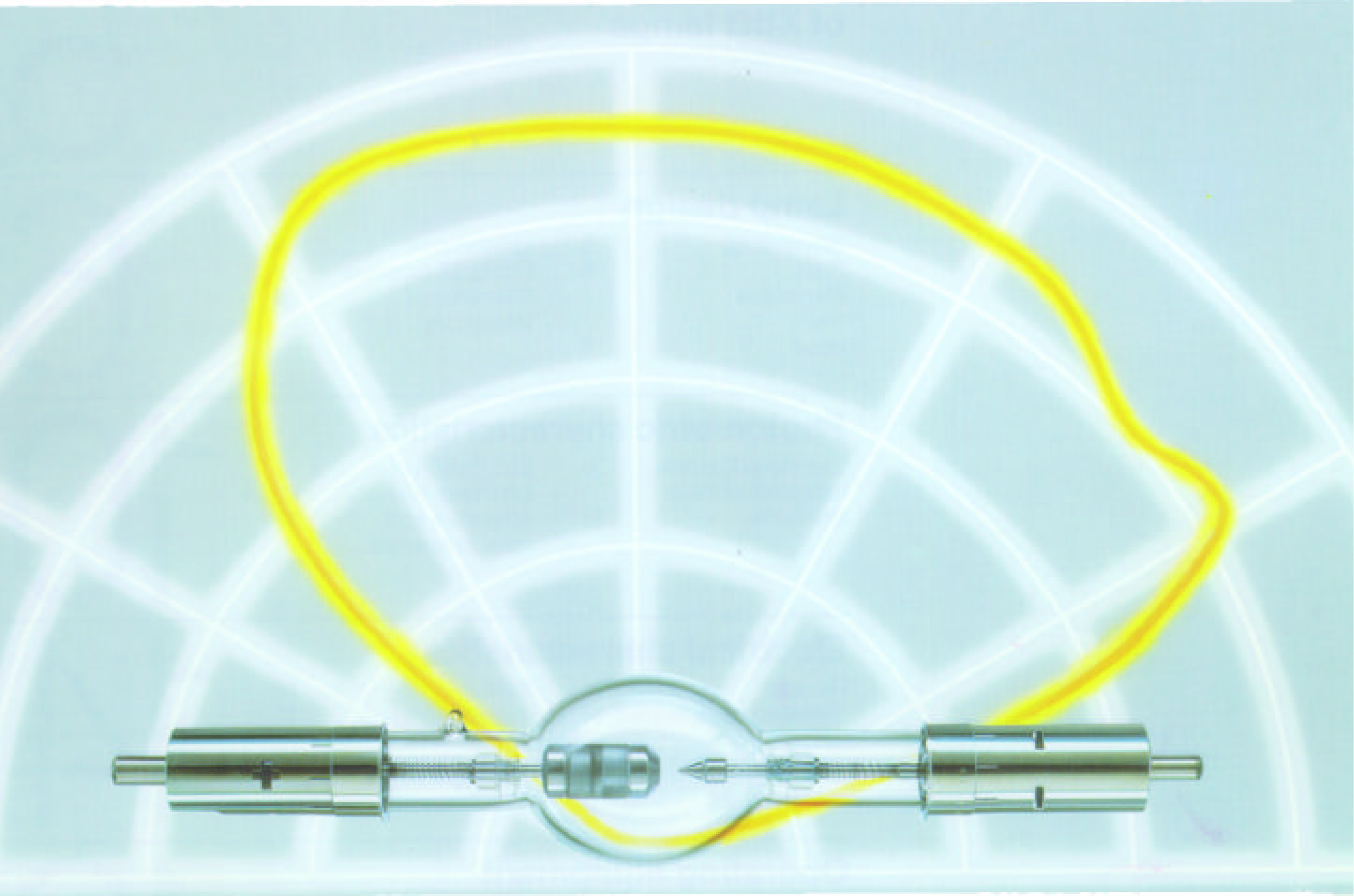
Technology and applications

XBO THEATRE LAMPS



THERE IS LIGHT. AND THERE IS OSRAM.

OSRAM

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Introduction

The purpose of this document is to give as complete an overview as possible of all questions relating to the use and operation of XBO lamps. It is therefore aimed at all operators and users of XBO lamps and at appliance designers, whether of operating equipment such as rectifiers and igniters or of lamp housings and optical systems.

This brochure deals not so much with the physical and photometric principles on which the generation of light in XBO lamps is based, or the photometric characteristics of the generated radiation, but rather with the practical requirements which must be met to operate the lamps reliably and profitably, the problems which can occur during operation, and ways of solving these problems.

Although the remarks which follow relate mainly to the use of XBO lamps in film projection (their most important application from the commercial point of view), much of what is said also holds for other applications such as solar simulation or searchlights. The brochure focuses on the high-wattage XBO lamps rated at over 450 watts which are used in the dominant application; wherever these show marked differences from lower-wattage XBO lamps this is always pointed out.

This publication is intended as a reference work and therefore has a detailed table of contents at the front and an index at the back.

Historical overview

XBO lamps are short-arc discharge lamps based on a steady-state high-current arc discharge in pure xenon gas, and were developed by OSRAM in the fifties. Their dominant application right from the start was as the light source in commercial film projection, where they replaced carbon arc lamps almost overnight. XBO lamps have been especially popular since about 1970 when lamps were successfully designed which could be operated not only in a vertical burning position, as prescribed until that time, but also horizontally. This development made it possible to increase the brightness of the theatre screen by about 30% with the same lamp wattage.

Over the past twenty years, reliability and lamp life have been constantly improved by continuous development of lamp components and manufacturing procedures. Today, a product range is available from 75 to 10,000 W divided into many wattage levels and types.

1. In 1984 OSRAM was awarded the coveted OSCAR by the American Academy of Motion Picture Arts and Sciences for developing and perfecting XBO lamps.

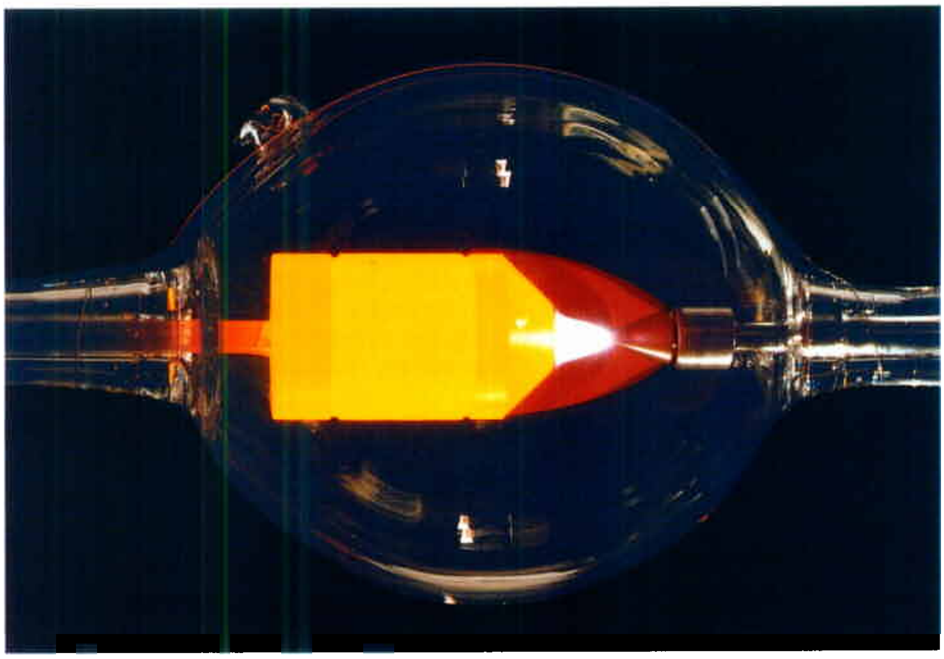
General description of XBO lamps

XBO lamps belong to the family of discharge lamps. In these lamps, light is generated by a discharge arc burning freely in pure xenon gas between two electrodes. The length of the arc is the same as the distance between the two electrodes and is only a few millimeters, even at high power levels of several kilowatts. This means that the lamps come very close to the ideal of a point source of light.

The pressure in the discharge vessel is some tens of bars in operation, in order both to achieve the high spatial level of light concentration desired and to obtain a still acceptable operating voltage for the lamp. Operating voltages are mostly in the order of 20-30 V, with extreme values between 15 and 60 V. At the wattages usually used, this makes these lamps extremely high-current lamps, currents of up to 160 A being advisable and necessary. The current must be provided in the form of well smoothed direct current by the power supply unit.

One of the main photometric advantages of XBO lamps, besides their above-mentioned high brilliance due to being point sources of light, is the daylight quality of the light generated. At 6200 K on average, not only do they very closely approach the color temperature of the sun; the color rendering index – the degree to which body colors are reproduced "naturally" – is only a few points under the ideal value of 100, and this color quality cannot be changed or affected, and is always the same irrespective of lamp type, wattage, lamp life and whether or not dimming is used.

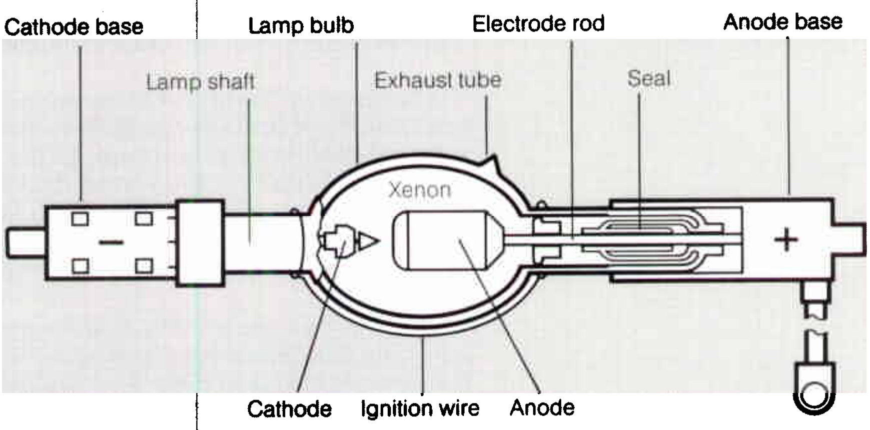
A number of applications also make use of the fact that the lamps can be reignited at any state of cooling, and that when started from cold the full light output is available almost immediately.



2. XBO lamp in operation.

Lamp design

Terminology



3. Schematic sketch of an XBO lamp showing its main components

XBO lamps are double-ended discharge lamps. Fig. 3 is a schematic drawing showing the main components:

The **quartz glass lamp bulb** is the discharge vessel containing the **electrode system** and is filled with xenon gas. The bulge extends outwards into the **lamp shafts** or **lamp necks.** These cylindrical parts are called **sleeve tubes** in certain types of lamp.

The lamp's "nose", through which it is filled during manufacture, is called the **exhaust tube** or **exhaust tube tip.** It is located either on the bulb or on one of the sleeve tubes.

The discharge arc burns between the two **electrodes** that project into the discharge vessel. The electrodes are diametrically opposed with a short gap between them, the electrode gap. In operation, the electrode gap becomes the **arc length.** The smaller electrode is the **cathode**, the larger the **anode.**

In most types of lamp the electrodes are mounted on electrode rods.

Both electrodes are **hermetically sealed** into the discharge vessel.

The **bases** are used to make the external electrical connection and to hold the lamp mechanically. One is the cathode base (negative pole), the other the anode base (positive pole).

The **ignition wire** passes round the outside of the bulb; depending on the type of lamp it either goes from neck to neck or from neck to neck to a base.

Bulb

XBO lamp bulbs are always made of quartz glass. Only quartz glass can withstand the high mechanical load caused by the operating pressure of some tens of bars and the thermal load at surface temperatures of over 700°C.

Depending on type and dominant application, a more oval or more round cross section is chosen. The quartz wall is a few millimeters thick. Only the best types of quartz free of striae and bubbles are used in order to give the arc the best possible imaging quality.

The bulk of the quartz glass is generally doped or coated, invisibly to the human eye, to absorb undesirable UV radiation. XBO lamps with bulbs made of pure quartz glass generate ozone in air during operation; this is detrimental to health at high concentrations and if inhaled over long periods.

Electrodes

The electrodes in XBO lamps are always made of tungsten.

The smaller electrode, the **cathode,** supplies the current i.e. the electrons. The best material for performing this task is doped tungsten. The geometry of the cathode with its relatively sharp tip and (in some types) its heat reflective groove also facilitates the emission of electrons. This shape also lends itself to the formation of a stable and sharply delimited arc base, which is necessary for a high concentration of generated light immediately in front of the cathode tip and for good spatial stability of the arc root.

The **anode** receives the electrons emitted by the cathode. They penetrate the anode at high speed and come to a halt there. The dissipated energy is converted to heat. This heat must be dissipated, and is mostly radiated away. The anode is large and bulky to keep its temperature as low as possible in the interests of long lamp life. The surface is often treated to improve its infrared radiation characteristics; to the human eye it appears either highly polished or pasted grey.

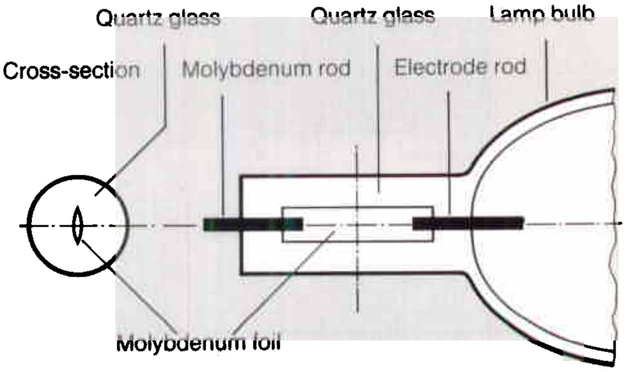
Besides its shape, the other crucial factors that determine how long the anode can withstand the bombardment of electrons are the composition and structure of the material. Whereas in the past pure, very high density tungsten was used, today we use additives and strictly controlled thermal and mechanical processing to give the metal an internal structure that produces substantially better anode characteristics. The crucial factor is always how long the front face of the anode keeps its shape. The process of attrition is also markedly affected by the special conditions under which a lamp is operated.

Seal

The seal, of which every XBO lamp has two, makes the hermetically gastight connection for the electric current between the outside world and the inside of the lamp.

As is usual for metals, tungsten has a relatively high thermal expansion coefficient. Quartz glass by contrast hardly expand at all when heated. For this reason a tungsten rod – the anode rod for example – cannot be embedded in quartz glass, as the tungsten metal would break the quartz glass when it heated up, so certain tricks have to be employed to create a seal between glass and metal.

Tip number 1:
The current is conducted through the quartz glass by a molybdenum foil (see Fig. 4). The foil is only 20mm or so thick (thinner than a hair) and is etched to a sharp cutting edge at both sides. When it heats up, the absolute expansion of the foil across its thickness is so slight that the quartz glass is capable of absorbing the force. Across the width, the sharp edges can easily bury themselves in the quartz glass without breaking it. This **foil seal** method is used for all low-wattage XBO lamps up to about 300 watts. It cannot be used for higher wattages as the thin foils are only rated up to about 10 amps.

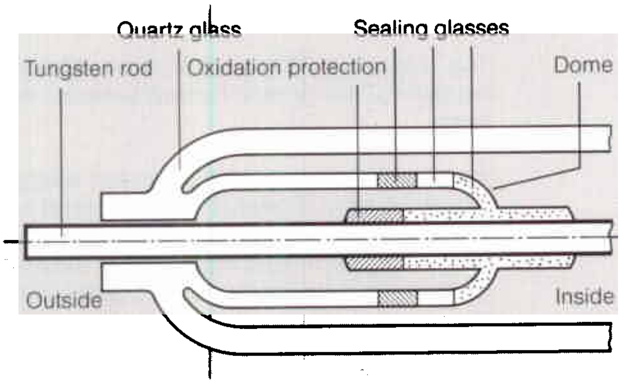


4. Schematic sketch of a foil seal

Tip number 2:
To increase the current rating of the foil seal, several foils can be connected in parallel resulting in a **multiple foil seal.** The problems with this are firstly the manufacturing process (each foil must be sealed separately) and secondly the mechanical joining of the foils at the electrode and the external electrical connection. This can result in ugly constructions that are technically difficult to reproduce and susceptible to faults.

Tip number 3:
Instead of a number of foils connected in parallel, a circular foil pressed into the shape of a cup can be used, making a **"moly cup seal".** This is basically a good idea except for the high cost of manufacturing the cup-shaped foil and the unreliability of the seal along the circular cutting edge.

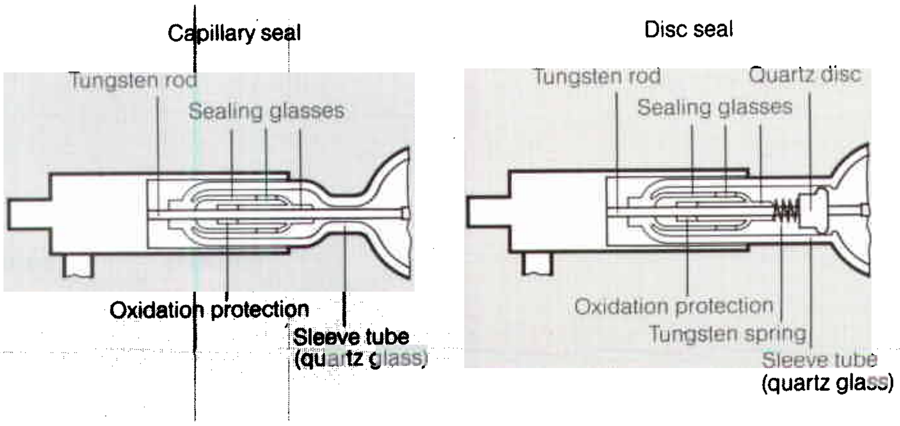
Tip number 4:
The mechanically and electrically most reliable method is to pass the current directly through the rod to which the electrode is fastened. As however the rod cannot be embedded in the quartz glass, it is necessary to mediate between the tungsten and the quartz in respect of the expansion coefficient. This is done with a series of different types of glass which are placed around the tungsten rod and whose coefficients of expansion successively fall the further away they are from the tungsten rod: a high coefficient similar to metal directly next to the metal, a low coefficient similar to quartz sealed to the quartz glass, and one or two "mediators" in between. This is known as a **graded seal.** As the seal glass may only be subjected to pressure, the result is a geometry reminiscent of a finger stool turned inside out (see Fig. 5). The important part of the sealing glass is called the seal dome.



5 *Schematic drawing of a graded seal*

The graded seal is today regarded as the most reliable and clean type of seal for high-current lamps like XBO lamps.

As the sealing glass is temperature-sensitive, it must not be located too close to the heat-generating arc and anode. A number of different methods of fixing the heavy electrode solidly in the lamp bulb are used. The most important of these are shown in Fig. 6:



6 *Capillary seal and disc seal to hold the tungsten rod*

In the **capillary seal** the sleeve tube is sealed close to the tungsten rod over a certain length. This results in the rod being well supported but a rather delicate mechanical design.

In the **disc seal** the electrode rod is centered in the large-diameter, robust sleeve tube by a disc shaped rather like a valve head as used in the automobile industry. A tungsten spring presses the disc into its seat. The main advantage of this type is its reliability of manufacture which ensures a high quality level.

An important design detail of the graded seal is **oxidation protection.** This consists of a special glass with a relatively low melting point applied externally to the tungsten rod at the seal. Its particularly close physical and chemical bond with the tungsten rod makes a good additional seal against the atmospheric oxygen which tries to penetrate the sealing glass.

Base

The two bases of XBO lamps are used for electrical connection and mechanical fixing. For high-wattage lamps they generally consist of metal sleeves fastened to the lamp shafts with a clamping ring assisted by a graphite band. A flexible lead inside the base makes a strain-relieved connection between electrode rod and base. Attached to the sleeves are either a cable, a threaded pin, a simple cylindrical pin or a combination of these. The sleeves are high-gloss nickel-plated for permanently good electrical and thermal contact. Polarity identification marks are usually punched into the bases; these serve both for identification and for cooling the interior of the base.

Ignition wire

The ignition wire is a thin, thermostable iron-nickel wire slung from one lamp neck to the other and – depending on lamp type – sometimes continued as far as the base sleeve. Its existence makes igniting the lamp easier, especially when rectifiers and igniters have diminished in efficiency with increasing age. Its function is twofold: firstly it distorts the high-voltage electrical field applied to ignite the lamp, producing inhomogeneities which cause peaks in the field distribution, a condition favorable to sparkover. Secondly, partial discharges take place on it, these can knock electrons from the cathode by a photoelectric effect, and these in turn initiate the discharge.

Filling, fill pressure

XBO lamps are filled with pure xenon gas. Xenon is the rarest of the stable inert gases and occurs in air at a very low concentration of <0.00001%. It can be obtained by liquefying air in an industrial process. It is very expensive compared with other inert gases like argon and krypton, which are also obtained from air. The gas must meet extremely stringent purity standards to ensure high lamp life. Corrosive impurities may only be present in the ppm (parts per million) range.

Depending on lamp design, cold XBO lamps are filled to a pressure between 8 and 10 bar. In order to obtain this positive pressure in the lamps, the xenon is frozen into the lamp body during manufacture. The pressure in the lamp rises during operation to about three times the value because of the temperature.

Geometrical tolerances

As point sources of light, XBO lamps are often used in high-quality optical systems. This requires precise positioning of the arc, or more precisely of its hot spot, the point of maximum brilliance. As these lamps are of hand-crafted molten glass, their overall geometry is naturally subject to greater tolerances than are known from rotationally symmetrical turned metal parts. To facilitate adjustment of the lamps in optical systems however, and even allow it to be omitted where requirements are not so exacting, the position of the arc relative to a reference base (usually the cathode base) in terms of distance and excentricity is subject to very close tolerances of usually ±0.5 to 1 mm. All other dimensions may have tolerances of several millimeters. This must be allowed for in the design of appliances and lamp housings.

In some types of lamp the diameter of the base pin is also closely toleranced if it is to be used to make the electrical connection. A close fitting tolerance provides for a large area of contact.

Photometric characteristics

Luminous flux and luminous efficacy

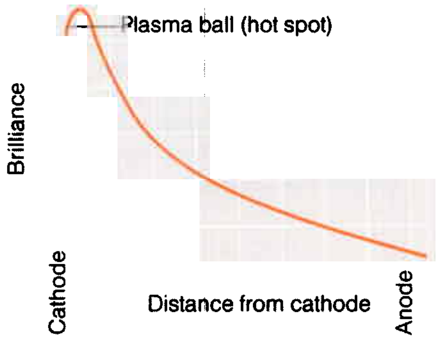
At typical average wattage levels, about 80% of the electrical energy put into XBO lamps is converted into radiation. The rest is lost through heat conduction and convection. Only about 60% of the energy used is radiated by the electric arc, and most of this is in the invisible near infrared region. The remaining 20% of the radiation originates from the electrodes (chiefly the anode) and from the bulb which does reach a temperature of about 700°C.

Referred to visible light, the **luminous efficacy** of the above example is about 30 lm/W and is thus comparable with maximum-load short-life tungsten-halogen lamps. The lower the wattage of an XBO lamp, or more correctly the lower the lamp voltage, the worse is the luminous efficacy and vice versa. It ranges from only 15 lm/W to 50 lm/W. Lamps with a shorter electrode gap also generally have a lower luminous efficacy.

If the electric current applied to a given lamp is increased, the **luminous flux** increases approximately proportionately to the lamp current to the power of 1.5. This improvement in efficiency results from the simultaneous increase in lamp voltage which produces a higher wattage, higher temperature and higher pressure.

Brilliance

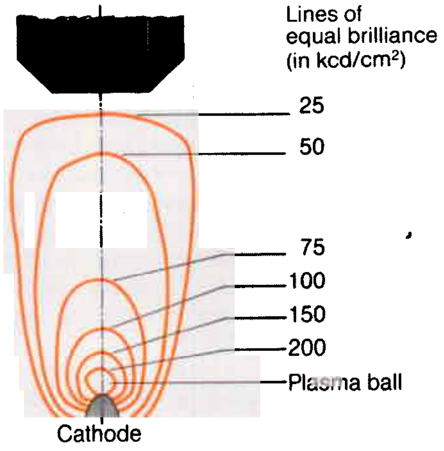
For most applications, probably the most important characteristic of XBO lamps is their **brilliance.** Because in these direct current lamps the arc is geometrically highly compressed a short distance in front of the cathode (for which the shape of the cathode, its heat balance and the electromagnetodynamic forces in the arc field are responsible), a marked area of maximum brilliance occurs there; this drops off rapidly towards the anode (see Fig. 7).



7 Brilliance distribution in the arc along the lamp axis

In the vertical burning position, **brilliance distribution** in the arc is strictly rotationally symmetrical. In horizontal operation, the arc is deflected slightly upwards by the lift it is given in the cooler surrounding xenon gas. The amount of deflection is proportional to the electrode gap and inversely proportional to the current.

In order to rate the brilliance of a given lamp in figures, an **average brilliance** is defined (see Fig. 8).



8 Brilliance distribution in the arc of an XBO lamp

The rules for measuring this are as follow: A small area about 0.02 mm wide over the entire length of the arc along the lamp axis is masked out and its average brilliance determined. This defines the **axial brilliance.** The measured area (the gap) is then moved to both sides of the axis until a value half that of the axial brilliance is measured. This is the average brilliance of the arc. The **luminous area** is obtained from the arc length and the fall in axial brilliance to half its value.

Typical XBO lamps achieve average brilliance values about half that of the surface of the sun. Sophisticated lamps for special applications with a particularly small electrode gap can exceed the sun's brilliance by a factor of 3 or 4.

The table in Fig. 9 compares the brilliance of some natural and artificial light sources.

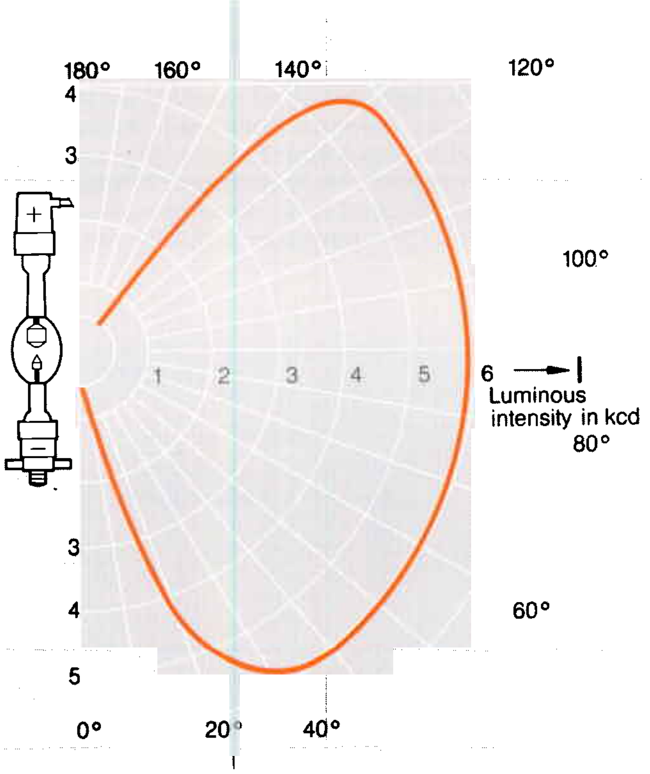
Light source	**Brilliance** (cd/cm²)
Natural	
Midday sun	100,000 to 150,000
Full moon	0.25 to 0.35
Clear sky	0.3 to 0.7
Cloudy sky	0.01 to 0.1
Artificial	
Short-arc xenon lamp	20,000 to 500,000
Carbon arc lamp	20,000 to 180,000
Clear incandescent lamp	200 to 5000
Clear high-pressure sodium vapor lamp	300 to 550
Fluorescent lamp	0.3 to 2

9 Brilliance of selected natural and artificial light sources

Distribution of luminous intensity

Besides brilliance, an important factor in the design and dimensioning of optical systems for XBO lamps is the spatial **distribution of luminous intensity** around the lamp.

Because of the rotational symmetry of arc and lamp, the distribution of luminous intensity is also practically the same in all planes through the axis of the lamp (see Fig. 10). This also applies where lamps are operated horizontally; although the arc is deflected to a greater or lesser extent from the lamp's axis of symmetry, most of the radiation originates in the region near the cathode, the root of the arc, and this is virtually unaffected by convective forces.



10 Typical distribution of luminous intensity of an XBO lamp

Because of cathode and anode geometry and their geometrical arrangement, in most lamps the distribution of luminous intensity fills a total solid angle of about 10 steradians almost evenly (full solid angle = $4 \cdot \pi$ = about 12). Hence the luminousintensity can be approximately derived from the luminous flux of a given lamp as follows:

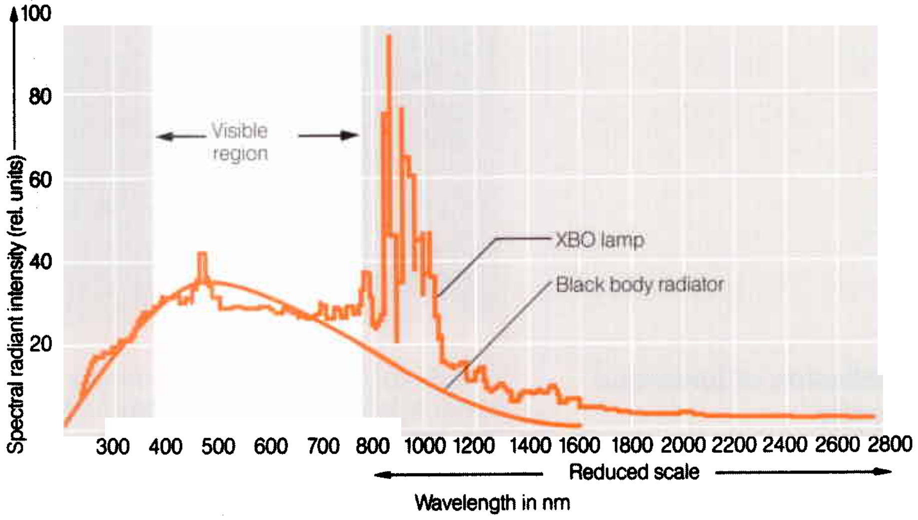
Luminous intensity (cd) = Luminous flux (lm) divided by ten

Conversely, the total luminous flux of a lamp can easily be calculated from the measured luminous intensity.

Spectrum and color properties

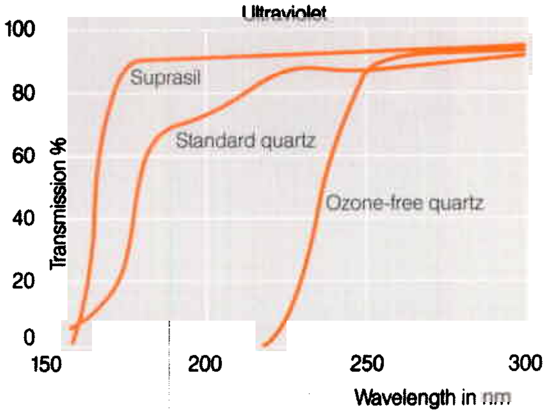
Besides their high brilliance it is their spectral color properties that make XBO lamps attractive for a number of applications.

In the visible region between 380 and 780 nm, the **xenon lamp spectrum** very closely follows the spectral curve of a 6200 K black body radiator (see Fig. 11). It is thus pure white like the midday sun.



11 Spectral distribution of radiant intensity of a typical XBO lamp and a 6200 K black body radiator

About 6% of the electric power consumed is emitted in the form of **UV radiation** below 380 nm. The spectrum ends at about 170 nm because it starts to be absorbed by standard quartz glass. Synthetic Suprasil quartzglass, which is especially low in impurities, allows utilization of the arc radiation down to about 155 nm, which decays more or less exponentially towards the shorter wavelengths. Lamps with doped or coated quartz glass are used for all applications in which UV radiation is a nuisance. These can effectively suppress the region below about 240 nm, with the result that no ozone (O_3) is generated during operation in air (and hence in oxygen). The development of **'ozone-free'** lamps has above all meant substantially reduced expenditure on ventilating cramped film projection booths. Fig. 12 shows the spectral transmission of UV by different types of quartz glass.



12 Spectral transmission of different types of quartz glass in the UV region

It is important to note that the reduction of UV radiation in ozone-free lamps by means of doped or coated quartz glass does not mean that these lamps do not generate UV radiation. The remaining UV radiation above 240 nm is also detrimental to health (see section on "Safety", page 41).

With regard to the spectra of discharge lamps, the outstanding feature of XBO lamps is their continuity in the visible region; this is reflected in their color rendering index of about 98.

It is also worthy of note that both color temperature and color rendering index are virtually independent of special operating parameters. Lamp-specific differences in the color temperature of different versions are mainly caused by the varying proportion of electrode radiation: high-wattage lamps with large anodes usually have a lower color temperature, resulting in a higher proportion of red in the spectrum. The fluctuation varies between about 6000 and 6500 K.

In particular, the color temperature is virtually independent of

- lamp type
- wattage
- lamp voltage
- lamp current
- dimming/boosting
- age of the lamp.

This stability of the color characteristics of xenon discharge lamps has made them the light source of choice for all high-quality sunlight simulation systems.

Electrical characteristics

General

XBO lamps are operated with direct current. All attempts to develop alternating current lamps have failed because of short lamp life and high arc instability. The reason for this is that XBO lamps are high-current lamps, with currents approaching 30 amps even in the low-wattage range of less than 500 W. Such current levels require cathode (negative) and anode (positive) to be highly specialized for their respective tasks: the cathode must deliver a powerful electron stream and the anode must receive it. This definitive electrode layout also means that the consequences of incorrect polarity are disastrous; the lamp will self-destruct within seconds, especially the cathode.

Direct current is generally provided by rectifiers connected to the ac mains. The parameters and characteristics of the operating equipment influence the behavior and particularly the life of XBO lamps more strongly than for other lamp types. A sound understanding of electric lamp behavior is therefore essential for constructing such equipment.

Steady-state operation

Leaving aside ignition and startup of XBO lamps for the moment, their electrical characteristics can be described by a steady-state current-voltage characteristic.

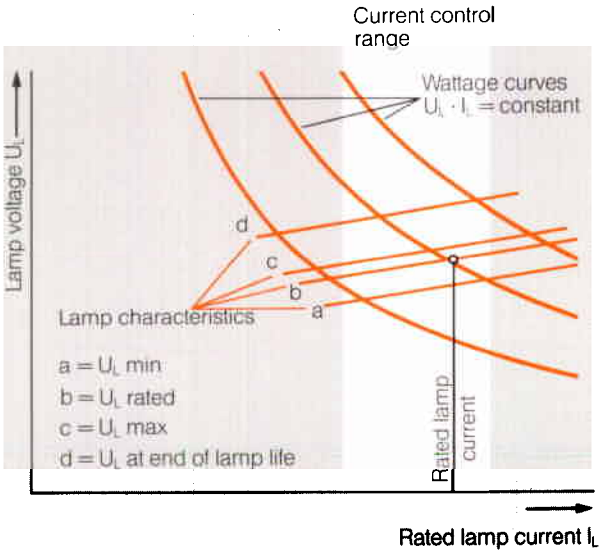
In the operating range, i.e. the region around the rated current, this **characteristic** is linear and can be described with the following equation:

$$U_L = U_G + I_L \cdot R_L$$

where
U_L = Lamp voltage
U_G = Base voltage
I_L = Lamp current
R_L = Static differential internal resistance

The base voltage is a variable used to describe the virtually linear relationship between current and voltage in the operating range. As Fig. 13 shows, the characteristics rise slightly towards the higher currents. The manufacturing tolerances for a type of lamp are expressed as a plus-or-minus tolerance for the base voltage, typically ± 2 volts. During the course of each lamp's life, its lamp voltage will rise somewhat as a consequence of the cathode tip eroding slightly, causing the arc length to increase. This gives the upper tolerance line. This rise too is in the order of 2 volts.

Most XBO lamps (except for some low-wattage lamps, see below) are **constant-current** lamps, which means that they should be operated at a specific current. The lamp voltage then adjusts itself in accordance with the individual characteristic.



13 Schematic diagram showing steady-state current-voltage characteristics of an XBO lamp

A **current control range** around the rated current is also specified for most XBO lamps. This can be used to match the brightness of a lamp to individual requirements or to compensate for the slight loss of luminous flux during a lamp's life with more current and hence greater output.

The technical lamp data also specifies a **lower lamp current limit** as well as the current control range. It is typically 30% to 50% of the rated current. It is possible to operate the lamp down to this limit without the arc breaking and the lamp going out. Details of this can be found in the section on „Operating parameters – Current control range“ on page 26.

XBO lamps in the 150 W and 250 W wattage levels do not allow a current control range but must always be operated with the rated current. Deviations downwards would lead to unacceptable arc instability, deviations upwards would speed up cathode loss and also cause a risk of explosion.

Unlike all other xenon lamps, 75 W and 100 W XBO lamps must be operated at **constant wattage.** Because of their short electrode gap and the large relative change during the lamp's life associated with this, these lamps may only be operated at their rated wattage; if the wattage is exceeded there is a risk of explosion. Rectifiers must be suitably designed for this mode of operation.

To ensure maximum stability of lamp operation, the output characteristic of the rectifier should cut the lamp characteristic at an angle of about 90° if possible.

Ignition

When cold, XBO lamps are outstanding insulators. Applying the lamp supply voltage of, say, 100 V (the open circuit rectifier voltage) has no effect. To start the lamp, special measures are needed to make the insulating gas between the two electrodes conductive by ionizing it. This is normally done by means of a high-voltage discharge or flash. A number of boundary conditions must be met for a flash of this type to become a stable, steady arc, including:

- a sufficiently high peak voltage (ignition voltage) from the igniter
- sufficient electrical energy in the ignition spark
- current flow in the rectifier starts sufficiently quickly
- adequate open circuit voltage in the rectifier.

If the igniter **peak voltage** is not sufficient to bridge the electrode gap, there will be no discharge.

If the ignition voltage is sufficient to obtain a discharge but there is not sufficient **energy in the ignition spark,** the spark goes out before the lamp can come near to its steady-state operating range and the rectifier can maintain the discharge. What happens in practice is that the lamp flashes briefly.

If the rectifier is unable to provide the required current quickly enough after the discharge, the lamp again goes out; the only difference from the previous case is that its flash may have lasted very slightly longer.

To enable a smooth transition from spark discharge to stationary dc operation, the rectifier must fulfil minimum requirements in respect of its **open circuit voltage.** This is typically greater than the lamp voltage by a factor of 3 or 4.

Due to practical design considerations, the ignition voltage is normally generated in the form of a series of **high-frequency pulses.** If the pulses follow each other in rapid enough succession, at a frequency of 300 Hz for example, ignition of the lamp is facilitated by the fact that the conducting path between the electrodes generated by the first discharge is maintained and extended by the subsequent pulses.

Once the lamp has been ignited, the igniter should be switched off. Though relatively small, the ignition spark energy can still damage the cathode over a long period of time. **Operating times** between 0.2 and 0.5 seconds are advisable for the igniter.

In principle, XBO lamps can be ignited with a single pulse. This method is favored more and more, firstly to reduce the otherwise jarring ignition noise and secondly to minimize electromagnetic interference in surrounding electronic equipment. **Single-pulse igniters** require approximately 20 % higher peak voltages because they lack the supporting effect of the pulse chain.

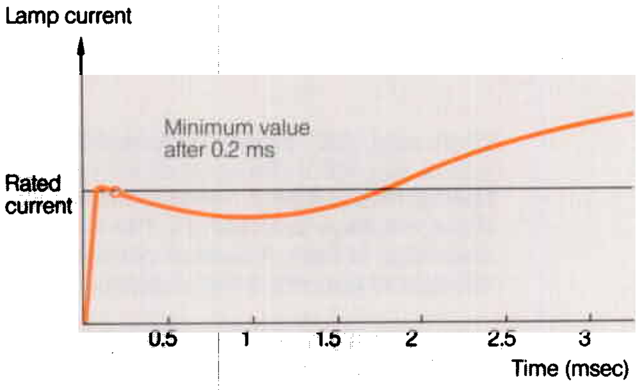
The positive effect of the **ignition wire** has already been discussed in the section on "Lamp design" (q.v. page 9).

Startup

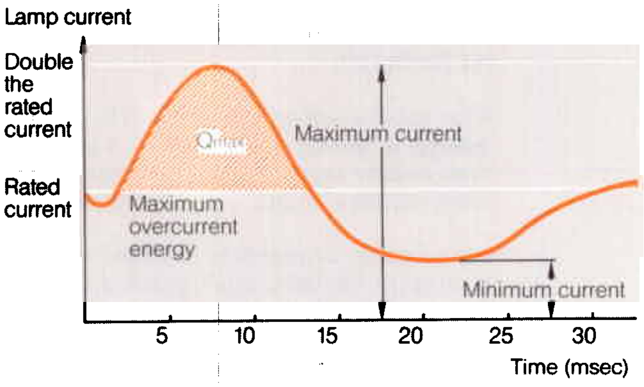
In steady-state operation after a constant current has been established, XBO lamps have a gently rising, positive current-voltage characteristic. The parameters of ignition – production of a discharge between the electrodes – are described in the previous section. Lamp behavior immediately after the ignition spark has produced a conducting, ionizing path is very complex.

If the lamp is regarded as an ohmic resistor (which of course it is not), the resistance falls after the ignition discharge within a very short time from infinity to a few tenths of an ohm. How it gets there, and that the lamp does not go out again after this dynamic and explosive process, depends on the characteristics of the rectifier.

Figs. 14 and 15 show typical **inrush current curves** for the first 3 msec and 30 msec after the start.



14 Inrush current curve up to 3 msec after ignition for reliable lamp start



15 Inrush current curve up to 30 msec after ignition for reliable lamp start

It is important both for the path created by the ignition spark to be fed quickly enough with enough electrons to be kept alive, and for the still cold electrodes not to be damaged by excessive current levels. The following boundary conditions must be fulfilled for reliable arc formation:

1. The rated lamp current must be reached at least 0.2 msec after the discharge.
2. For a non-damaging start, the inrush current peak should not exceed twice the rated current, and in no case should it exceed the maximum peak value specified in the data sheet.

3. During the startup phase the current must not fall to below half the rated current.

4. The total overcurrent energy (ampere-seconds) applied to the lamp in the first second must not be substantially more than 50% above the rated value (i.e. rated current multiplied by time).

The first requirement can normally only be achieved with an **auxiliary ignition capacitor** connected in parallel with the lamp. To fulfil the second requirement, a suitably dimensioned series resistance must be installed in series with it. The third requirement means that the rectifier must deliver enough current to maintain the arc within the discharge time of the auxiliary ignition capacitor. Meeting the fourth requirement will protect the cathode.

Current ripple

A basic requirement for operating XBO lamps is direct current; in fact, direct current as supplied only by batteries. Direct current generated by rectification betrays its origins by a current ripple superimposed to a greater or lesser extent on the direct current. The quality of direct current is specified as a percentage of its residual ripple.

The term **"residual ripple"** must be more precisely defined. The "lamp current ripple pi" is a determining factor in the behavior of XBO lamps and is defined as:

$$p_i = \frac{i_{max} - i_{min}}{i_{max}} \cdot 100\%$$

where i_{max} and i_{min} are the maximum and minimum current over time (see Fig. 16 overleaf).

This ripple must be as low as is technically feasible and economically viable. The lower the ripple, the better the long-term lamp behavior. Excessive ripple is the dominant factor in reducing lamp life. The following maximum permitted values are specified:

$$p_i < 10\% \text{ for lamps up to 3000 W}$$

$$p_i < 5\% \text{ for lamps over 3000 W}$$

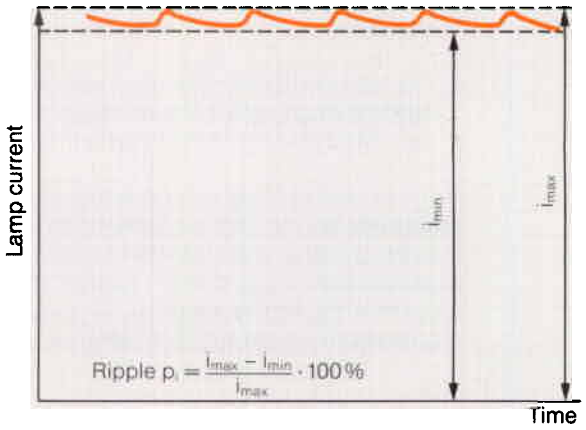
Fig. 31 on page 32 shows a cathode fissured after a long period of operation with excessive current ripple.

Lamp current ripple can be reduced by **smoothing elements** in the rectifier. Chokes can be used to a certain extent, but most of the smoothing effect must be produced by high-capacitance capacitors. These capacitors are subject to an ageing process during which they lose their capacitance. Monitoring and measuring current ripple is therefore an important theme in trouble-free lamp operation.

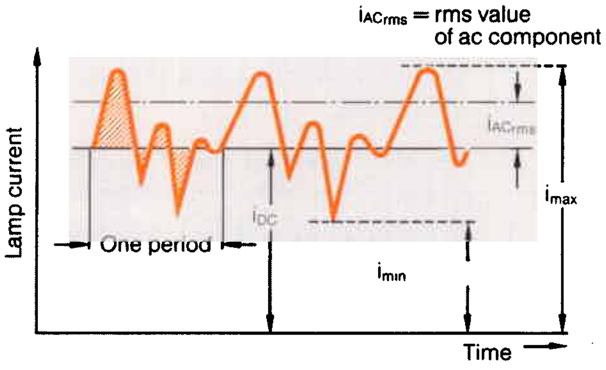
A technically sound way of **measuring current ripple** is to use a low-induction shunt (series resistor of a tenth of an ohm or less) in the lamp circuit. The voltage drop at this shunt is analyzed with an oscilloscope and the ripple calculated using the formula given above.

It is important to record the actual current ripple. Measuring the voltage across the lamp or even the open circuit voltage of the rectifier can give completely false results. On the one hand XBO lamps act like reactive components with inductance and capacitance in the face of the alternating current component, and on the other hand the steady-state characteristic (see page 14) is itself much flatter than with an ohmic resistance. The **voltage ripple** is therefore always markedly lower than the current ripple.

Users should also be warned against determining the alternating current component of the direct current with an **rms** instrument. The diminishing effect on lamp behavior is caused by the actual current peaks on top of the direct current, not by the rms value of the alternating current component. See Figs. 16 and 17 for clarifi-



16 *Definition of residual lamp current ripple pi*



$$\text{Ripple } p_i = \frac{i_{max} - i_{min}}{i_{max}} \cdot 100\,\% \neq \frac{i_{ACrms}}{i_{DC}}$$

17 *Difference between lamp current residual ripple and rms ripple*

cation of the difference between rms value and instantaneous peak value. A difference of a factor of 10 is not unusual in ripple curves occurring in practice.

A better method is to estimate the ripple by means of the light. Using a fast enough photocell and an oscilloscope, it is possible to ascertain whether the ripple is in the correct order of magnitude by **measuring the light,** without using a great deal of equipment. With a ripple of between 5 and 10 % the light ripple is about 50 % higher, as the luminous flux is proportional to the lamp current to the power of 1.5.

Increasing use of **electronic rectifiers** (i.e. electronic control gears ECG) has brought new problems. They generate a regulated direct current without using a heavy mains transformer by high-frequency chopping of the rectified mains current at about 20 kHz. In this system, the XBO lamp “sees” not only the slow ripple that passes through from the mains frequency but also a high-frequency ripple originating from the chopper. High-frequency current ripples of about 50 % have been observed in some types of rectifier, the “switched-mode power supply units”. The extent to which these fast, very high but also very short current peaks impair lamp behavior has not yet been sufficiently investigated. Care is advisable however, because the cathode has to supply electrons even for short current peaks.

Operating equipment

Lamp housings

XBO lamps are high-brilliance light sources which generate a not inconsiderable amount of UV radiation and are under high internal pressure. For these three reasons, XBO lamps must only be operated in closed housings.

These housings are designed to suit the particular application, whether film projection, spotlighting or solar simulation. They must all have the following features however:

Protection from **glare:** lamp housings must be designed so that the arc cannot be viewed directly. The brilliance of the arc is so high that it can destroy the retina.

Protection from **UV radiation:** lamp housings must be so designed that UV radiation emitted by the lamp cannot leave the housing unfiltered either directly or in the form of scatter. This does not of course apply to luminaires designed expressly for the utilization of UV radiation.

Protection from **quartz glass splinters:** lamp housings must be designed so that if the lamp bursts in operation no quartz glass splinters can escape.

Sufficient space for fitting and removing lamps should be allowed to enable a lamp's **safety cover** to be removed at the last moment before closing the lamp housing.

Special attention should be paid to the **mechanical fixing** of lamps. They should be clamped in position at one end only in order to allow for expansion and distortion of the housing when it heats up as a result of operating the lamp. The other end must move freely. A soft, yielding support is necessary for fairly large lamps operated in the horizontal burning position.

It is useful to provide suitable holes and viewing plates for **observing the arc,** especially for lamps operated horizontally, in which case a magnet has to be placed in the correct position to stabilize the arc.

The **electrical design** must comply with current rules and safety requirements. A door contact (interlock) which completely interrupts the supply voltage on opening the lamp housing is useful. Allowance must be made for the high currents demanded by XBO lamps and the high voltages of 10-60 kV needed to ignite them. As the discharge arc can be slightly deflected by magnetic fields it is necessary to ensure that it is not affected by any interference fields from the electrical wiring and components. This also applies of course to remanent fields from the actual lamp housing.

The highly concentrated output of XBO lamps makes **cooling** essential. Suitably designed convection cooling will sometimes be adequate for large open lamp housings. Forced cooling is usually essential for close-packed appliances and very compact lamps. See the section on "Operating parameters: Cooling", page 25, for further details on cooling lamps.

Additional external extraction of air from the housing is often advisable to supplement the internal cooling. This is necessary for non ozone-free lamps to prevent the operating personnel from being subjected to nuisance and hazard.

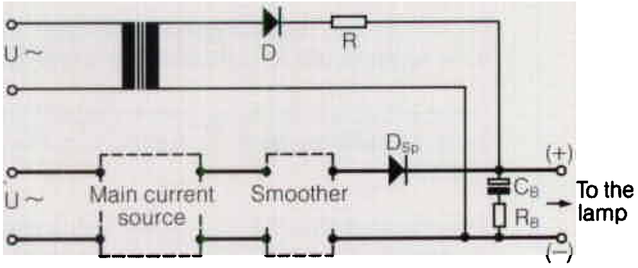
Rectifiers

As a rule, XBO lamps are operated with rectifiers. Direct **battery** operation is also possible in principle, though there are problems with the often low battery voltage and the ability to regulate the current.

The general requirements which rectifiers must meet to render them suitable for operating XBO lamps are described in the section on "Electrical characteristics" on page 14.

Rectifiers are manufactured for both single-phase and **multiphase** operation. In the latter case the necessary smoothing of the lamp current is less complicated. Highly unbalanced three-phase networks can nevertheless give rise unnoticed to increased current ripple. Warning equipment must also be provided in order to prevent the lamp from being operated with excessive residual ripple if one phase fails.

Because in conventional (i.e. non-electronic) rectifiers the open circuit voltage level is a considerable factor in the cost, **booster** circuits are often used (see Fig. 18). The main current source is designed for continuous operation at the rated wattage buthas a open circuit voltage markedly lower than the minimum requirement. The higher voltage needed only at the moment of ignition is supplied from an additional rectifier. For reasons connected with the dimensioning of electrical components, the booster open circuit voltage should be clearly greater than the minimum required for standard rectifiers.



D_{Sp}: Blocking diode
C_B : Booster capacitor
R_B : Booster series resistor
D: Diode
R: Charging resistor

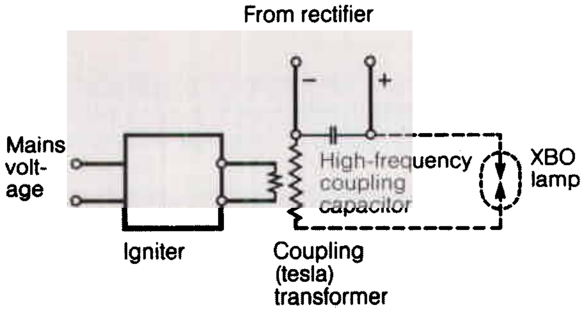
18 Block diagram of a booster circuit

Electronic rectifiers (also known as electronic control gears ECG) are increasingly being used, especially for mobile use. Their main advantages are much lower weight and simple electronic regulation of the lamp current or wattage. Provided they comply with the general requirements for rectifiers used to operate lamps, there is no objection to their use. However they often introduce new, as yet unknown and so also insufficiently studied operating parameters. This is not a bad thing in itself, but it must be taken into account. See the relevant description in the section on "Electrical characteristics – Current ripple" on page 17.

Igniters

XBO lamps require a high voltage to ignite them. Details are given in the section on "Electrical characteristics – Ignition" on page 15.

The most commonly used types of igniter are high-frequency superimposing igniters. Fig. 19 shows a typical circuit of comprising rectifier, superimposing igniter and lamp. The high voltage is coupled into the lamp circuit by a tesla transformer. A component still important today for these igniters is a **spark gap** which operates as a high-voltage switch. It is subject to a certain amount of wear due to its design, and must therefore be either replaced or readjusted at regular intervals. If the electrode gap in the spark gap changes, both the level and the number of ignition pulses change too, usually for the worse.



19 Block diagram showing inductive coupling of high-frequency ignition pulses into the lamp circuit (superimposing igniter)

Modern igniters are fully electronic and do not suffer wear. They are often of the one-pulse ignition type and so particularly mild in their effects on surrounding electronic equipment due to their reduced electromagnetic interference radiation.

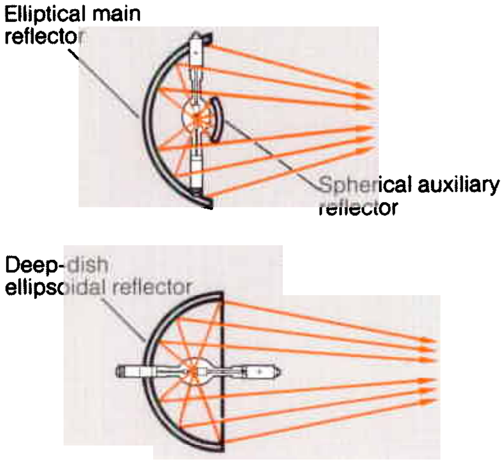
All igniters should switch off automatically after the lamp has been ignited, in order not to damage the lamp. **Minimum operating times** should be about 0.2 seconds, maximum operating times about 0.5 seconds.

To minimize (high-frequency) high-voltage losses between igniter and lamp, the distance between these two units should be as small as possible, and never greater than 50 cm.

Operating parameters

Burning position

The first XBO lamps were designed and suited solely for vertical operation. Only in this burning position could an arc of sufficient stability be achieved. A double reflector system consisting of an elliptical main reflector and a spherical auxiliary reflector were used for optimum utilization of the luminous flux. Not until 1970 were lamps successfully forced into the horizontal position, albeit with a resulting reduction in lamp life, which is still the case today for some lamps. This burning position enabled the use of lighting systems with deep-dish elliptical reflectors such as were usual in the carbon arc era, which give an approximately 30% increase in utilization factor. Fig. 20 shows schematic diagrams of the two types of system.



20 Optical configuration of vertical and horizontal lamp housing for theatre projectors

From the functional point of view the most favorable burning position for XBO lamps is the **vertical burning position,** with the anode at the top. In this configuration everything is rotationally symmetrical. The electrons emitted by the cathode firstly take gas particles with them, and secondly the widening out of the hot arc causes a gas jet in the direction of the anode. With the anode at the top, the convection forces exerted on the arc act in the same direction. The result is an arc that burns extremely smoothly and is stabilized by both electromagnetic and thermodynamic forces alike.

If a lamp is mounted in the reverse position with the anode at the bottom, the gas jet and convection forces work against one another with the result that the arc fidgets and the lamp is unusable.

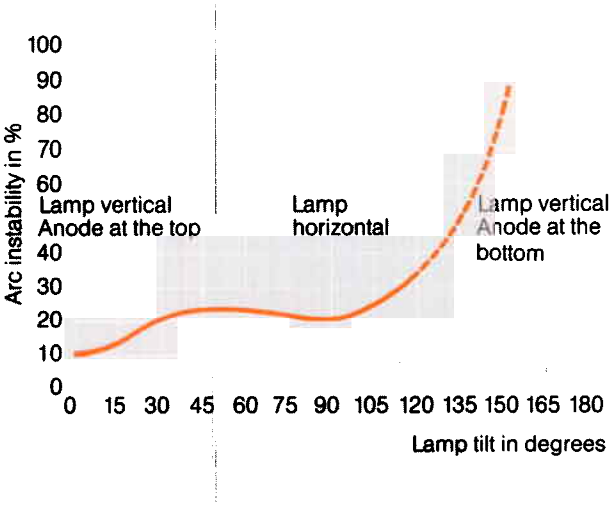
Clearly, any amount of inclination of the lamp will inevitably disturb the stabilizing symmetry. The greater the tilt, the greater the disturbance. The **permitted tilt** for lamps designed to be operated vertically is typically limited to ±30°.

In the **horizontal burning position,** the convection force acts perpendicularly to the direction of flow of the hot xenon gas; the gas is deflected upwards, half drifts past the anode and undulates about. This mode of operation was only made possible firstly by introducing magnetic arc stabilization and secondly by developing lamps with very short electrode gaps, high currents and a new bulb geometry.

The shorter the arc length for a given current, the more rigid is the arc and the less easily it can be deflected for example by convection. Altering the bulb geometry at the same time from a narrow oval to a wide-bellied shape enables the influence of the gas stream – which still drifts upwards despite the rigid arc – on the quartz walls to be controlled.

The performance of XBO lamps operated horizontally is nevertheless always worse than that of vertical lamps. The arc burns much less smoothly and the life of the electrodes is considerably reduced because of the off-center arc geometry which gives rise to wear on one side.

After the vertical burning position, the horizontal has the next greatest number of factors of symmetry. Deviations from the horizontal, especially **tilting** downwards, will result in markedly greater arc instability (see Fig. 21). Tilting the lamp with the anode at the bottom is the worst position. In this case, the convection forces act increasingly against the xenon gas jet and the instability of the are worsens dra-



21 Schematic diagram showing arc instability as a function of tilt in XBO lamps

matically. Where a fairly large degree of tilt downwards cannot be avoided, it is therefore necessary to consider turning the lamp round in the optical system so that the cathode is at the bottom. Depending on the layout of the optical system, this can sometimes result in a loss of usable light, but it also results in much better lamp behavior.

Every lamp designed for horizontal operation can also be operated vertically to advantage.

Magnetic arc stabilization

As described in the previous section, when lamps are operated horizontally thermal convection acts on the arc perpendicularly to its direction of flow. Depending on the rigidity of the arc it is deflected to a greater or lesser extent from the cathode-anode axis.

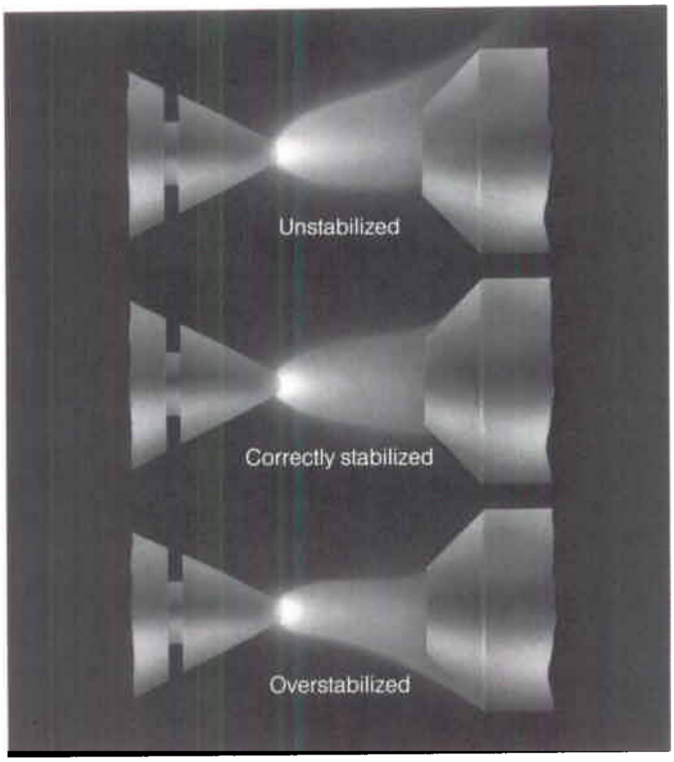
This deflection can be compensated for to a great extent by exploiting the fact that the gas stream is coupled to the electron flow. Electrons can be deflected by means of magnetic forces, so that a suitably installed magnetic field with a downward acting force component can almost completely eliminate the effect of convection.

The **size of the magnetic field** needed at the site of the arc is small and is only slightly greater than the magnetic field of the earth. In practice, this field can be generated with a small rod-shaped permanent magnet about 5 cm in length attached across the lamp axis if possible directly under the arc. Looking along the lamp from cathode to anode the north pole must be on the right; otherwise the arc would be pushed upwards. If the magnet cannot be mounted directly under the lamp due to lack of space, it can also be moved forwards or backwards relative to the lamp axis.

Mounting the magnet beneath the lamp has two advantages. Firstly it has been found that "pulling" the arc downwards gives more stable conditions than "pushing" it downwards. Secondly, heating of the magnet by the lamp can be better controlled. If the magnet reaches a temperature of about 600°C it can lose its magnetism.

It is essential to **adjust the magnetic field** to obtain correct compensation of the convection force. Its strength can be varied by altering the distance between magnet and arc; the nearer it is, the stronger the magnetic force. In some cases an active magnet – an iron core surrounded by a coil through which a current is passed – is used. In these the field strength can be changed very simply by adjusting the current. The most important factor in adjustment however is the ability to observe the shape and position of the arc.

A view of the horizontal position of the arc is the most important. A view from above is also advisable to be sure that the arc is not deflected across the axis by mistake because of a distorted magnetic field. It will generally be necessary to make suitable observation holes in the reflector and in the outer wall of the lamp housing.



22 Magnetic arc stabilization

Fig. 22 shows how the shape of the arc changes when the magnetic field is adjusted. The aim is to make the arc hit the front face of the anode centrally. Fig. 35 on page 38 shows a typically deformed anode with a nose-shaped growth such as can occur in long term operation without magnetic stabilization or with it incorrectly adjusted.

Magnetic stabilization is not required for some types of horizontal lamp with a stiff enough arc to ensure adequate lamp behavior throughout their life. Though the behavior of these lamps too can be further improved with optimally adjusted magnetic stabilization, in this case the principle that no magnetic stabilization is better than poorly adjusted stabilization applies.

Rotating lamps

There are two main disadvantages of operating XBO lamps horizontally: firstly, the electrodes are subjected to uneven load even with a rigid arc and excellent magnetic stabilization, and secondly vaporized electrode material is deposited in the bulb.

Loading the electrodes unevenly means incomplete utilization of their potential life.

Deposition in the bulb means that the tungsten vaporized from the electrodes does not accumulate in the 'dark' region behind the anode as it does to advantage in vertical operation, but – because of convection – above the anode in the belly of the bulb. There the dark accumulated material causes radiation to be absorbed (with consequent lessening of the light) and hence the quartz glass to be additionally heated.

For these two reasons it is recommended that these lamps be turned through 180° halfway through their life. The electrode material is then used from a new place, the bulb blackens in a place that was hitherto clear, and overheating is prevented.

Against this positive effect of turning the lamp is the fact that sometimes the arc burns much more unstably afterwards. This is mainly due to the fact that the arc root at the cathode tip is produced as before in the usual position where energy conditions are favorable, but this position is not the best from the point of view of convection. It usually takes a while for the arc to re-establish a stable root, and until this time the root of the arc can jump about noticeably. This period of instability can be reduced by operating the lamp at the current control range maximum, after which it will also burn stably at lower operating currents.

In the light of modern lamp technology the recommended turning operation must be considered more closely. Enormous advances in tungsten metallurgy have greatly improved the blackening behavior of present-day lamps compared with past ones. Severe bulb blackening normally does not occur until long past halfway through a lamp's life, which means that an important reason for turning the lamp about its axis no longer exists.

In recognition of this, the following **recommendation** is given:

To avoid a period of increased arc instability, a lamp should not be automatically turned halfway through its life but only when blackening is clearly evident in the upper part of the bulb. In many cases this will render turning the bulb halfway through its life unnecessary.

The practice operated by many users of turning the lamp not once through 180° but more frequently through a smaller angle such as 90° has met with success. This can sometimes prevent the period of arc instability that may result from turning the lamp. However, there is certainly no need to keep turning the lamp by a tiny amount after every few hours of operation.

Cooling

Some types of XBO lamp manage without forced cooling, especially when they are operated in large, open lamp housings and a chimney effect is achieved through good design. In other types of lamp however the output is so highly concentrated that forced cooling of the base connection parts and sometimes also of the quartz glass bulb is essential.

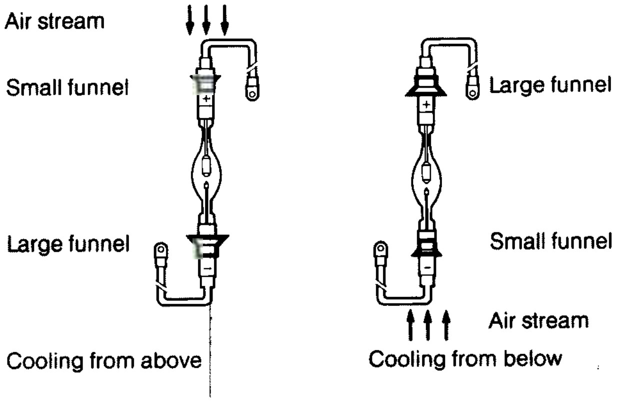
Cooling is done with air. The cooling air stream, generated with fans, should be as cylindrical as possible along the lamp axis. In horizontal theatre lamp housings in which the cathode end of the lamp is inserted into the reflector, the cooling air is normally blown from here towards the anode. Blowing is better than extraction because it is very simple to create an airstream with a defined flow. In vertical lamps, cooling from the hot anode end at the top is better overall as the bulb is cooled by air that has already been prewarmed, so reducing possible turbulence in the lamp's interior.

The first criterion of adequate cooling is **base temperature.** This must not exceed 230°C. The temperature is measured at the end of the base remote from the lamp. Stick-on temperature sensors or thermally sensitive paint can be used for measurement. The temperature limits must not be exceeded even in worst-case conditions such as high ambient temperature or contaminated filters in the cooling air stream. Sometimes a cooling air stream directed specifically at the base is useful, especially for the anode base which is particularly hot.

For those lamp types which require **bulb cooling,** the air speed at the lamp's equator 5 mm above the surface should be about 5–8 m/sec. This is measured with a commercially available anemometer. It is not advisable to measure the bulb temperature, firstly because at 600–900°C it is very high, and secondly because the lamp housing must be opened with the lamp lit to perform the measurement, which is at least potentially dangerous because of UV radiation and the risk of bursting. Blowing air on the bulb on one side only must be avoided because this generates additional stresses in the quartz glass and unbalances the inner convection symmetry, resulting in turbulence. The consequences of this would be an unstable arc and risk of bursting.

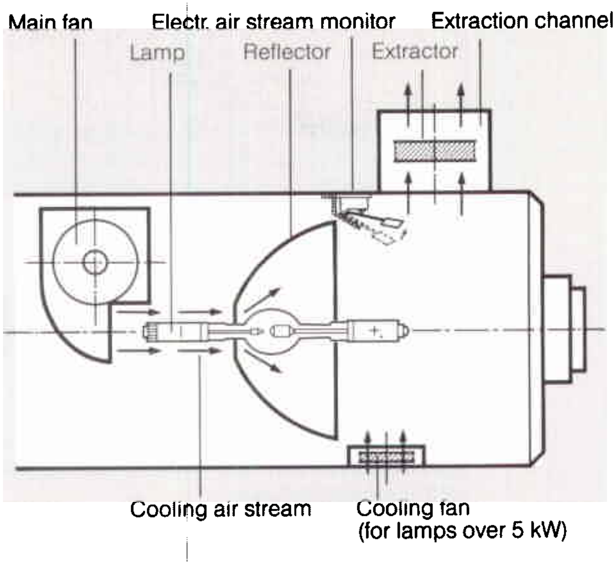
Excessive cooling is not good because it too can bring about increased arc instability due to turbulence in the lamp bulb. If the lamp voltage with cooling falls by more than 1 volt compared with uncooled operation, this normally means that cooling is excessive.

Some types of lamp are supplied with special **cooling air funnels** for the bases. These are designed to direct part of the air stream into the interior of the base. Care is needed to mount the funnels correctly, as this depends on the direction of the cooling air stream. Both the direction of the opening and the size of the two funnels must be carefully noted (see Fig. 23 on page 26).



23 Correct mounting of cooling air funnels with a cooling air stream from above or below

In addition to the internal cooling cycle, an adequately dimensioned external extraction system for the entire lamp housing has proved to be a good solution in many cases. Extraction of the air from the lamp housing into the open air is mandatory for non ozone-free lamps to protect against ozone damage. Fig. 24 is a schematic diagram depicting this arrangement.



24 Schematic cross-sectional sketch of a typical cooling system in a theatre lamp housing with internal fan and external extraction.

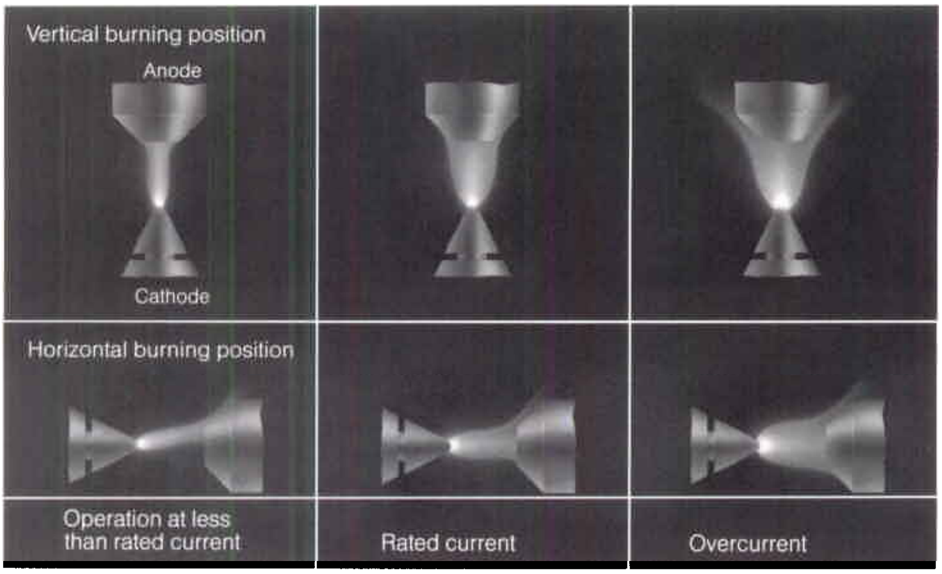
Current control range

By far the majority of XBO lamps have a current control range. This is a range round about the rated current in which the lamps may be operated in order to adapt to the individual requirements of the application. More current means more light, but also usually shorter life as a result of greater load on the electrodes.

The best results in terms of lamp life are usually obtained by operating the lamp initially at slightly less than its rated current and then taking it to the maximum by the end of its period of use. The main purpose of the current control range is to compensate for the slight loss of light due to blackening as the lamp ages. It is not advisable to operate lamps continuously at **minimum current.** The expected increase in lamp life often does not take place as the arc is constricted at the cathode, makes a small area hotter and so offsets possible gains in lamp life with increased blackening. If a lamp is operated at minimum wattage because it is too bright, it is usually advisable to use a lamp with the next lower wattage.

As a rule, it is also inadvisable to operate lamps continuously at **maximum current.** This always reduces lamp life compared with operation at the rated current. Where this type of operation cannot be avoided, users must also check whether a lamp with the next higher wattage would be worthwhile.

The current control range must not be confused with the **lower limit value** for the lamp current given in the data sheets. This only states the minimum level to which the current can be reduced for a brief period without the lamp going out. Lamps must not be operated continuously at such low currents, i.e. at less than the current control range minimum, otherwise severe electrode damage and short lamp life will result. If the operating current is too low the arc discharge becomes strangled, the root of the arc at the cathode becomes extremely constricted, and very heavy local overheating and hence erosion of the cathode tip take place.



25 Arc root and arc shape at less than rated current, rated current and overcurrent

Fig. 25 is a schematic diagram showing the change in **arc shape** and arc root at the cathode at different currents with the lamp operated vertically and horizontally.

There is frequently a requirement, during intervals for example, to operate a lamp with a **standby current** in order to economize on power, to reduce heating of the equipment, to avoid sound interferences during ignition and to increase lamp life.

Taking into account the above reasons, standby operation is basically useful provided the current is not reduced to below the current control range minimum. It is not advisable to operate a lamp at lower currents between the minimum current and the lower limit for a fairly long time, as in most cases negative effects on the electrodes would more than offset any hoped for advantage.

Operating duty cycle

XBO lamps have their highest life expectancy if once switched on they are not switched off again. Every additional startup, especially from cold, shortens lamp life. This is because in cold ignition – and in this context this means everything more than 5 to 10 seconds after switching off the lamp – the high startup current needed to set up an ignition path must be handled by the cathode in its cold state when its emission capability is very limited. This torture erodes the cathode tip (tungsten particles can be split off) thus altering its robust surface, and sudden local overheating can cause depletion of the doping material added to the tungsten in the cathode to improve its emission capability. At an impoverished cathode the arc wanders restlessly to and fro searching for the place where emission conditions are best, without ever finding it.

The **average life** specifications for high-wattage XBO lamps refer to a burning time of 90 minutes per switching operation, in accordance with typical operating times in modern theatres. If intervals are short (less than 20–30 minutes) it is advisable to leave the lamps burning, or to operate them in standby mode at the current control range minimum in cases where the lamp current can be adjusted. See the previous section for relevant information. This type of operation also has the advantage that the greater arc instability in the first minutes of operation of a still cold lamp does not occur, and that there is no possibility of ignition pulse interference in the sound equipment.

Lamp behavior

Lamp life

The average life of XBO lamps means the operating period after which half the lamps from a not too small number of a given type no longer have to comply with the specified data. For the lamps under consideration this means that they are allowed to show a **reduction in luminous flux** of 30% after this time.

It is assumed that the lamps are operated with the correct equipment (rectifier, igniter and lamp housing) and according to specification (current, burning position, switching cycle).

The main factors that reduce lamp life are:
- overcurrent
- undercurrent
- high operating duty cycle
- high inrush current
- high current ripple
- unfavorable burning position, tilt
- incorrect or inadequate magnetic arc stabilization
- inadequate cooling.

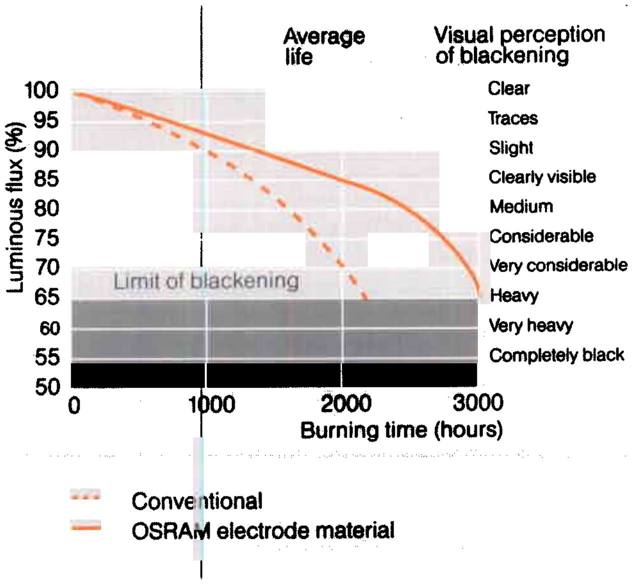
XBO lamps can normally be operated beyond the average hours burned, provided their light output is still sufficient for the application. They should however be replaced after exceeding this time by 25%. After this time, even if blackening is still at an acceptable level the quartz glass has usually recrystallized to such an extent that there is a considerably increased risk of bursting. Recrystallization means that the structure of the quartz glass changes from the glass phase into the crystalline phase under the influence of the high bulb temperature and the temperature cycle. This initially causes the quartz glass to lose its strength; at an advanced stage it also becomes opaque.

This factor is becoming increasingly important as a result of the fact that fundamental developments in tungsten metallurgy are suppressing blackening to an ever greater extent. See also the next section.

Blackening

An important factor that normally limits the life of XBO lamps is blackening of the lamp bulb. This is caused by tungsten gradually vaporizing from the electrodes and being deposited on the "cooler" bulb. The vaporized tungsten is deposited in the place to which it is carried by the internal gas flow. In vertical lamps this is usually the dark region behind the anode, which means that bulb blackening has virtually no effect on the luminous flux emitted by the lamp. The situation is different in horizontal lamps, where material vaporized from the electrodes is carried by the gas jet from cathode to anode and by the convection current directly to the upper part of the belly of the bulb.

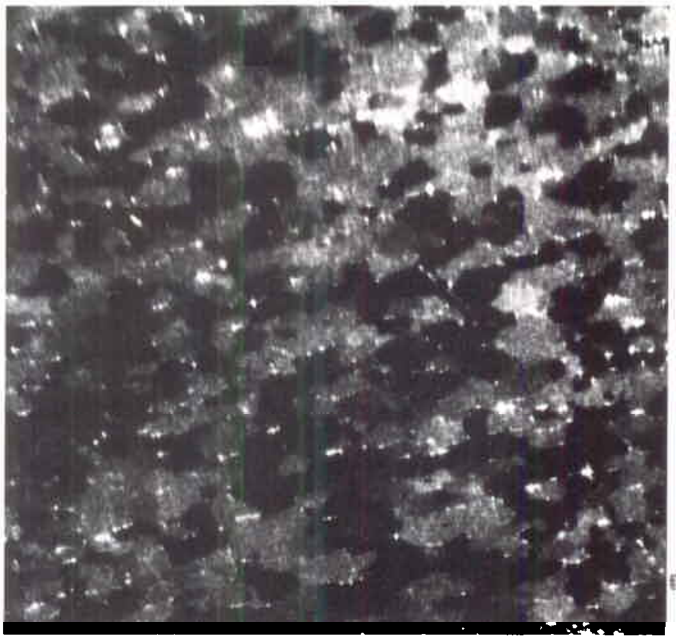
Blackening has the disadvantage that it **reduces light** and also increases the amount by which the quartz glass heats up due to the absorption of radiation.



26 Typical luminous flux curve as a function of burning time using different tungsten materials for the anode

As blackening increases, the **spectral characteristics** of the light also change slightly. Thin layers of tungsten mainly absorb UV radiation and the blue region of the spectrum, so that the light from blackening lamps becomes increasingly more yellowish.

As blackening originates from the electrodes, their characteristics and condition are crucially important. Electrode life, especially the life of the anode, has been considerably improved by OSRAM in recent years by fundamental developments in metallurgy. Fig. 26 shows an example of what has been achieved. The main key to this, besides the composition and density of the material, is control of the **structure of tungsten metal.** The size, shape and orientation of the microscopically small crystallites determine the macroscopic behavior of an anode during its life (see Fig. 27). A geometry that stays the same ensures little blackening.



27 Grain structure of the tungsten material near the surface of an anode

Within the framework of a 30% drop in luminous flux by the end of average lamp life, it is normal for the lamp bulb to blacken initially very slowly and then more rapidly.

Sudden **complete blackening** of the bulb, sometimes accompanied by deep blue or light yellow coatings, is a fault and indicates that air has penetrated the lamp. Another cause of immediate blackening can be incorrect polarity. In this case the narrow cathode takes the thermal load of the anode; within seconds its tip melts to a round shape (see Fig. 34 on page 35), the vaporization products are on the bulb wall and the lamp has become irreversibly unusable.

The speed at which normal blackening takes place depends on a large number of factors. The process is accelerated by the following operating parameters:

Overcurrent: this makes the anode and cathode hotter and causes them to vaporize more quickly. In severe cases the electrode surface may erode, causing heavy local overheating which further accelerates the blackening process.

Undercurrent: this causes the arc to constrict at the cathode tip, resulting in local overheating of the cathode surface and consequently increased vaporization.

Residual lamp current ripple: the higher this is, the more rapidly the cathode surface becomes fissured and the front face of the anode deformed. The arc then prefers to start at the peaks and highest points, which become especially hot because of reduced heat conduction in the electrode body. In severe cases a lake of tungsten may even form. Excessive residual ripple is the main factor in fissuring of electrodes.

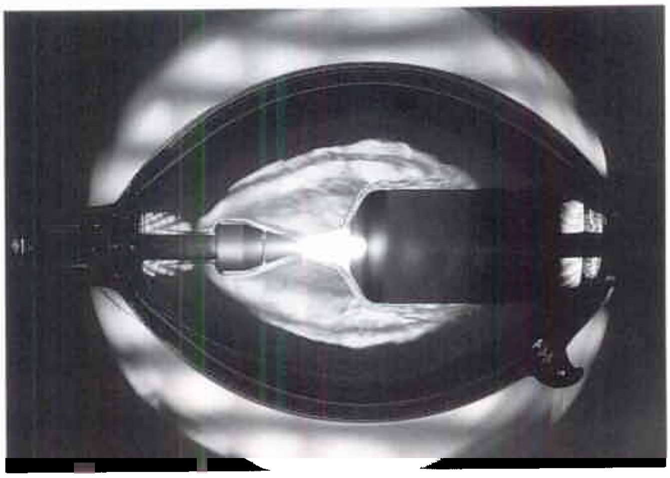
Peak inrush current: when the lamp is ignited the cathode, still in its cold state and reluctant to emit electrons, has to deliver the high inrush current. Especially if this is above the permitted level (see section on "Electrical characteristics – Startup" on page 16), it only manages this by spattering and sudden local overheating.

Switching cycle: the more frequently the lamp is switched on and off, the more frequently it must go through its startup cycle; see previous paragraph.

Arc stability and flicker

The discharge arc in XBO lamps is mainly electrode-stabilized. This means that its position and shape are substantially determined by the position and geometry of the anode and cathode. Added to this static mechanical fixing is intrinsic stabilization by electromagnetic and dynamic gas forces. The electron stream produces a force acting in the direction of its axis, and the thermodynamic forces of the hot gas jet in the surrounding cooler xenon gas act in the same way. Taken in their entirety, these phenomena make XBO discharge lamps burn very stably and are the main reasons why they are used as light sources in projection systems.

Nevertheless, the arc is not completely stationary. The tail of the arc in particular is subject to slight fluctuations caused for example by gas turbulence in the lamp (see Fig. 28). Emission conditions at the cathode tip can also change resulting in the root of the arc moving.



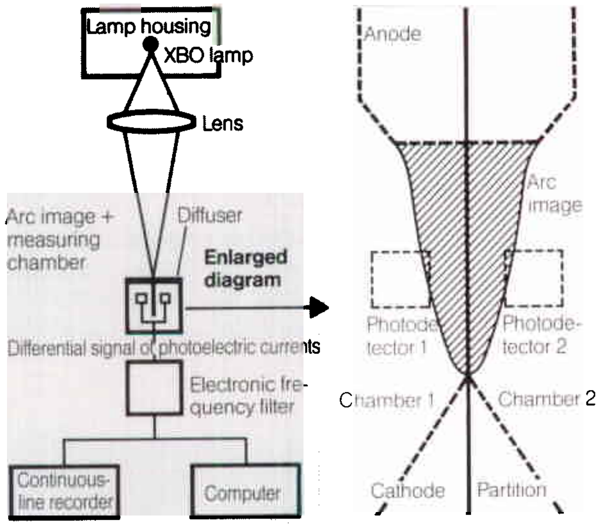
28 Schlieren photograph of the gas stream in a burning lamp

A definition or method of measurement is necessary to assess arc stability or instability.

Two-chamber brilliance method:

An image of the arc is projected through a lens onto two photodetectors separated optically from each other by an opaque partition (see Fig. 29). The differential signal is analyzed electrically. To start the measurement the differential signal is zeroed by adjusting the image through the two chambers; this means that each photodiode sees exactly half of the arc, divided along its axis. If the arc moves at the cathode tip or its tail wanders during the measuring time, a signal not equal to zero is produced because one photocell chamber is receiving more light than the other. To determine arc instability quantitatively, the maximum measured signal is related to the signal that occurs when a complete image of the arc is projected onto a single photodiode. This method enables highly reproducible determination of spatial arc stability. It has the advantage that luminous flux or brilliance fluctuations of electrical origin – caused for example by current ripple from the rectifier – do not affect the result. The top diagram in Fig. 30 shows the actual course of arc deflections over time, the bottom diagram the change in arc instability (within a fixed interval) during the hours burned and a statistical evaluation of the same.

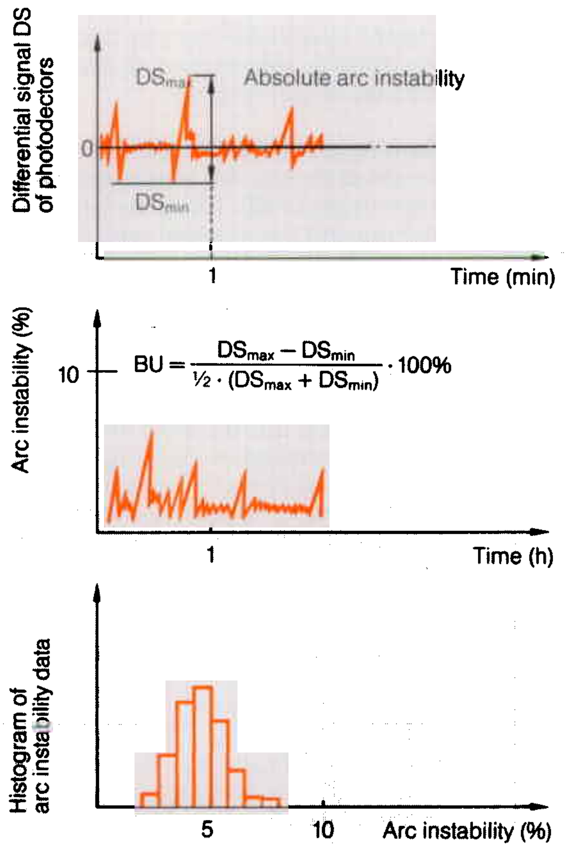
As well as this very expensive measurement procedure, other less expensive methods have been documented, such as measuring the fluctuation over time of the luminous intensity or of the hot spot (the area of maximum brilliance in front of the cathode).



29 Schematic diagram of the two-chamber brilliance method of measuring arc instability

All the methods however have the flaw that the particular arc instability being measured may not necessarily be crucial to the application. Practically all XBO lamps are used in optical systems (projectors or spotlights or light guides), and all optical systems respond differently to the different components of arc instability, irrespective of individual lamp adjustment. General statements can however only be made on the basis of a standard measuring method.

To analyze the effects of arc instability, cathodic and anodic instability must be separated. **Cathodic instability** is present if the arc root is not stationary at the cathode tip but wanders, jumps or changes its shape. This type of instability is mainly determined by the condition of the cathode material and its surface. **Anodic instability** is caused by the tail of the arc fluttering; it is mainly a function of gas flow and turbulence, but is also affected by the geometry of the front face of the anode.



30 Analysis of an arc instability measurement. Top: change in arc deflection over time (arc instability plot). Middle: arc instability over time (within a measurement interval). Bottom: statistical analysis of arc instability over long periods

Lamp-related arc instability is affected by the following factors:

Lamp current: the higher the lamp current, the more rigid and stable the arc, and the softer and larger the root of the arc at the cathode. The lower the current, the more constricted the arc root at the cathode; local overheating occurs, causing local partial depletion of emitter material and fissuring of the surface. The result is that the arc jumps about restlessly, trying to find the best emission conditions. Fig. 25 on page 27 shows arc shape as a function of lamp current.

Residual lamp current ripple: this is an effect over time. High residual ripple leads to fissuring of the cathode tip (see Fig. 31) and, if it continues, also to distortion of the anode surface. Excessive ripple values can be regarded as the most important cause of inadequate arc stability.

31 Fissuring of the cathode tip as a result of excessive current ripple

Inrush current: excessive inrush current peaks combined with frequent switching of the lamp erode the cathode tip, with consequent cathodic arc instability.

Bulb cooling: excessive forced bulb cooling increases the temperature gradient between arc and bulb wall, resulting in greater radial gas flow and turbulence which mainly affect the tail of the arc.

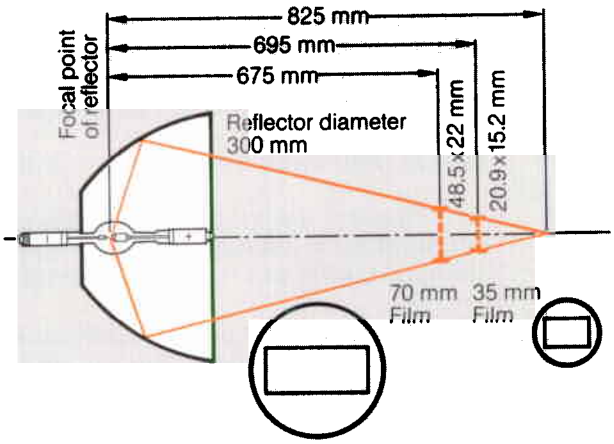
Start-up timetime: increased arc instability is observed shortly after igniting the lamp, when all the components except for the arc are still cold. This is mainly caused by turbulence in the anodic region, but also in the cathodic region before the cathode has reached its operating temperature. This effect passes after a few minutes of burn-in time.

Burning position: the optimum burning position for arc stability is vertical with the anode at the top. Arc instability increases with tilt (some lamps have a level maximum at about 45). Tilting the lamp further beyond the horizontal so that the anode is more and more underneath increases arc instability dramatically (see Fig. 21 on page 23).

Lamp life: even under optimum operating conditions, the cathode and anode geometry and structure undergo changes that lead to a gradual increase in arc instability.

In contrast to arc instability which is determined by the lamp, **flicker** is defined as a sudden change in useful light over time, occurring in the application. In theatre projection systems for example it would be instability of the light reflected from the theatre screen. As has been described above, different optical systems respond with greatly differing sensitivity to existing arc instability. Measures taken by users can often magnify or reduce this application-related instability. We shall take a look at two examples:

Defocussing: most optical systems for XBO lamps use the stable maximum brilliance in front of the cathode. Light from the relatively unstable tail of the arc usually contributes very little to the useful luminous flux (see also Brilliance distribution in the arc, Fig. 7, page 10). If however the optical system is defocussed so that the useful luminous flux also – or mainly – comes from the tail of the arc, flicker may result. This often occurs in theatre projection systems when there is a change of format (see Fig. 32). When changing from standard format to Cinemascope, or another large film gate, the correct procedure is to change the mounting distance,



32 Diagram showing correct adjustment of a theatre lamp housing for minimum screen flicker when changing format. The lamp itself only needs minimal adjustment.

i.e. the distance from reflector to picture gate. If instead the easier option of only readjusting the lamp in the reflector is taken, it is still possible to illuminate the larger format adequately, but then areas of the arc remote from the cathode form part of the useful luminous flux, resulting in increased flicker.

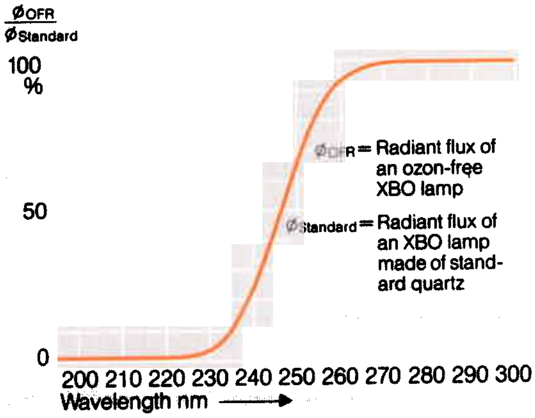
Burn-in time: shortly after XBO lamps have been ignited, they undergo a period of increased arc instability because of the as yet unstable thermal balance. This period passes in a few minutes. Flicker effects can often be eliminated by allowing a short burn-in period before the actual period of use.

Generation of ozone

An electric discharge in xenon gas generates a spectrum ranging from about 140 nm in the UV region to far into the infrared region. If the quartz glass bulb is transparent between at least 180 and 220 nm in the UV region, this radiation converts a small proportion of the atmospheric oxygen (O_2) into ozone (O_3). Ozone is itself a colorless, odorless gas (what you can smell are the reaction products of ozone as its attacks air-borne pollutants and nitrogen compounds); it is extremely aggressive and will damage your lungs if inhaled at relatively high concentrations over a long period of time.

Ozone emission can be suppressed by using quartz glass which absorbs radiation in the relevant UV region. The result is "ozone-free" lamps, which have the letters **"OFR"** added to their lamp designation. The quartz glass used is either bulk doped or suitably coated. See the UV radiation output in Fig. 33.

Occasionally, even ozone-free lamps give off an "ozone scent" shortly after ignition. This has two possible causes: the ozone is produced either as a result of the (temporary) radiation of the spark gap used for ignition, or from the fact that when the quartz bulb is in the cold state the absorption edge can shift and small amounts of ozone-producing radiation can leave the bulb. Both effects cease once the lamp has started up and are cause of no significance.



33 Comparison of normalized UV radiation output from XBO lamps made of standard quartz and ozone-free quartz. Radiation below about 230 nm is cut off.

Handling

Mechanical installation

XBO lamps are extremely robust. They must withstand the mechanical stresses exerted by their heavy electrodes, especially the anode which can weigh up to 400 g, and the high internal pressure of up to 30 bar, or even more in low-wattage lamps. But they are still made of glass and need to be handled accordingly; in other words they must be protected against shock, impact and excessive force.

Certain precautions must therefore be observed when handling them.

All XBO lamps are supplied in a **safety cover.** This protects users from possible spontaneous or induced bursting of the lamp. There is enough energy stored in the lamp bulb to send quartz splinters flying several meters across a room.

When the lamp is installed, its safety cover must not be removed until after it has been fitted in the lamp housing and shortly before the housing is closed. It goes without saying that you should wear leather gauntlets and protective goggles or complete face protection covering the arteries and veins of your neck, such as a transparent plastic mask.

If the design of the lamp housing does not permit the lamp to be fitted together with its safety cover, it should be wrapped in strong cloth.

In some types of lamp the safety cover acts a tool for screwing the lamp into its holder at the cathode end.

Under no circumstances must force be exerted on the lamp during installation. For example, screwing in the cathode base by holding and turning the lamp at its anode base is grossly negligent.

The lamp may only be clamped in position at one end, in order to allow for expansion and distortion of the housing. Small (short) lamps can be left free and unsupported at the other end. Larger (longer) lamps must have a soft, flexible support, which calls for a mechanical solution. It should support the lamp but allow unrestricted expansion, including expansion perpendicular to the lamp axis.

Lamps may only be stored if suspended freely from their bases in their (open) safety covers. Leaving them to roll around unprotected on a desk or shelf can result in microcracks in the surface of the quartz glass, and burst lamps later on.

If the lamp is inadvertently operated inside its safety cover, the sleeve will melt within a few seconds and the lamp will be unusable.

When removing lamps, the reverse procedure must be followed: first put the safety cover round the lamp, then remove the lamp.

Electrical connection

Similar precautions must be observed for connecting XBO lamps electrically as for handling them mechanically.

Lamps without a cable connection often have their "loose" end connected to the supply unit with a gripping device. In these cases the gripping device must be fastened first and only then can the lamp be fixed in its permanent connection, even if this is somewhat complicated. Otherwise there is a risk of unintentionally exerting strong bending forces on the lamp under which it may break.

The lamp must be connected electrically by means of the base components provided for this purpose, for example the base pins or cables. Under no circumstances must the cable be cut and the power supply connection passed through the base sleeve. This can result in an impermissible circuit and possible destruction of the lamp.

All electrical connections must fulfil the criteria for high-current connections. Connecting components must be clean and offer the maximum contact area. In cases of doubt, it is better to recondition or preferably replace the contacts rather than risk lamp failure due to corroded and overheated contacts. In most cases good electrical contact is synonymous with good thermal contact to dissipate the heat produced by the lamp. Nickel or chrome-plated brass or bronze are the main materials used; other metals such as aluminum are unsuitable.

Care must be taken to ensure that the lamp is connected with correct polarity; the positive pole of the rectifier must be connected to the base marked "+", the negative pole to the base marked "-". Incorrect polarity results in total lamp failure within a few seconds; the cathode fuses over immediately as a result of being overloaded as the anode.

34 Ball-shaped fusing of the cathode in consequence of brief incorrect polarity.

The relevant insulation gaps must be observed when installing the parts that conduct high voltage from the igniter to the lamp (protection against flashover and capacitive RF losses against ground).

Cleaning lamps

XBO lamps may only be held by the base. If the quartz bulb or the shafts should ever be inadvertently touched with bare fingers (which should never happen because unprotected lamps should only ever be handled with leather gloves), the fingerprints must be removed immediately. A lint-free cloth moistened with spirit is best for this, after which the lamp should be rubbed dry, taking care not to scratch the quartz glass surface. Damage to the glass may cause the lamp to break during later operation.

If fingerprints are not removed they burn into the quartz glass surface where they act as a seed for ever-expanding recrystallization of the glass. This causes the glass to lose its strength and increases the risk of bursting.

Transport

XBO lamps are supplied packed in printed cardboard boxes for shelf storage and in an outer transport packaging. Inside the transport packaging the shelf packaging is freely suspended and mechanically cushioned; in this condition lamps can be sent through the post without any problem. The cushioning is cleverly designed so that the lamps cannot be damaged even by severe transport conditions and mechanical vibration.

Most lamps will break if transported in the shelf packaging only. Even immersing the boxes in a sea of styropor chips is no gurantee of success.

XBO lamps withstand the vagaries of transport best if they are sent individually in vertical position. Their resistance to sudden shock is about ten times greater along the lamp axis than perpendicularly to it.

If XBO lamp housings have to be transported, the lamps – especially high-wattage lamps – should be removed and transported separately in their original packaging.

Storage

XBO lamps can be stored indefinitely, as far as can be determined for a product only 35 years on the market. The ambient conditions must however be non-aggressive, for example, no storage temperatures over 50°C, no condensation, and a non-corrosive atmosphere. In these circumstances the material properties of quartz glass and tungsten change so slowly that no ageing effects are evident. Where storage effects do occur they usually affect external lamp parts such as the interiors of bases, the bases themselves and the power leads.

Disposal

Burnt-out XBO lamps can either be returned to the manufacturer for appropriate disposal by methods consistent with modern recycling, if possible in the original transport packaging or in that of the replacement lamp, or they can be destroyed by the user.

To do this, lamps must be wrapped in strong, coarse cloth, observing all the precautions given in the section on "Mechanical installation" on page 34, and broken with a hammer. The xenon gas that escapes is not poisonous and returns to the atmosphere from where it came. The remains of the lamp can be disposed of as rubbish and the electrodes and rods (i.e. tungsten material) sent for recycling.

Problems – trouble-shooting – tips

Lamp does not ignite

The following parameters are important for igniting XBO lamps:

- Level of high voltage applied by the igniter
- Number of ignition pulses per unit time
- Energy contained in an ignition pulse
- Level of rectifier open circuit voltage

If the lamp ignites poorly or not at all the following checks should be carried out:

- Is the ignition spark gap operating (auditory and visual check)?
- Is the electrode gap in the spark gap correct?
- Is the high voltage in the path from the igniter to the lamp lost through partial discharge?
- Is the lead between igniter and lamp as short as possible to prevent capacitive losses?
- Does the auxiliary ignition capacitor still have its specified capacitance (ageing)?
- Is the series resistance in series with the auxiliary ignition capacitor correctly dimensioned?
- Is the ignition wire correctly attached?
- Does the rectifier deliver the minimum supply voltage?
- Has the lamp reached the end of its life?
- Is a lamp fitted?
- Is the power lead interrupted?

Flicker

Flickering of the useful light may result from a faulty lamp, unsuitable operating equipment or impermissible operating mode. Please read the section on "Lamp behavior – Arc stability and flicker" on page 30.

If flicker effects are observed after installing a new lamp, the following must be checked:

- Has the lamp burned in for long enough to obtain thermal stabilization (5–10 minutes)?
- Is the lamp being operated at the correct rated current?
- If a magnet is used to stabilize the arc, is it correctly set (visual check in two planes)?
- Is the correct type of lamp for the lamp housing being used?
- Is the lamp correctly adjusted in the optical system (in the reflector)?
- Is the distance between reflector and picture gate suitable for the film format? (see Fig. 32, page 33).

If flicker effects are observed during the course of a lamp's life, the following must be checked:

- Is the cathode tip fissured and have growths developed on the anode?
  - If yes:
  - Does the current ripple comply with requirements?
  - Is the maximum inrush current peak observed?
  - Is the magnetic arc stabilization system (if specified and used) correctly set up?
  - Is the lamp being operated in a permitted burning position?
  - Is the lamp being operated inside the permitted current control range?
  - Is the lamp being too heavily or asymmetrically cooled?

- Has the lamp just been turned halfway through its life?
  - If yes: operate the lamp for 30 minutes to 2 hours at the permitted maximum current to reform the cathode root

- Is the lamp correctly adjusted in the optical system (in the reflector)?
- Is the distance between reflector and picture gate suitable for the film format? (see Fig. 32, page 33).

Short lamp life

XBO lamps normally reach the end of their life when the luminous flux drops as a result of the lamp bulb blackening. If bulb blackening starts sooner than is allowed, see the section on "Blackening", page 28. Less frequently, a lamp ends its life due to flicker (see page 30) or non-ignition. An exploding lamp is rarer still. In all cases of short life the electrical data of the operating equipment and the operating conditions of the lamp must be carefully checked before a new lamp is fitted.

Incorrect polarity

XBO lamps are purely direct-current lamps. This means among other things that the cathode and anode are specifically designed for their particular tasks. Because of this specialization, the lamps may not be operated with reversed polarity. If this should inadvertently occur, the cathode becomes fused over within a few seconds (see Fig. 34, page 35) and the emitter vaporizes, making the lamp unusable. Lamps connected with incorrect polarity usually go out by themselves after ignition.

Deformed electrodes

The material structure and the shape of XBO lamp electrodes are carefully suited to their respective tasks. During the course of a lamp's life changes varying from slight to clearly visible occur in the electrode surfaces and geometry, even if the lamp has been correctly operated throughout.

Large changes are frequently a symptom of faults, either in the electrode material (extremely rare), in the mode of operation (rare) or in the electrical operating conditions (frequent). Experienced technicians can obtain important information about the causes of faults from the type and extent of the changes.

A spherical cathode tip (Fig. 34, page 35) is easy to diagnose as incorrect polarity.

Fig. 31, page 32 shows a cathode tip fissured as a result of increased current ripple.

Fig. 35 shows the front face of an anode the growth on which was caused by a lop-sided arc in horizontal operation (incorrect magnetic stabilization).

35 Nose-shaped growth on the front face of an anode

Burst lamp

XBO lamps are made of quartz glass and have a high internal pressure (about 30 bar in operation). However they are very safe and burst lamps are rare. Usually a burst lamp is preceded by damage to the lamp.

Possible reasons for a burst lamp:

- Lamp life exceeded by more than 25 %; advancing recrystallization weakens the mechanical strength of the quartz glass.
- Scratches on the outer skin of the quartz glass due to inappropriate handling (rolling around on a bench/shelf)
- Microscopic cracks caused by very dusty cooling air.
- Recrystallization on the surface of the quartz glass bulb caused by fingerprints which have not been removed and so have burned in.
- Excessive wattage, overcurrent. The higher the wattage input, the greater the internal pressure.
- Blackening. This causes a large part of the radiation from the lamp to be absorbed by the quartz, resulting in a rise in temperature and pressure which can lead to bursting. See page 28 ff for the causes of blackening.

Discoloration of base, cable and cable lugs

XBO lamps produce an extremely high concentration of electrical power, converting up to 10,000 watts in the small space contained by a lamp bulb. Most of the electrical power must be dissipated as heat by convection and radiation. Thermal blockages and excessive temperatures must be avoided.

The base temperature is a good indicator of correct thermal balance in the lamp (see section on "Operating parameters – Cooling" on page 25). If the upper limit of 230°C is exceeded the bases discolor light yellow if the temperature is only exceeded a little, then straw yellow, yellow-orange, brown and blue.

If lamps with bases like these are found, the lamp's cooling system must first be checked.

The electrical connections must then be checked. These sometimes include the cables screwed into the bases. Loose screw contacts both give poor thermal contact resulting in insufficient thermal dissipation via the connecting cable, and also act as an additional heat source because of the increased contact resistance due to faulty electrical contact. Arcing spots and then rampant overheating are the consequence.

The adjustment of the lamp in its housing (its projector) may also have to be checked. If the optical components such as the deep-dish reflector are focusing the light on a base, this can also result in overheating.

Rarely, the various electrical connections inside the base between the electrode rod and the base are responsible for overheating.

The cause of a discolored base must always be ascertained before a new lamp is fitted.

If the cable lugs of a lamp have turned blue or started to tarnish, the cause is always a loose electrical contact.

Not enough light

During the course of an XBO lamp's life, the luminous flux is allowed to decrease by 30%. (This is the definition of lamp life for XBO lamps.) If the decrease is fairly severe or rapid, the following must be checked:

- Has the lamp noticeably blackened?
  - ▶ If yes: check the electrical data of the rectifier and the igniter.
  - ▶ Has the lamp been operated at overcurrent (overload)?
- Is the lamp being operated at the correct current?
- Has the electrode gap been noticeably reduced due to growth on the anode?
  - ▶ If yes, the lamp voltage is reduced and the lamp is consuming too little power. The reasons for the electrode growth must be elicited (see "Flicker", page 37).
- Is the lamp bulb contaminated on the outside by a dirty atmosphere?
- Is the optical system (reflector, lenses) contaminated?
- Is the optical adjustment of the lamp correct?

Uneven illumination

This fault occurs in slide and film projection. Uneven illumination of the screen (dark center or corners) is usually attributable to imperfect adjustment of the lamp in the optical system (the reflector) or to an incorrect mounting distance (distance between reflector and picture gate).

Occasionally a lamp blackened on one side in horizontal operation is responsible; this is usually recognizable from the patchy illumination. In these cases the lamp should have been turned sooner through 180° (see section on "Operating parameters – Rotating lamps", page 24). If blackening has occurred too soon the equipment settings and the operating parameters must be checked (see "Blackening", page 28).

Shrinking lamp

In the past there have been one or two cases of lamps becoming shorter during operation in the vertical burning position. This remarkable phenomenon was attributed to the effect of very slight but continuous vibration from for example a powerful fan, which caused the attachment of the lamp shaft in the lower base to loosen slightly and the lamp to slide little by little into the base. This type of shrinking lamp could be repaired. The lamp housing should also be checked for abnormally high vibration levels.

Continuous burning

XBO lamps that do not go out even after the power supply plug has been withdrawn are extremely rare. It is more frequent for the average lamp life to be exceeded by considerable amounts. Care is recommended in all cases where 25% of the average lamp life is exceeded, as the possibility of bursting due to recrystallization of the quartz glass is significantly increased. **Lamp life records** are not risk free!

Safety

Pressure

Even when cold, XBO lamps have a high internal pressure (of about 8 bar), and this rises to about 30 bar in operation. This means that burst lamps cannot be ruled out.

XBO lamps must therefore always be handled in their safety cover.

Whenever work is carried out on XBO lamps, leather gauntlets that effectively cover the arteries in the wrist, and safety goggles or better protective masks that protect the arteries in the neck, must be worn.

Brilliance

XBO lamps are nearly ideal point sources of light. The brilliance of the arc can exceed that of the sun.

If the arc is viewed directly with the naked eye this can severely damage the retina.

Housings must therefore be designed to prevent the discharge arc from being viewed directly.

UV radiation

Besides visible and infrared radiation, XBO lamps emit nearly 6 % of the power they consume in the UV region below 380 nm.

This radiation is harmful to health and can burn the skin (erythema) and damage the eyes (e.g. conjunctivitis).

Unprotected use of XBO lamps is therefore not permitted. Lamp housings must be designed so that neither direct radiation from the arc nor scattered radiation can emerge unfiltered.

In appliances such as solar simulation equipment designed to utilize the UV radiation, the owner is responsible for protecting the operating personnel from UV radiation – and also from glare, see above – by means of suitable measures specific to the purpose.

Generation of ozone

A few types of XBO lamp generate ozone during operation (see section on "Lamp behavior – Ozone generation", page 33). These are mainly types of lamp that are also used for solar simulation. They can be recognized from the fact that the letters "OFR" are not included in the lamp designation.

With these types of lamp, damage to human health must be prevented by suitably extracting the air from the lamp housing and/or the operating room into the open air. Under no circumstances may the current **maximum workplace concentration** values be exceeded.

Index

Further reading

The following OSRAM publications and technical documents contain further information:

- Lighting Program Photo Optics
- Requirements for controlled power supply units for XBO short-arc xenon dc lamps
- Requirements for igniters for XBO short-arc xenon lamps
- Notes on designing lamp housings and luminaires for XBO short-arc xenon lamps
- Various technical information sheets on selected topics

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