induced into the DC line going to the bulb.

The igniter has one function: to break down the arc gap, or the space, between the electrodes of the bulb. After the arc gap is broken down, the xenon power supply takes over in two steps. First, there are a couple of large capacitors in the power supply which discharge across the arc directly following the breakdown by the igniter. This phase of ignition is called the **boost current** and is typically two to three times the normal operating lamp current. This boost current cycle, or phase, of the ignition process lasts for no more than 250 milliseconds (one-quarter of a second). This is the most detrimental phase of the ignition cycle to a bulb's life. Excessive boost current of higher than 300% of the operating current will help start hard-starting bulbs, but it in turn destroys cathode electrodes. In a study done by the military in the late 1960's, it was found that each bulb ignition, because of the effect of boost current, decreased the expected bulb life by thirty minutes.

The last portion of the ignition cycle is the running DC voltage supplied by the power supply rectifier. Most theatre xenon bulbs operate between 22 and 33 volts DC, depending on the size and wattage. This running voltage, along with the corresponding current, follows the boost circuit in the ignition process.

Failure to Ignite (continued)

Most theatres have automation systems to light the lamp and operate the projector. This is the simplest item to eliminate in an ignition problem. See if the bulb lights *without* the automation; if it does, then the problem is in the automation system. Refer to that specific system's manual or drawings to correct the problem.

Another item that is easy to eliminate is the lamphouse or console auto-strike circuit. This circuit typically consists of a relay and a zener diode which senses that the open circuit voltage is high enough. The auto-strike circuit then provides a closure to the high voltage transformer in the igniter. If the bulb starts using the "manual" or "emergency ignition" switch, but does not start otherwise, the problem is in this circuit. When using the "manual" or "emergency ignition" switch, never hold the switch longer than *two seconds*, as you can destroy the igniter's high voltage transformer. In certain power supplies, a shorted blocking diode will also cause this problem.

The reason that lamphouse manufacturers include an auto-strike circuit is to ensure that the open circuit voltage is at a pre-determined level prior to bulb ignition. This pre-determined level provides the proper level of charge for the power supply boost capacitors for bulb ignition. Depending on the lamphouse manufacturer, this open circuit level is between 80 and 150 volts DC, and can usually be monitored by depressing the bulb voltage switch. If the lamphouse does not have a voltage switch, the open circuit voltage can also be read at the power supply using a voltmeter.

If the bulb doesn't attempt to strike with the "emergency" ignition switch, the problem is usually in the igniter. In most cases, it is either a defective high voltage transformer or spark gap. If you can hear the igniter operate, but the bulb fails to light, it is a good idea to turn off the booth lights, and, looking into the lamphouse observation port, try to ascertain where the arc is occurring. The lead from the igniter to the bulb should be one-half inch from any metal lamphouse components. If the path between the lead and a metal component is shorter than the gap between the bulb electrodes, the arc will occur between the lead and the lamphouse, and *not* across the bulb's electrodes.

If an arc does go across the electrodes, and the bulb does not start, the problem is **not** in the igniter. Look at the boost circuit of the xenon power supply. A very common reason for this phenomenon is loose or corroded DC connections in either the lamphouse or the rectifier. These connections should be checked during periodic lamphouse maintenance, or whenever the bulb is changed. Another possible cause is a defective boost capacitor in the power supply. If you have repeated occurrences of this nature in the same system with several consecutive bulbs, it's a good idea to exchange these capacitors with those from another system not exhibiting the same problems. See if the problem follows the capacitors. If you change the bulb, and the problem is corrected for five or six hundred hours before it recurs, try the capacitor trick and document the results; see if there is a pattern.

The bulb itself can also be the cause of ignition problems. The cathode contains thorium to lower its work function and provide easy ignition. If the bulb is operated at a level of less than 75% of its rated amperage, the cathode electrode will not become charged enough to replenish the surface thoria. In turn, the bulb will exhibit starting problems after four or five hundred hours of operation. Bulb-related ignition problems usually center on the cathode electrode. A good visual examination of the condition of the cathode is in order if you are encountering ignition problems. A cathode with a mushroom-shaped tip can cause erratic ignition problems.

Failure to Ignite (continued)

Bulb fill pressure and arc spacing can also be suspect in bulb ignition problems. While high xenon fill pressure will provide higher initial light output in a xenon bulb, it can also lead to poor bulb ignition after the bulb ages and some contaminants are induced into the xenon from the normal outgassing of the electrodes during operation. The higher the xenon pressure, the higher the resistance of the arc in the bulb will be. The spacing of the arc also effects the resistance of the arc; the wider the gap, the higher the resistance. Running a bulb at higher than the rated current will cause excessive burn-back on the cathode electrode and in turn increase the length of the arc.

So what is the purpose of the wire around the outside of the envelope? This wire is usually made of nickel or nichrome (short for nickel-chromium). It is used to set up an “E” field during bulb ignition. Picture it as a grid of an electron tube. Without this wire on the bulb, you will more than likely experience ignition problems halfway through the bulb’s life, particularly if the bulb is hot when you try to start it.

Bulb Explosion

A bulb explosion does one thing for the projectionist, technician, or manager/operator: it causes respect for the warning labels on the bulb box. The pressure inside an operating xenon bulb is as much as three times the non-operating pressure, which is typically 60 p.s.i. (pounds per square inch) absolute pressure. When the bulb explodes, it makes an extremely loud “bang,” and usually causes considerable damage to the lamphouse. Once you’ve experienced a bulb explosion, you will become an avid advocate of wearing the recommended safety equipment when handling xenon bulbs.

What causes a bulb explosion? The Number One cause is excessive strain on the bulb’s quartz envelope. Once the envelope has developed a strain pattern, it is only a matter of time and thermal cycling until the envelope ruptures, or actually *explodes* because of the high internal xenon pressure. It is a very rare occurrence for a bulb to explode when **not** in operation because of lack of temperature and the reduced xenon pressure of a non-operating bulb,. When the bulb is operating with strain in the envelope, the internal quartz pressure at the elevated temperatures work against the vitreous structure of the quartz (SiO_2), and the strain pattern actually grows until the integrity of the envelope gives way, resulting in an explosion.

Strain is usually induced into an envelope during the fabrication process of the bulb. However, this strain is removed by an annealing process at the factory and is inspected using a polariscope to ascertain its removal. The only other possibility of manufacturing-induced strain is during the filling operation, and the following tip-off from the fill station. Manufacturers do inspect for strain induced during this process and will reject the bulb if it is severe. The polariscope test for strain around the fill tube is not as accurate as that of the envelope because of the optical distortion created by the fill tube. This results in a judgement by the quality-control inspector as to the product’s acceptability.

Another cause of bulb explosions is *devitrification* of the quartz used in the envelope. The quartz used in xenon bulbs is both a chemically stable and a refractory material of pure silica. When this material is subjected to chemical impurities, such as the skin oil in a human fingerprint, and then heated, irreversible damage is done to the integrity of the material. The vitreous structure is changed to a crystalline condition, and the material’s strength is greatly reduced. This reduction in strength will eventually decay to a point where the bulb can no longer contain the pressure, and an explosion occurs.

Bulb Explosion (continued)

Operating a bulb with a very dark envelope will result in poor screen illumination. You will eventually lose a show when it explodes. The bulb envelope is transparent for two reasons: one is to let the light out, and the other is to let the heat out. The quartz envelope on a new, clear bulb can be up to 600° Celsius. As the bulb darkens, this temperature increases because the heat cannot escape the darkness of the envelope.

It goes without saying that one should always check the condition of the lamphouse's exhaust fans and blowers. Most lamphouse manufacturers run extensive tests in the development of their equipment's bulb cooling needs. Another thing to remember is to *clean the dust off* the bulb occasionally, using a clean towel free from lint and oil. This will help prevent external envelope contamination which leads to devitrification.

Leaker

A "leaker," as the name implies, is caused by a seal failure that allows the xenon to escape from the bulb. This can be detected by monitoring your lamphouse ammeter. A leaker will have higher-than-normal amperage and lower-than-normal voltage. It is also signified by low screen illumination. When observing the arc through the observation port, you will notice a much larger flame of bluish color between the electrodes. When inspecting a leaking bulb after removal, you will sometime see discolored electrodes, and, depending on the severity of the leak, a white or blue colored envelope.

Three things can cause a seal failure: faulty manufacturing, overheated lamphouse, or mishandling during unpacking or installation. The individual bulb manufacturers usually know if they've had a high incidence of leakers in a certain model of bulbs. A good theatre supply dealer can also tell you if they've returned more bulbs of a certain model than another.

An overheated end seal is usually evident by the discoloration of the bulb's end fittings. While a bulb's envelope requires little if any external cooling, that's not so with the end seals. The maximum safe end seal temperature recommended by most bulb manufacturers is 250° Celsius. The reason for this, on both molybdenum and graded glass seal bulbs, is that tungsten and molybdenum oxidize at approximately 300° Celsius. When this happens, the mechanical structure of the refractory metal is destroyed, and it can no longer contain the pressure.

A discolored end fitting does not always mean that the lamphouse, or a lamphouse connection, has overheated the bulb. Inside the end fitting, where you can't see it, is a braze of braided nickel wire to end of the tungsten or moly-electrode shaft. This wire is there to provide a flexible joint between the electrode shaft and the end fitting. If the bulb manufacturer makes a high resistance, or poor braze, of this wire to the shaft, the seal will overheat and fail. Keep good bulb records on the individual systems to see if a pattern is established.

The last method of seal failure is caused mechanically. This occurs frequently during unpacking or upon installation into the lamphouse. Don't apply excessive pressure on the end fittings of the bulb! The seal is only an inch or so away, and you can easily fracture it. Never install an end cable without supporting the fitting into which you are connecting the lead; that is, do not hold a cathode end fitting when installing an anode lead.

Low Light Output

There are several things that can cause low light output of the xenon bulb. As we've discussed earlier, both a leaker and contaminated bulb can cause low light among other problems. However, if a dim bulb is operating within electrical specifications and is not contaminated, the problem lies elsewhere.

The light output of a xenon bulb falls off drastically over the first 200 hours of operation due mostly to the cathode electrode. With a new xenon bulb, the origination of the arc is very much like the point of a pin. There is large number of electrons confined to a very small area, and the lamphouse's optical system is focused on this point. In time, this pinpoint widens to one that more closely resembles the tip of a ten-penny nail. While the same number of electrons is still present, they are spread over a wider area and cannot be as efficiently collected optically by the lamphouse's optical system. This phenomenon is very evident if the bulb is operated in a micro-radiance fixture which projects the bulb's arc. It is called a *diffuse* arc, and cannot be corrected with current state-of-the-art technology. Therefore, make certain to install a lamphouse and bulb that will meet your illumination requirements when a bulb has burned for 2,000 hours.

In theory, a xenon bulb, when first installed, should meet your illumination requirements when operated at 80% of its rated amperage. At the end of the warranted bulb life, the same bulb should meet your requirements when operated at 100% of its rated amperage. However, simply raising the current won't guarantee the results. One should check the focus of the bulb in the lamphouse at approximately half-life of the bulb warranty, and readjust as required. It's also a good idea to periodically clean your lenses and porthole glass. If a single sheet of clear glass causes an approximate 8% light loss, just think what a dirty one must cause!

Unstable Arc or Flicker

To analyze this problem, you must first determine *which* problem you have. This is accomplished by observing the arc through the lamphouse's bulb observation port. You can usually see an unstable arc, while you can only observe flicker on the screen. Screen flicker is usually caused by the light level being too high; over 20 foot-lamberts. If you see screen flicker, try turning the power supply amperage down to see if the problem corrects itself. But, don't forget what happens if you run the bulb at too low of an amperage setting – you may have to de-focus the bulb to maintain proper current settings.

An unstable arc, on the other hand, is a much more complex problem. There are several things that can cause these phenomena, both within the bulb and within the lamphouse. Let's examine the most common ones:

Cathode Electrode – An improperly processed cathode will not have sufficient surface thoria, and in turn will raise the work function of the electrode. This will cause the ball of the arc to constantly seek an area with a lower work function on the cathode surface. On older bulbs, with more rounded or “ten-penny” looking cathodes, the arc will constantly pop from a diffuse arc to a point source on the cathode as the electrode heats up during operation. Another possibility is an improper vacuum prior to filling the bulb. Oxygen, while we need it to breathe, is extremely detrimental to the cathode electrode. When oxygen is present within an operating bulb, the oxygen molecules will combine with the thoria on the cathode tip to form thoria-oxide, which raises the work function of the cathode.

Unstable Arc or Flicker (continued)

Xenon Power Supply – A power supply with a high percentage of ripple can also cause an unstable arc. This happens because a xenon theatre bulb is a point source device, and requires pure direct current. You'll never get flicker on a perfect xenon bulb if you operate it on batteries. This, however, is impractical and very expensive. In layman's terms, "ripple" is defined as an AC component in the DC line of a power supply. If you're a technician, you can check for this by setting your multimeter on AC and reading the power supply's DC output. There are far more accurate ways to read this, and it makes sense to contact your dealer or manufacturer for their recommendations.

Overcooling – In the early days of the xenon bulbs and lamphouses, we were always taught that you could never have too much exhaust or airflow. This is far from the truth! The cooling of a xenon bulb is to prevent seal failure **only**. There are 30,000 watt bulbs in solar simulators and airborne searchlights that operate without cooling the envelope. They have water-cooled designs to maintain seals and electrode shaft temperatures at a desired level as dictated by the bulb's design. If the envelope of the bulb is properly designed, it will require no forced-air cooling. By blowing or exhausting large amounts of air over the cathode side of the envelope, you can actually create an unstable condition and affect the integrity of the cathode electrode.

Picture the envelope of your bulb as a chamber that contains heat and pressure – more precisely, a plasma-thermal arc chamber. If one side of the chamber is cooled more than the other side, you will set up excessive and even unpredictable gas flow patterns. This high density swirling action can and will interfere with the plasma arc between the electrodes and create an annoying arc instability.

Poor Electrical Connections – Another source of possible flicker is a poor electrical connection with or within the lamphouse or power supply. As these connections heat while the lamp is operating, the electrical conductivity of the connection is decreased because of thermal expansion, which creates a loose electrical connection. Periodically check the connections when performing routine maintenance.

Records

BE SMART and keep bulb and lamphouse performance records. When you do encounter a problem, it will be much easier to troubleshoot if you have some system history. You'll also find that this will eliminate the bulb or lamphouse manufacturer's blaming "the other guy." It will give you the analytical data you need to make a decision on your own.