TEMPERATURE PROFILES OF THE ELECTRODES OF SINGLE ENDED METAL HALIDE DISCHARGE LAMPS

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SUMMARY

The temperature profiles of electrodes in discharge lamps are important as they radically affect the fundamental chemical and physical transport processes within the lamp which have a direct influence on many important factors of lamp performance such as life, efficiency and lumen maintenance. In the past a number of investigations have been made into various aspects of electrode performance and, in particular, their temperature profiles but none have looked specifically at single ended discharge lamps.

The first objective of this investigation was to establish a reliable method of measuring lamp electrode temperatures and to this end a number of methods were reviewed and after some trials a technique utilising a disappearing filament pyrometer was decided upon. Having established a suitable measurement technique a number of electrodes were measured of several lamp types under various operating conditions both with alternating and direct current.

Having obtained a number of measured temperature profiles for various lamps, the second aim of the investigation was to develop a mathematical model to explain the measured physical results. To achieve this a solution to the second order differential equation describing heat flow along the electrode with radial radiation losses is sought. The solution is accomplished by making some basic assumptions regarding the conditions existing in the system. The solution obtained gives good agreement with measured temperature profiles and can also be used to obtain a value for power losses to the electrodes and relationships are established between the electrode power loss and lamp operating current and the electrode power loss and the electrode radius. The limitations of both the measurement technique and the presented model are discussed and suggestions as to where future work may improve and extend the investigation are presented.

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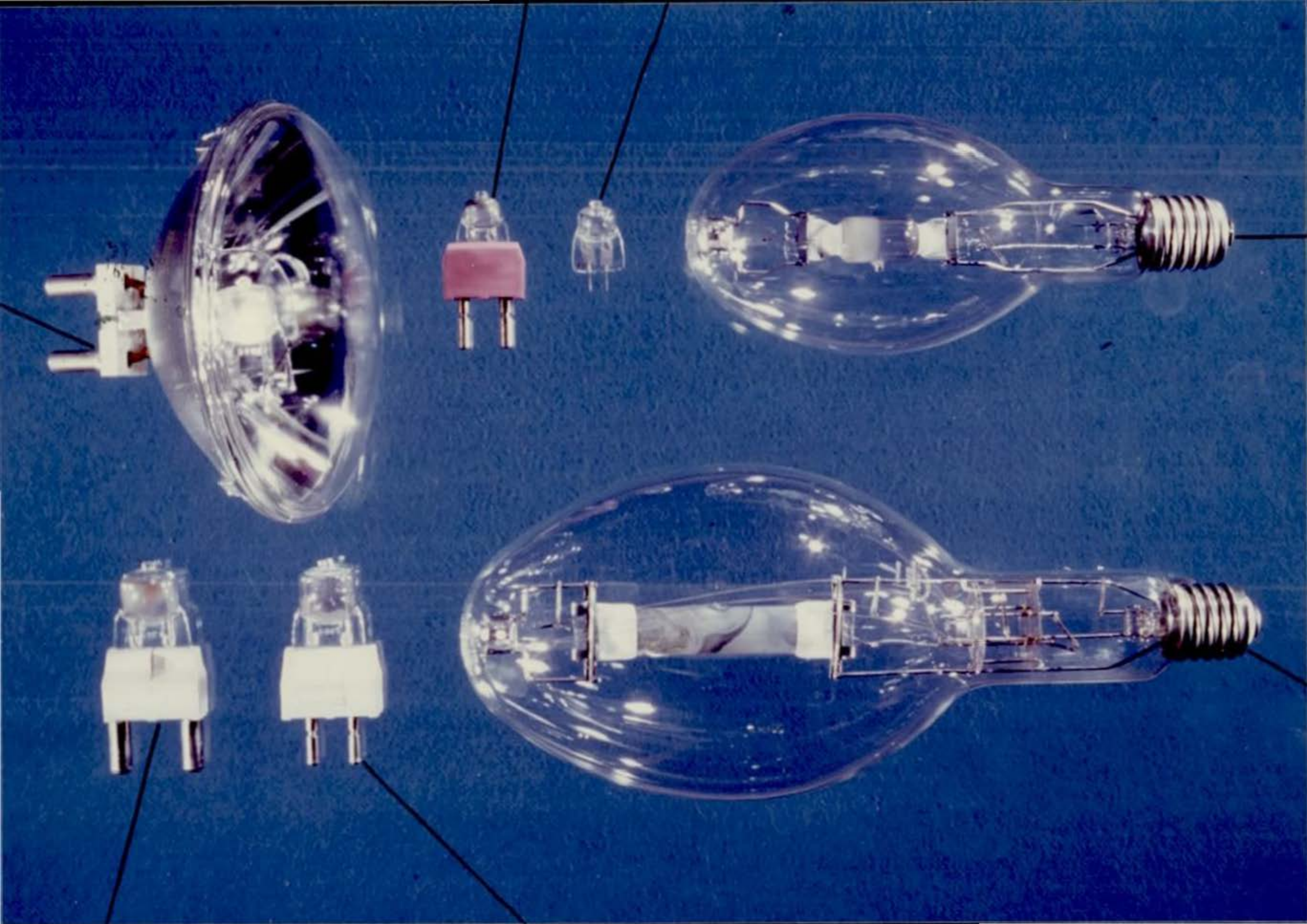
1. INTRODUCTION

1.1 The Lamps

The lamps, the electrodes of which form the subject of this investigation, are a range of single ended metal halide discharge lamps manufactured by THORN EMI Lighting which are known commercially as CSI and CID lamps.

CSI (Compact Source Iodide) lamps were first developed in 1969 in an attempt to utilise the high efficacies (80 - 100 lumens/watt) and good colour properties which were associated with the traditional larger double ended metal halide discharge lamps while being small enough to be compatible with the types of optical systems necessary for efficient use in projection, floodlighting and spotlighting applications. Commercial literature giving details of the CSI lamps are included in Appendix 1.

Figure 1 shows the range of CSI lamps which contains two ratings. The 400W which is available as an uncapped arc tube or as a capped lamp and the 1000 watt which has a capped and a sealed beam version. Both constructions of the 1000 watt lamp are available in two forms one known as the cold start which like most discharge lamps when extinguished cannot be restarted for several minutes and the hot restart version which after extinction can be instantly restarted. These differences do not affect this investigation as both versions utilise the same arc tube construction. Figure 1 also shows, for comparison, the more traditional double ended type of metal halide Kolorarc lamps of 400 watt and 1000 watt ratings and illustrates how the size of the CSI lamps have been significantly reduced and consequently the loading of the lamp increased.



400w CSI, capped/uncapped

1Kw CSI
sealed beam

400w Kolorarc
lamp

1000w Kolorarc
lamp

1Kw CSI Capped version

hot restrike

cold start

Figure 1. Range of CSI lamps with traditional metal halide lamps

The metal halide filling used in CSI lamps is a mixture of mercury and the iodides of sodium, gallium and thallium. The resultant spectrum is shown in Figure 2 and it can be seen that output in the visible region has a substantial background continuum with a line spectrum superimposed on this continuum. Figure 2 also shows that the CSI lamps emit a significant proportion of their radiation in the ultra-violet and infra-red regions of the spectrum.

The CID (Compact Iodide Daylight) range of lamps were developed as an extension of the CSI range and were produced in response to a demand from the TV and film industries for a discharge light source which simulates natural daylight having a correlated colour temperature of 5500^{o}K. In the 1kW rating the CID and CSI lamps are physically identical but contain different composition of components. The 1kW CID is available in the same embodiments as the CSI and the rest of the range consists of a 200W capped lamp, a 500W which can be a capped version or a sealed beam and a 2.5kW which is available only as a capped lamp. All of these lamps are of the hot restrike type and no cold start option is available. Figure 3 shows the full range of CID lamps and commercial literature (for the range) is included in Appendix 1. The metal halide fill used for CID lamps is a combination of mercury and the chloride, bromide and iodide of tin and in some ratings indium is also added to modify the spectrum of the resultant discharge.

A typical CID lamp spectrum is shown in Figure 4 showing the difference in spectral output from the CSI of Figure 2. In addition to the colour of the light output from a CID lamp closely matching natural daylight the use of the tin halide system gives the benefit that the lamp can be run as low as 50% of its rated power without any significant loss of efficacy or any change in the colour of the light emitted, making this a unique form of light source. CID lamps are used in any area of TV or film lighting where daylight is to be simulated or to enhance the available light in outdoor filming.

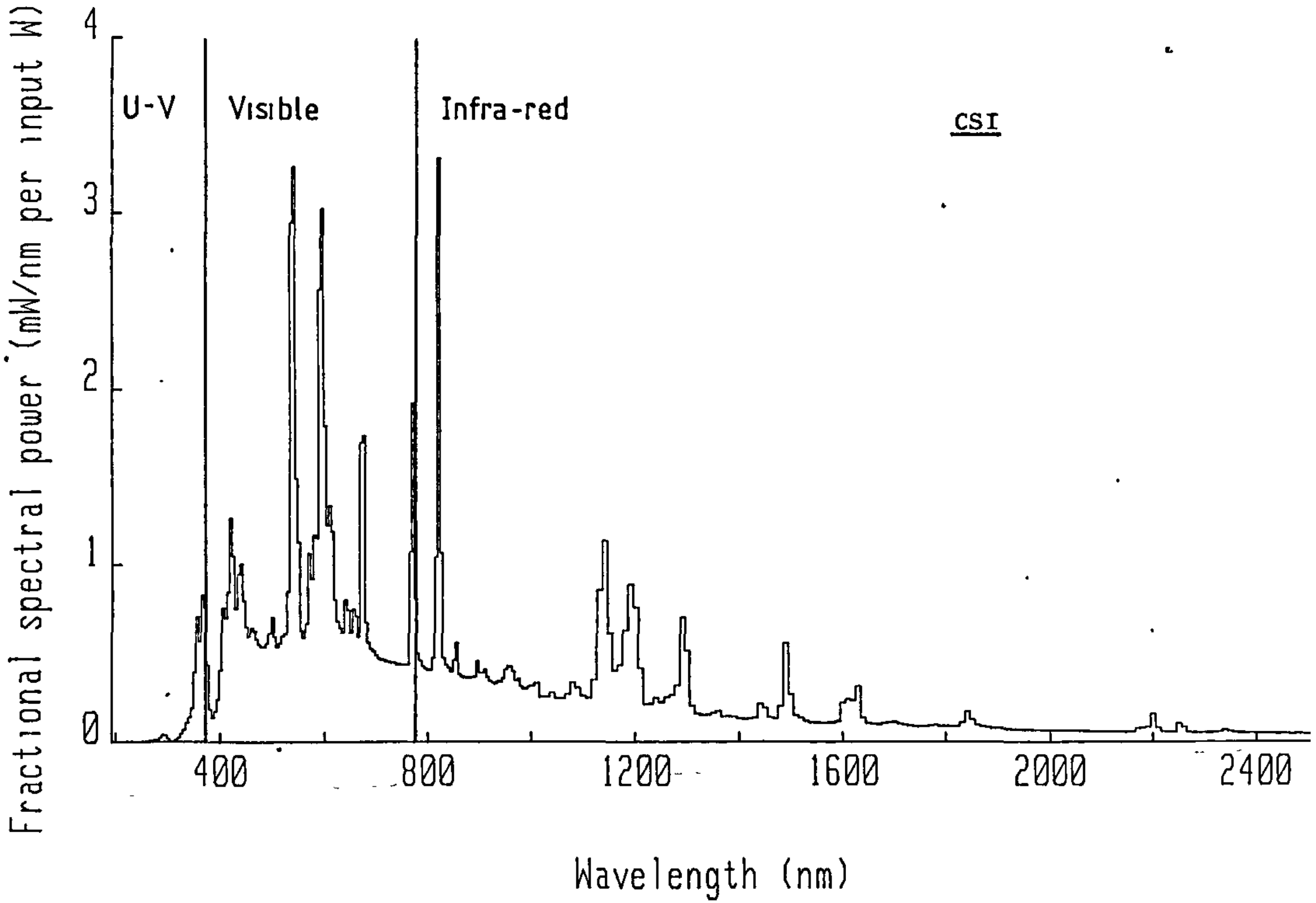


Figure 2. CSI Lamp spectrum

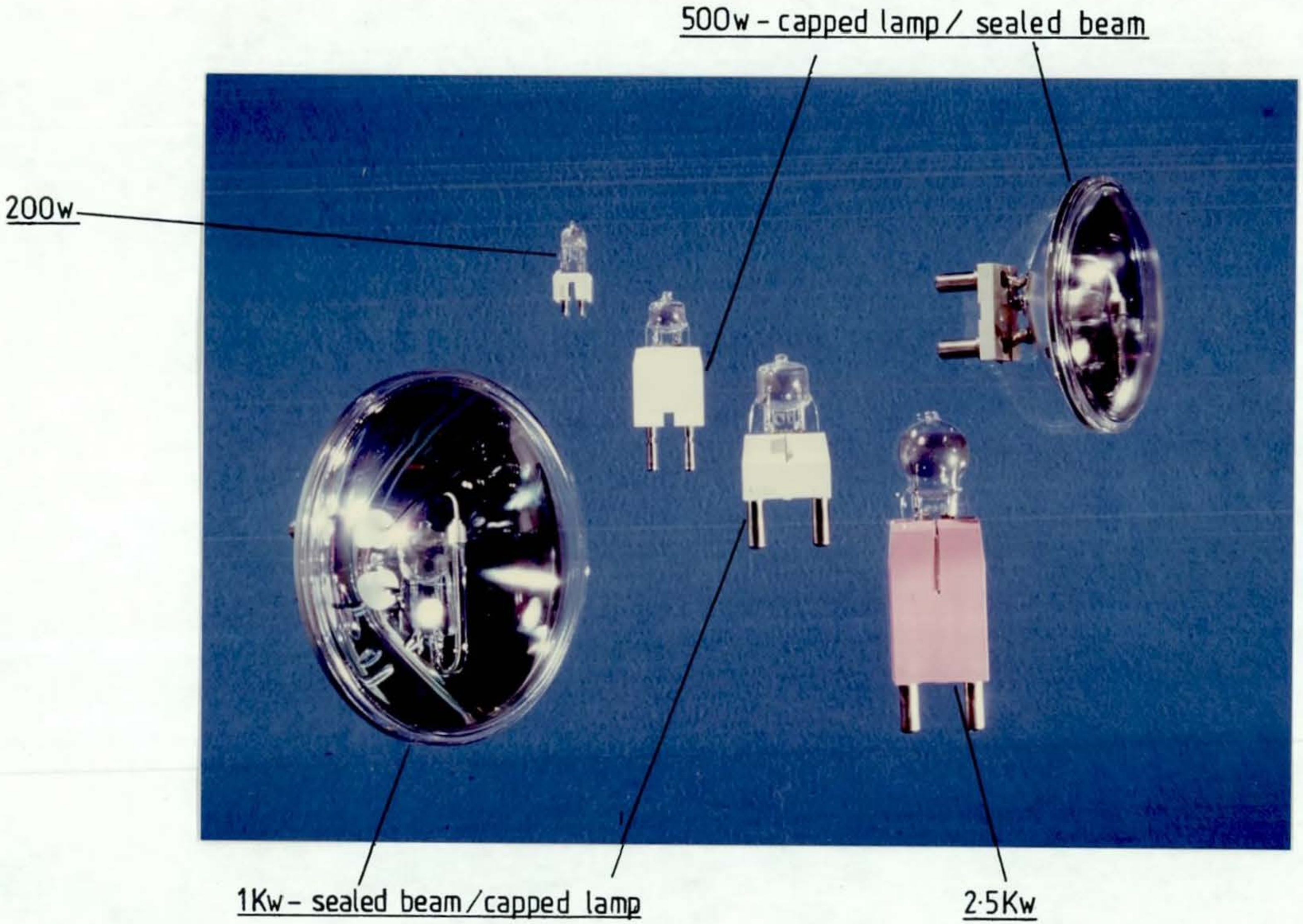


Figure 3. Range of CID lamps

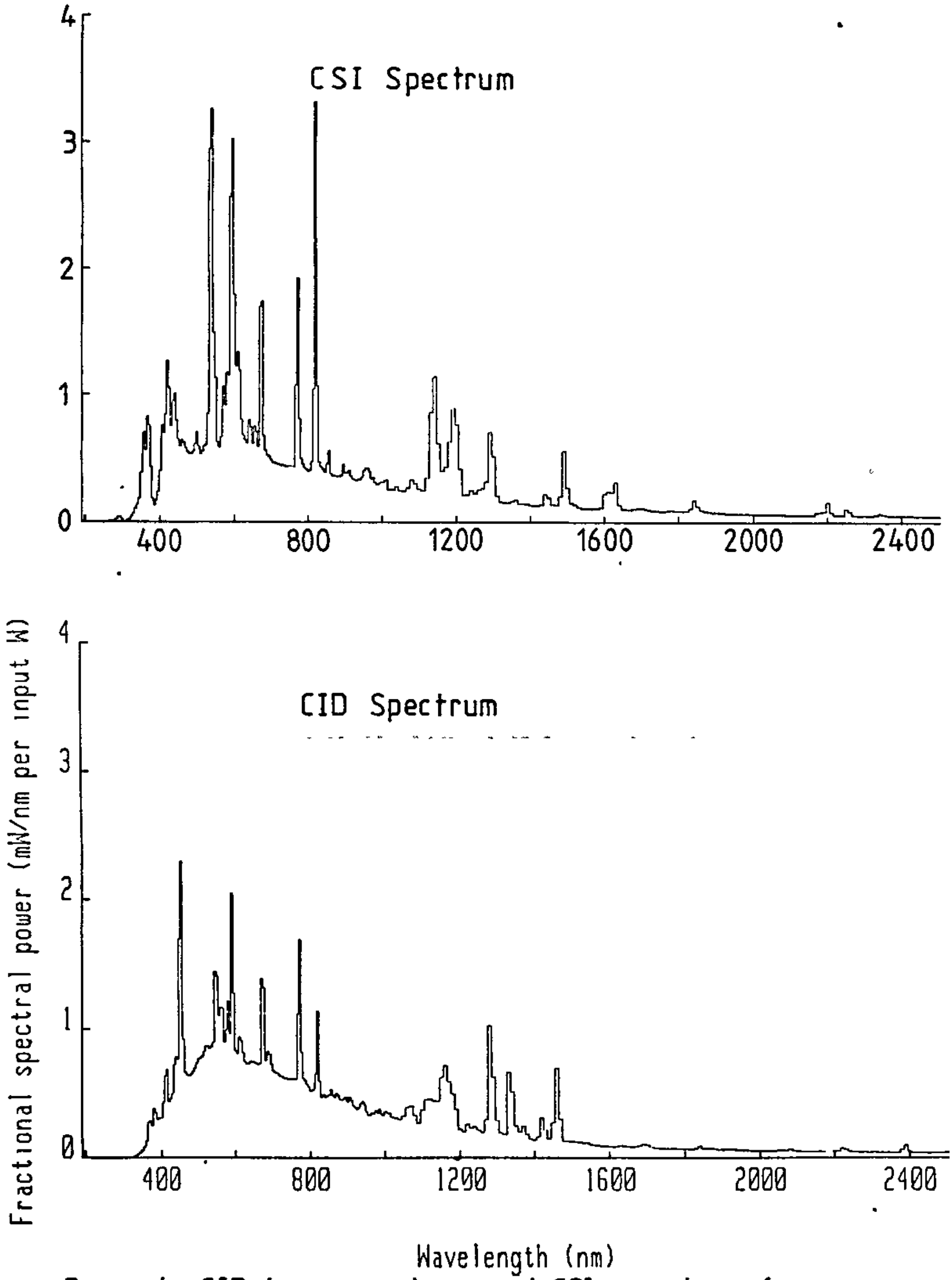


Figure 4. CID Lamp spectrum and CSI spectrum for comparison

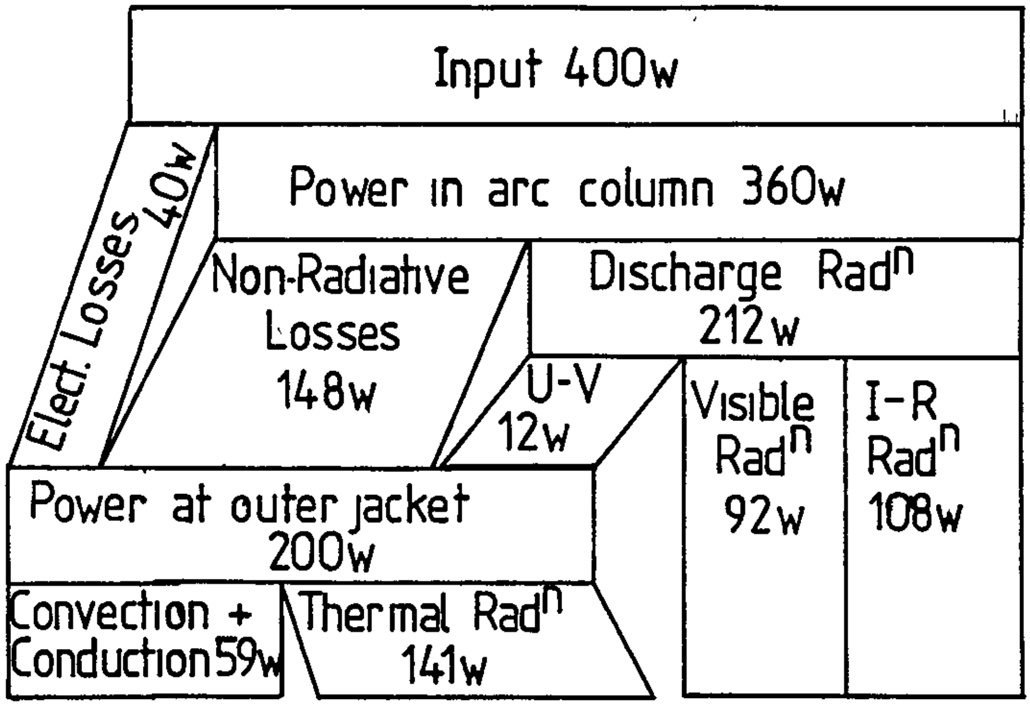
1.2 Project Introduction

The aim of this project was to obtain measured temperature profiles for the electrodes of CSI and CID lamps and to use those measurements to create a model describing the thermal performance of these electrodes.

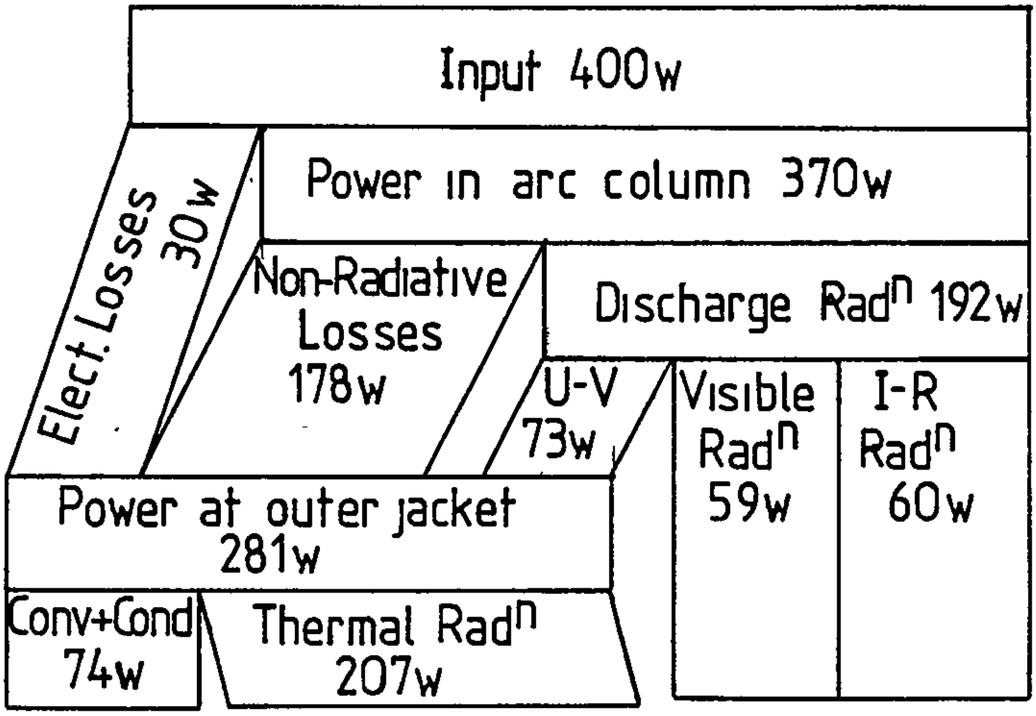
A limited amount of work is documented on the subject of thermal profiles of arc electrodes (5, 6, 7, 8, 9, 10). All previous work has been carried out on double ended electrode systems of several forms and much of the related work is concerned with the electrode to arc transition region and does not consider specifically the electrode. Although those investigations do have some common ground with this particular project there are sufficient differences to make this investigation unique.

The thermal balance of such electrode systems is an important parameter when considering the performance of discharge lamps as it is a major factor influencing the chemical and physical transport processes which affect elements of lamp performance such as lamp efficacy, lumen maintenance and lamp life.

If the lamp is considered as a device for converting electrical input energy into visible radiation a total energy balance can be constructed for the system. This traces the energy input and yields an insight into the efficiency of the lamp and can help in the development of more efficient lamps as an appreciation of how the energy is being dissipated is obtained. Some work has been done in this area for various discharge lamp types (2, 3, 4). Figure 5 shows two typical energy balance diagrams as calculated by Jack & Koedam for mercury and tin halide lamps (2). This shows that in these lamps approximately 10% of the power input to the lamp is lost to the



TIN HALIDE LAMP



MERCURY LAMP

Figure 5 Schematic representation of total energy balance of high pressure discharge lamps. (From Jack and Koedam – Reference 2) electrodes. Figure 5 also shows that the first division of the power input is between power dissipated by the arc column and power supplied to the electrodes and consequently the first step in performing a similar exercise on the CSI/CID lamps should have to be to quantify the power lost to the electrodes.

A further important gain to be obtained if a model could be developed to relate electrode temperature profiles and power lost to electrodes to the electrode geometry would be the ability to predict for a given geometry the performance which would be obtained by such a system. This would then be a very useful design tool capable of being used to design new electrode systems or to make improvements to an existing design. This could be particularly useful in the design of modified lamps to run on direct current as with standard electrodes the anode runs much hotter than the cathode giving rise to thermal stresses within the lamp which can cause premature failure. This temperature imbalance also gives rise to assymetric colour fringes in the arc which in many optical systems are unacceptable. A design model such as that referred to could make the development of a DC operating CSI/CID lamp much simpler and such a DC discharge light source would be of considerable commercial interest.

The investigation has been confined to the 2.5kW CID and the 1.0kW CID and CSI and in particular that section of the electrode actually within the discharge envelope and not the portion sandwiched within the quartz of the pinch seal region (see Figure 6).

The major objectives of this investigation can then be summarised in three broad categories.

(a) To develop a method to measure temperature at various points along the electrodes of a range of lamps.

(b) To develop a mathematical model capable of relating the electrode geometries to the temperature profiles obtained and able to quantify the amount of power lost to the electrode system during operation.

(c) To evaluate the measured and calculated data from (a) and (b) to establish a basic energy balance for the lamps and a possible design tool for calculating optimum electrode dimensions.

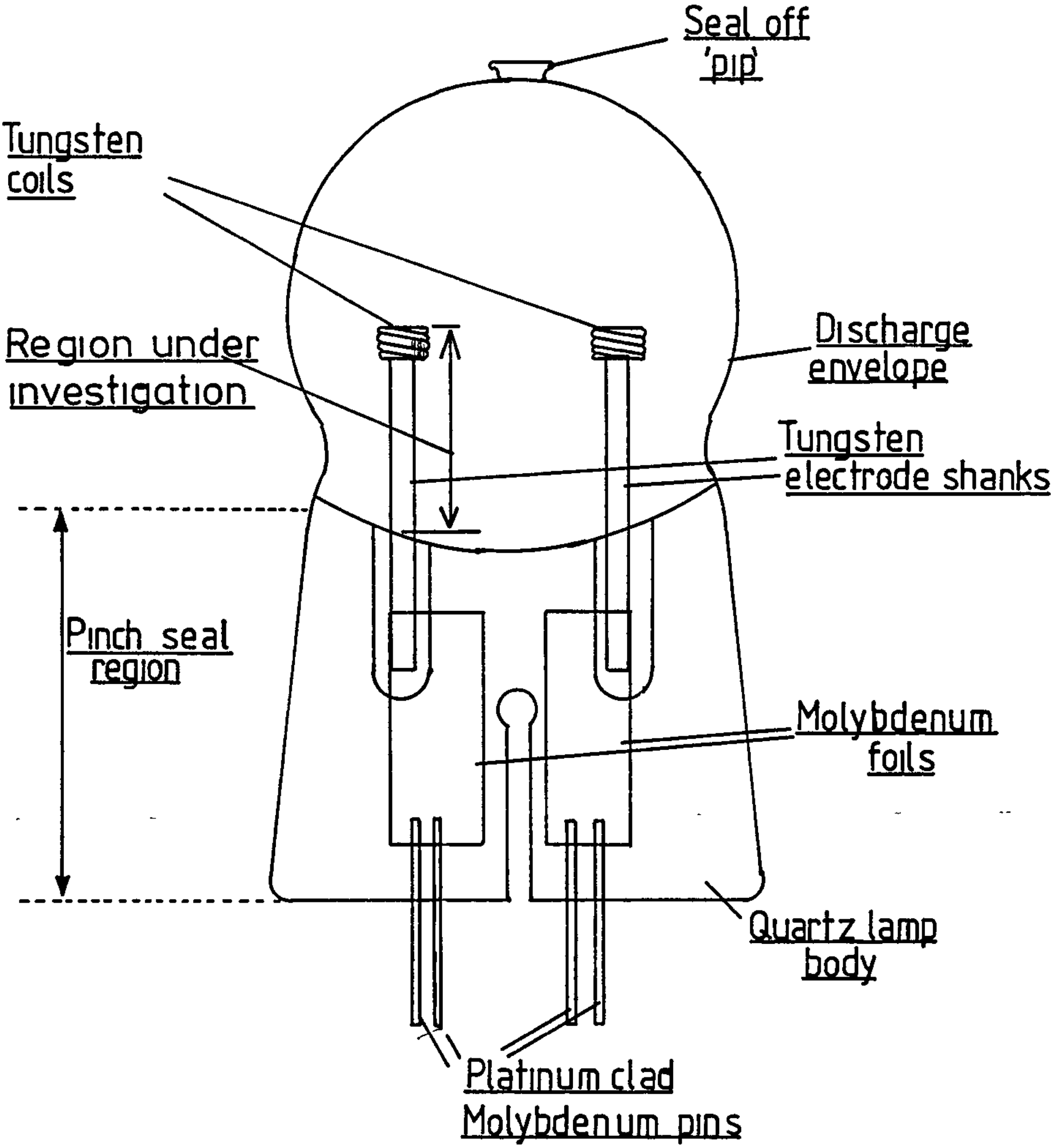


Figure 6. 2·5Kw CID Arc tube

2. LAMP MANUFACTURE AND OPERATION

2.1. Lamp Manufacture and Materials

The majority of lamps used in this investigation were manufactured by the production unit in the pilot plant at the THORN EMI factory at Leicester. Some special lamps were constructed and although following identical production techniques the lamps were made by myself with the assistance of other Laboratory personnel.

Figure 6 shows schematically how the lamp is assembled and Figure 7 shows a completed arc tube.

The system forming the current carrying element of the lamp from the external connection to the tips of the electrodes consists of two nominally identical electrode assemblies. As can be seen from Figure 6 the assembly consists of two platinum coated molybdenum pins which form the external electrical connection to the arc tube and are spot welded to a molybdenum foil about which the quartz will form a hermetic seal in the completed lamps.

The molybdenum foil has its edges etched to remove burrs and sharp pointswhich would make the formation of a good glass to metal seal difficult. The electrode shank is AKS tungsten and has an AKS tungsten coil at its upper end which is wound to be an interference fit on the shank. The shank has at its lower edge a flat ground at the area at which it is attached to the foil. This flat serves several purposes:- it enables a weld to be made to the foil without deforming the foil unduly, it helps in forming a hermetic seal as the quartz does not have to flow round both sides of the shank but is able to wet the molybdenum foil in that area and it helps to centralise the electrodes in the plane of the pinch seal.

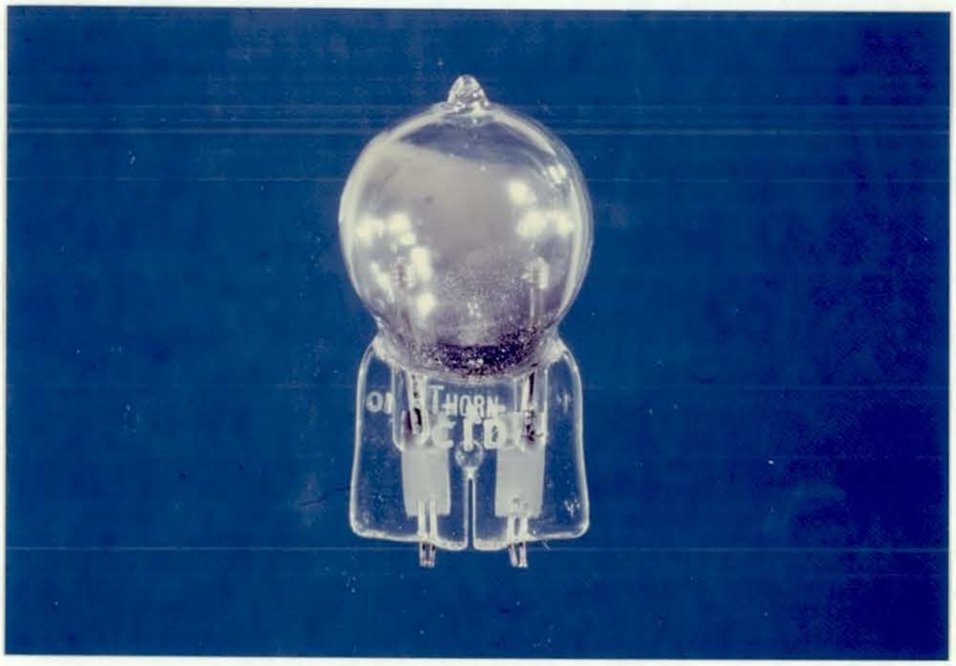


Figure 7. Completed 2·5Kw CID arc tube

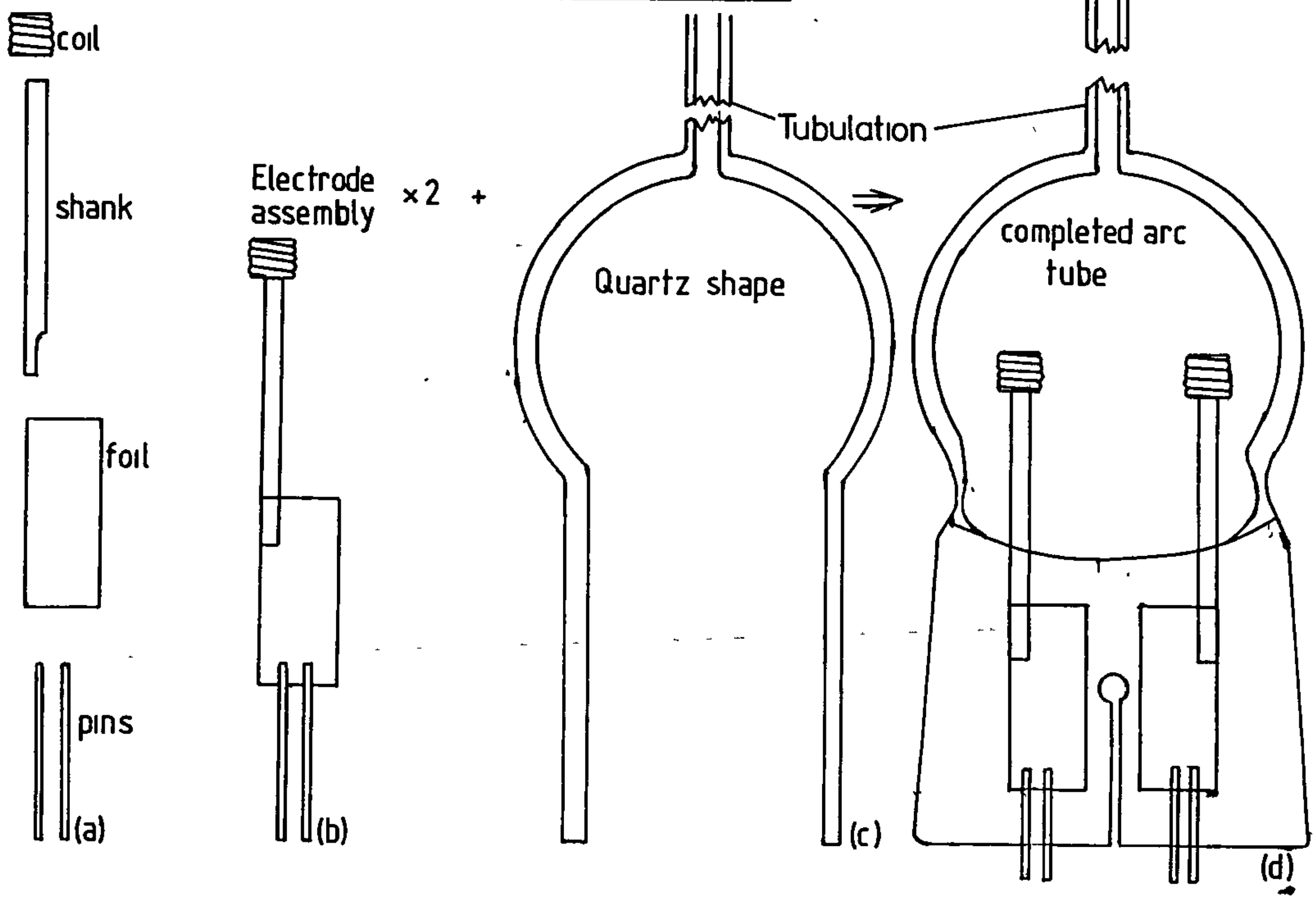
The tungsten shank to molybdenum foil weld utilises a piece of platinum foil as an intermediary to help achieve a stronger weld and also during pinch sealing the platinum is found to flow freely and help form a good electrical contact.

The various components of the electrode assembly also undergo some processing prior to the construction of the assemblies. The tungsten shank and coil are electrolytically polished in potassium hydroxide followed by vacuum furnacing at 2,500^{o}C. The molybdenum foils are subjected to an annealing process in a hydrogen atmosphere at 1050^{o}C. After completion the welded assemblies are heated in a hydrogen furnace at 1050^{o}C for 30 minutes.

The quartz shape shown in Figure 8c is blown from tubing of the size of the parallel walled lower section. At this stage great care must be taken not to overthin the wall of the tubing or the arc tube will not be able to withstand the operating pressure of the lamp which is in the range 5 to 20 atmospheres.

Two of the electrode assemblies as described are now sealed into the quartz shape by a process known as pinch sealing. This is done by positioning the quartz shape over the electrode assemblies which are held in position by the pins. The metalwork of the electrode assembly is protected from oxidation by the flow of inert gas shielding them. This is achieved by inserting a probe supplying argon into the tubulation and positioning the nozzle centrally in the bulb. The seal is made by heating the quartz by means of hydrogen-oxygen burners and when the quartz becomes sufficiently plastic the seal is made by press sealing the plastic quartz around the components of the electrode assembly by means of hydraulically operated jaws. The shape is now in the form as shown in Figure 8d.

Figure 8 . Steps in manufacture of 2·5Kw CID arc tube



As a result of the extreme heating the quartz suffers during pinch sealing white silica deposits are left on the electrodes and on the outside walls of the arc tube. This is detrimental to electrode performance and silica on the wall will cause obscuration of light emitted from the arc reducing the efficiency of the lamp. Internal deposits are removed by washing the lamp internally with hydrofluoric acid. External silica is recombined into the quartz in transparent form by a process called torch cleaning which involves heating the quartz to white heat for a short time using a hand torch whilst purging the arc tube with inert gas to prevent oxidation of the electrodes.

The lamp is now ready for heating in a vacuum furnace which is done for four hours at a temperature of 1150°C. This is done to minimise the hydroxyl levels, the presence of which has been found to adversely affect lamp starting and to accelerate the occurence of excessive halide erosion of the electrodes. The lamp shape is now ready to be filled.

All of the dose materials are put into the lamp via the tubulation. The tin and indium are added in the metallic form as wire which is precut and weighed. Mercury is dispensed in measured amounts using a syringe. Addition of the halides is done in a dry argon atmosphere in a chamber which is accessed via a vacuum port and which maintains a controlled dry argon atmosphere. This precaution is necessary as many of the halides used are very hygroscopic and the presence of even small quantities of water in the discharge envelope is catastrophic to lamp performance.

The halides are dispensed in two forms either as controlled mass pellets which can be simply counted into the lamp or as analar grade salts which must be accurately weighed before adding to the arc tube. The arc tubes are then stoppered and transferred to vacuum benches to be exhausted. The lamps are attached to the vacuum system by placing the tubulation in a compression head and the vacuum pumps used are mercury diffusion pumps. Lamps are alternately evacuated to a pressure of 1×10^{-3} torr and then flushed with argon. The lamp is finally evacuated and backfilled to a pressure of 240 torr of argon and sealed off using a hand torch. The processing described has been specific to the 2.5 kW CID lamp but would generally apply to all CSI/CID lamps with variations in physical sizes and doses used.

Figure 9 shows the lamps as measured. 1 kW lamps used the standard capped format having a G38* pin termination. The 2.5 kW lamp used the G38* pin termination attached via a copper leg which is brazed to these pins and lamp leads. This is the standard 2.5 kW CID lamp prior to capping and was the easiest format in which to obtain lamps for measurement. The special lamps constructed were manufactured as described in this section and differed from standard lamps only in their electrode configuration. Details of these lamps are given in Table 1. Also shown in Table 1 are the physical dimensions,as measured using a travelling microscope,for all lamps involved in the investigation.

* International Specification for Bipin lamp termination (17).

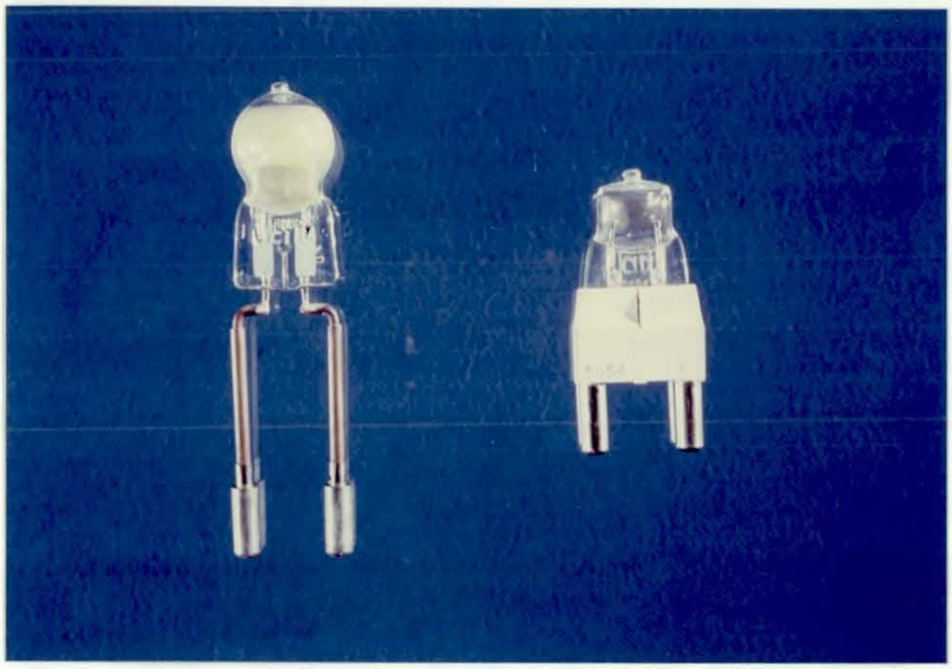


Figure 9. 2·5Kw and 1Kw CID lamps in the format as measured

LAMP NO.	LAMP TYPE	ELECTRODE	SHANK LENGTH L	COIL LENGTH C_L	ds SHANK DIAMETER	dc COIL DIAMETER
238	2.5kW CID (Std)	Right	3.0	0.4	0.2	0.37
		Left	3.0	0.4	0.2	0.37
301	2.5kW CID (Std)	Right	3.0	0.42	0.2	0.39
		Left	3.0	0.39	0.21	0.4
339	2.5kW CID (Std)	Right	3.0	0.38	0.19	0.38
		Left	3.0	0.36	0.21	0.38
1	2.5kW CID (Special)	Right	3.0	No coil	0.21	No coil
		Left	3.0	No coil	0.19	No coil
2	2.5kW CID (Special)	Right	3.0	No coil	0.29	No coil
		Left	3.0	No coil	0.28	No coil
6	2.5kW CID (Special)	Right	3.0	No coil	0.29	No coil
		Left	3.0	No coil	0.19	No coil
5180	1kW CSI (Std)	Right	2.3	0.23	0.18	0.3
		Left	2.3	0.25	0.185	0.3
3847	1kW CID (Std)	Right	2.3	0.32	0.175	0.3
		Left	2.3	0.29	0.185	0.3
5654	1kW CID (Std)	Right	2.3	0.24	0.19	0.3
		Left	2.3	0.26	0.195	0.29

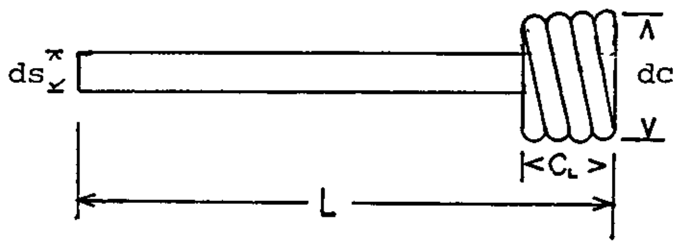


TABLE 1

Physical dimensions of the electrodes of lamps used in the investigation as measured with a travelling microscope. (All dimensions cm).

2.2 Lamp Operation and Control Gear

2.2.a. AC Operation

Control gear for any type of discharge lamp is very important and serves two main purposes:- firstly it must provide the conditions to ignite the lamp initially and then regulate the lamp current during operation. Control circuits for discharge lamps can be very complex and greater details can be found in references 11 and 12. The current control element of the circuits can, for alternating current applications, be resistive capacitative or inductive but for direct current is almost exclusively resistive.

The standard A.C. control circuits for THORN EMI lamps are predominantly inductive ballasts as resistive ballasts tend to be very inefficient with the ballast consuming as much power as the lamp itself and capacitative ballasts give highly peaked current waveforms which are detrimental to electrode life. Consequently the inductive ballast is considered to be the most effective compromise. The open circuit voltage required to initiate the discharge is, for CSI/CID lamps, provided by an ignitor which delivers pulses of up to 50 kV.

The control circuit used for the 2.5 kW CID lamps in this investigation is shown in Figure 10. Regulation of lamp current is achieved by the use of inductive ballasts and in this case that recommended is two commercially available 1 kW CSI/CID ballasts wired in parallel. The ignitor is a Bauch 902 KZ pulse ignitor which is shown schematically in Figure 12 and is a commercially available ignitor recommended by THORN EMI for the 2.5 kW CID circuit. Normally it delivers a 50 kV pulse in order to restrike the discharge, while hot

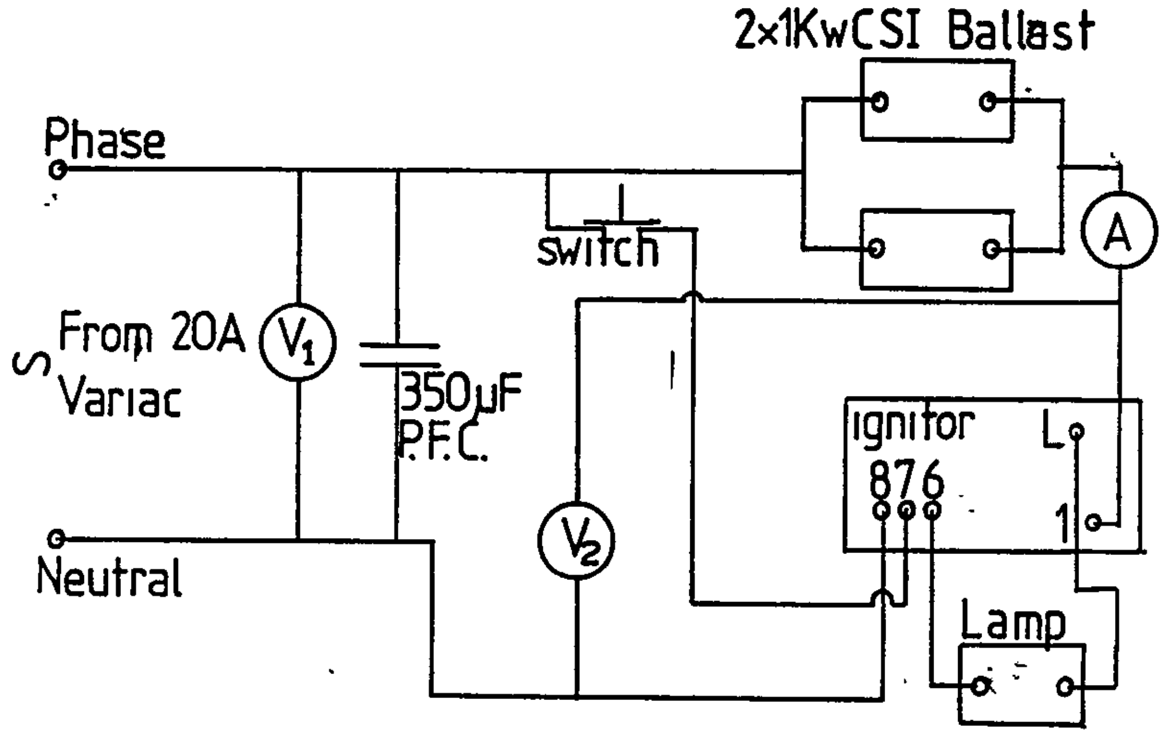


Figure 10 A.C. Circuit for 2·5Kw CID Lamps.

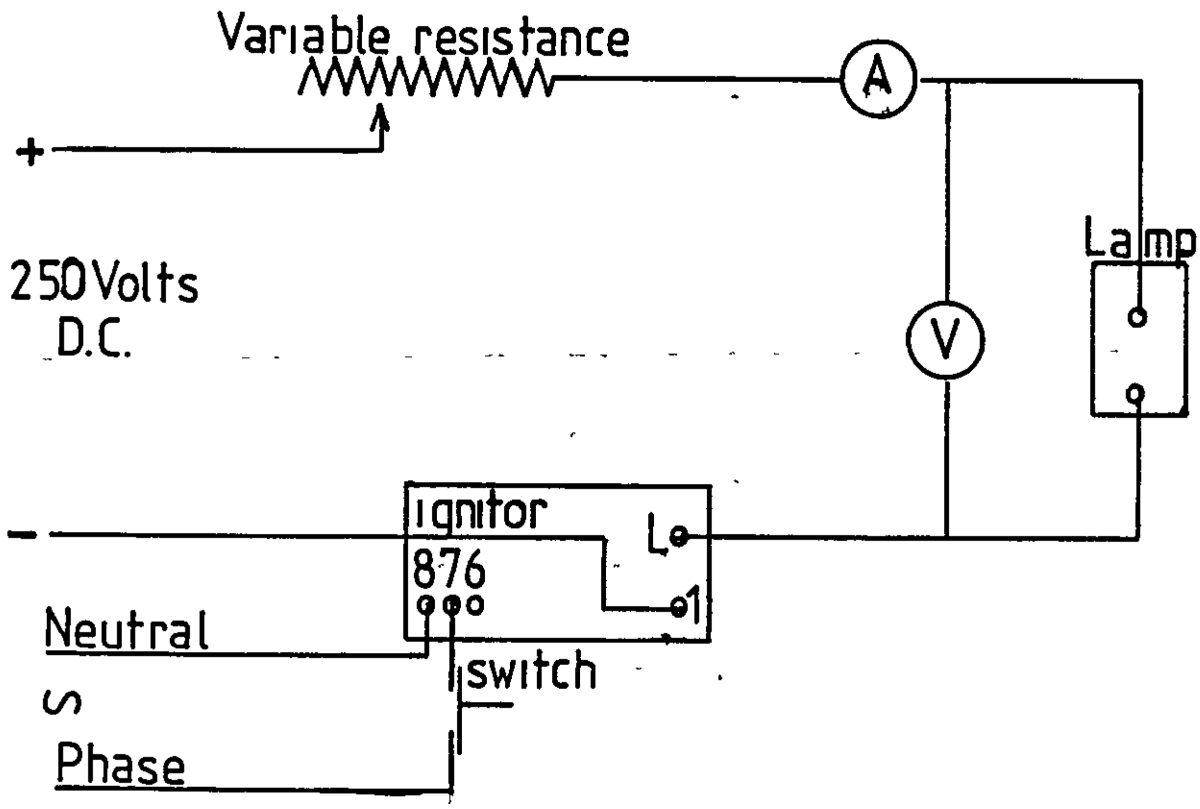


Figure 11. D.C. Circuit for 2·5Kw CID Lamps

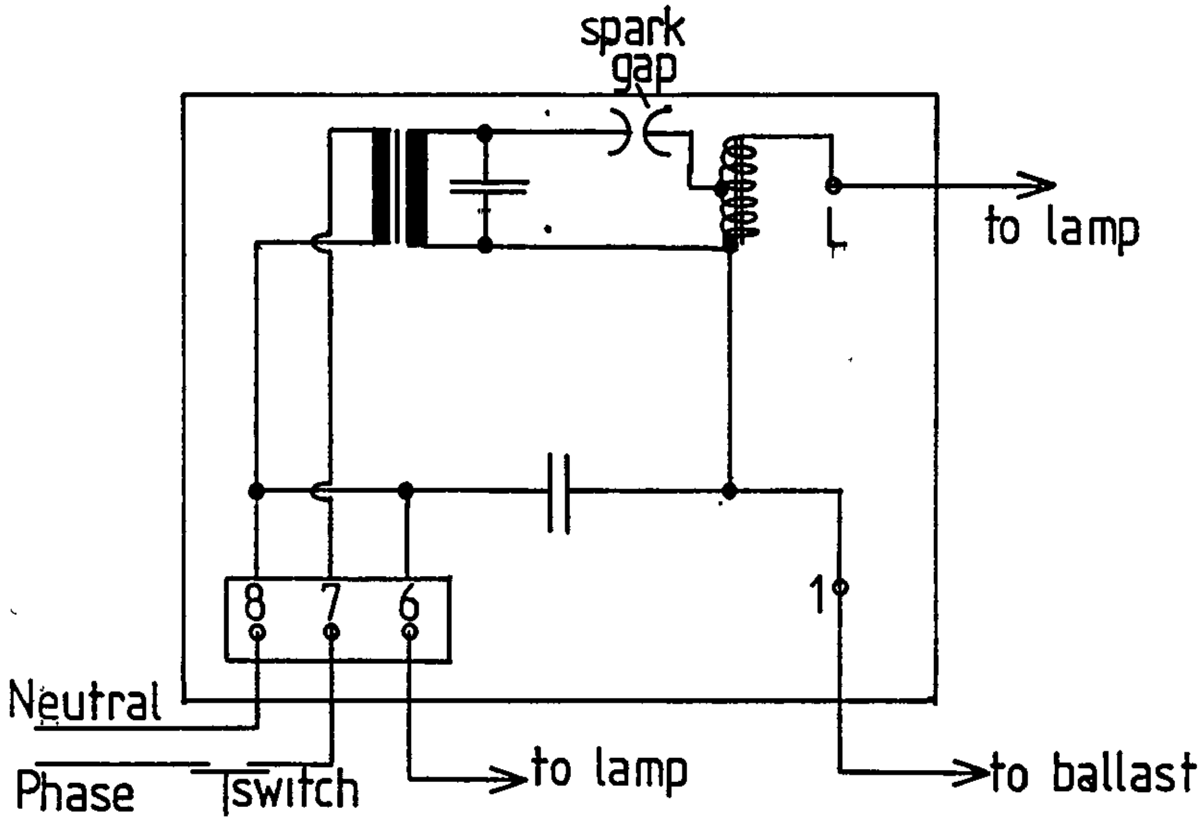


Figure12. Details of Bauch 902KZ Ignitor

but for the purpose of this investigation that capacity was not essential and the ignitor had been modified to deliver only a 9 kV pulse. The ignitor is wired via a push switch which is depressed to ignite the lamp and released when the lamp has started. As can be seen from Figure 10. A 350 μF capacitance is placed across the power supply to the lamp circuit. This is necessary to balance the inductive ballast and obtain a line power factor of approximately 0.9. The supply to the lamp circuit is taken from a variable AC transformer enabling the supply voltage to the circuit to be altered allowing regulation of the lamp current and hence lamp wattage to be achieved. As is shown in Figure 10 a voltmeter V_1 was used to monitor the voltage input to the circuit, this was only used as an approximate indicator and a standard panel meter was used. Measurement of lamp volts, current and wattage is far more important and this was monitored using a calibrated Cambridge AC test set. The upper current range of this test set is lower than the normal operating current of the 2.5 kW CID lamp and consequently it was necessary to use a calibrated transformer to step the current down to a value capable of being measured by the test set. Typical electrical characteristics for the 2.5 kW CID are lamp voltage 100 volts, current 27 amps giving a lamp wattage of 2500 watts.

The 1kW CSI/CID lamps run on a similar circuit but using a single ballast and only 175 μF of power factor correction. Typical electrical characteristics for the 1 kW CSI and CID lamps are lamp voltage 75 volts, current 15 amps for a lamp wattage of 1000 watts.

2.2.b. <u>DC Control Gear</u>

The circuit used to operate lamps run on Direct Current is shown in Figure 11. In this case current regulation is achieved by the use of a resistance ballast, this took the form of a series of resistance elements wired in parallel which can be switched in or out in order to achieve current control with a fixed 250v DC supply. Lamp starting was achieved using the same pulse ignitor as in the AC case which is only switched in circuit for sufficient time to initiate the discharge.

Measurement of the lamp current, voltage and wattage were obtained using a direct current moving coil ammeter, the Cambridge test set used for AC measurement and a DC wattmeter respectively.

3. REVIEW OF TEMPERATURE MEASUREMENT TECHNIQUES

3.1 Objectives

Having established the method of manufacturing and operating the lamps under investigation it is now necessary to consider the physical processes which affect the electrode systems and to review the possible methods available to obtain temperature profiles of those electrodes.

Firstly the electrode systems will only be considered under steady state conditions. That is when the lamp has reached thermal equilibrium which, as will be shown, occurs within fifteen minutes and is the condition in which the lamp will spend the majority of its operational life.

In this steady state condition energy will be supplied to the electrode from the arc predominantly by conduction through the area of arc attachment but some energy will be supplied by resistive heating of the electrodes by the passage of current. This energy will be dissipated by radiation from the surface of the electrode and conducted along the electrode shank. Some energy may also be lost to the gases circulating in the arc envelope by convection.

The majority of energy supplied to the electrode is conducted through the arc-electrode attachment area and is a function of lamp current, work function of the electrode material, electric field density and ratio of ion to electron current. The resistance heating of the shank will play a much smaller role in supplying energy to the electrode, typically less than a watt under normal operating conditions.

If we examine visibly the region under investigation (Figure 13) a rough estimate of the temperature range of the electrodes can be made from the colour of the electrodes. From Figure 13, which was taken immediately after switch off, a temperature range of $1500^{o}K$ to $3000^{o}K$ would appear a reasonable estimate. At these elevated temperatures radiation would obviously be the dominant mode of energy dissipation but conduction along the rod would be expected to play a significant part.

The first step in achieving an understanding of the thermal balance of the electrode systems is to establish a measurement technique in order to obtain some temperature profiles of the systems under investigation.

The ideal technique will give a method of scanning an electrode making temperature measurements with the lamp operating. This presents a considerable problem as the structure whose temperature is to be measured is relatively small, typically a 2mm diameter rod, enclosed within a hermetically sealed envelope operating at several atmospheres pressure and in a highly chemically active environment. Any method of contact measurement is unsuitable and the elevated temperatures involved further limit the options. The following sections will detail the review of possible measurement techniques available and indicates the strengths and weaknesses of the various methods.

3.2 Radiation Physics

Having eliminated contact thermometry as a possible measuring technique the most likely method will then be some form of radiation thermometry. Before any practical radiation thermometers are discussed a number of concepts central to any study involving radiative energy transfer must be defined.

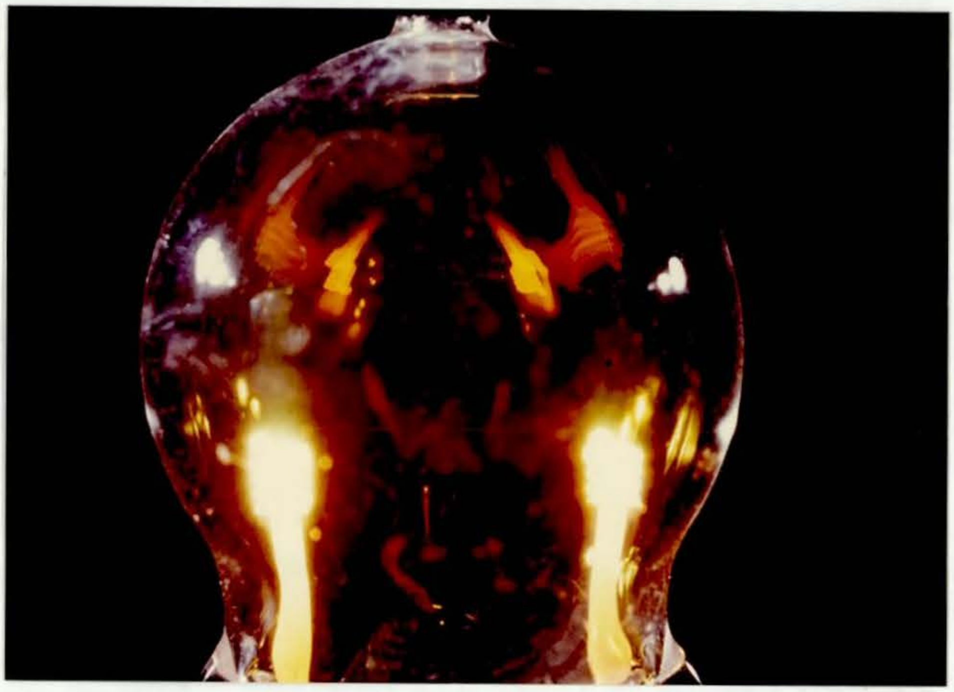


Figure 13. Electrodes of operating 2·5Kw CID lamp

Basic to any study of radiative transfer is the concept of the black body which is defined as an ideal body that allows all incident energy to pass into it and absorbs internally all that incident radiation (i.e. no reflection). This is true for all wavelengths and angles of incidence. This means a black body is a perfect absorber of incident radiation and all other qualitative aspects of black body radiation can be derived from this definition.

It can be shown by simple thermodynamic considerations that a perfect absorber must also be a total radiator at all wavelengths and in all directions and that the total radiant energy emitted by a black body is a function of its temperature only. The above qualitative laws can be derived from classical thermodynamic considerations only but the formulation of an expression for the magnitude of the emitted intensity at each wavelength constituting the radiation spectrum required the introduction of quantum theory.

As has already been stated, most of the properties of a black body can be derived from classical thermodynamic considerations and several texts deal with the theory and details of such derivations (18, 19). Here it is intended to simply state the more important relationships concerning black body radiation:-

The Stefan-Boltzman law states that

$$W = \sigma T^4 \qquad 3.1$$

where W = total radiation emitted per unit area by a black body at a temperature T

σ = Stefan-Boltzman Constant = $5.67 \times 10^{-8}\ Wm^{-2}\ K^{-4}$

Wien's displacement law relates black body temperature to the wavelength which will emit the most energy:-

$$\lambda m = \frac{C_3}{T} \text{ where } C_3 = 2897\ \mu m\ K \qquad 3.2$$

Consequently the maximum of radiation will be displaced to shorter wavelengths as the temperature increases.

Classical thermodynamics could not derive an expression to relate how at a particular temperature the intensity of radiation is distributed among different wavelengths of a radiating black body surface. Following the development of quantum mechanics an expression was derived which described adequately the observed spectral distribution of a radiating black body.

This expression is known as Planck's Law:-

$$N = \frac{C_1}{\lambda^5\left[\exp\left(C_2/\lambda T\right) - 1\right]} \qquad 3.3$$

Where N = watts radiated per square cm of surface per micron wavelength band at temperature T K

λ = wavelength

C_1 = Plancks first radiation constant = $3.73 \times 10^{-16} Wm^2$

C_2 = Plancks second radiation constant = 0.014388mK

At short wavelengths and not too high temperatures equation 3.3 can be reduced to a much simpler form as when λT is small compared with C_2 the -1 in the denominator becomes negligible in comparison to $\exp(C_2/\lambda T)$

So now we have

$$N = \frac{C_1 \exp(-C_2/\lambda T)}{\lambda^5} \qquad 3.4$$

This is known as Wien's radiation law. For a temperature of 3000 K and $\lambda = 0.7\ \mu m$ for instance, the use of the Wien law instead of the full expression would only result in an error of 0.1 per cent.

Having established the radiating properties of a black body, which cannot actually be realised, it then becomes necessary to determine how the performance of a real surface will relate to that of a black body.

The measure of the radiating properties of a material relative to a black body is known as its emissivity and is defined by the expression

$$\epsilon_A = \frac{W_A}{W_{AB}} \qquad 3.5$$

Where ϵ_A is the emissivity of the material in question under conditions defined by A

W_A = Flux density emitted by real body under Conditions A

W_{AB} = Flux density emitted by black body under Conditions A

It is important to define the conditions under which ϵ is measured as for some materials emissivity can be a function of temperature, wavelength and direction. From the definition of emissivity it can be seen that the emissivity of a black body must be 1 and all real materials will have emissivities less than 1.

3.3 Radiation Pyrometry

The basic processes involved in energy radiation from a hot body have been outlined and the following section will describe how these processes can be used in order to measure the temperature of a radiating surface.

The types of radiation pyrometers fall broadly into three categories:- radiance pyrometers, total radiation pyrometers and ratio or colour pyrometers.

A radiance pyrometer operates by measuring the radiance of a target material. As absolute measurement of radiance is very difficult and not very precise, it is far simpler to make measurements relative to some standard spectral radiance. In this investigation the radiance standard used as the calibration standard takes the form of an NPL calibrated tungsten strip lamp.

Total radiation pyrometry utilises the Stefan-Boltzmann law (3.1) in order to relate measured radiation to the surface temperature but again is usually used relative to a standard radiation source. Total radiation pyrometry would be impractical in this particular investigation because of the high levels of U.V. and I.R. radiation generated by the lamp, the target sizes involved and slow response times.

Finally, a two colour or ratio type pyrometer measures the ratio of two measured radiances at different wavelengths which, if the emissivity is identical at both wavelengths, the ratio is proportional to the surface temperature. Details of the above types of pyrometer, their theory and calibration can be found in references 13, 14 and 15.

A further difficulty in obtaining a reliable temperature measuring technique for this investigation is illustrated by figure 14 which shows the spectral output of a full radiator at 3,000 K, the region being investigated, compared to that of a 2.5 kW CID lamp showing how, in any region in which radiation measurements can be made, the arc also radiates very strongly.

3.3.a. Radiance Pyrometers

i) Optical Pyrometry

The optical or disappearing filament pyrometer is one of the simplest and most common forms of radiance pyrometer and is shown schematically in Figure 15. In this instrument a radiance measurement is made subjectively in terms of relative values obtained by visual impression by the operator who compares the

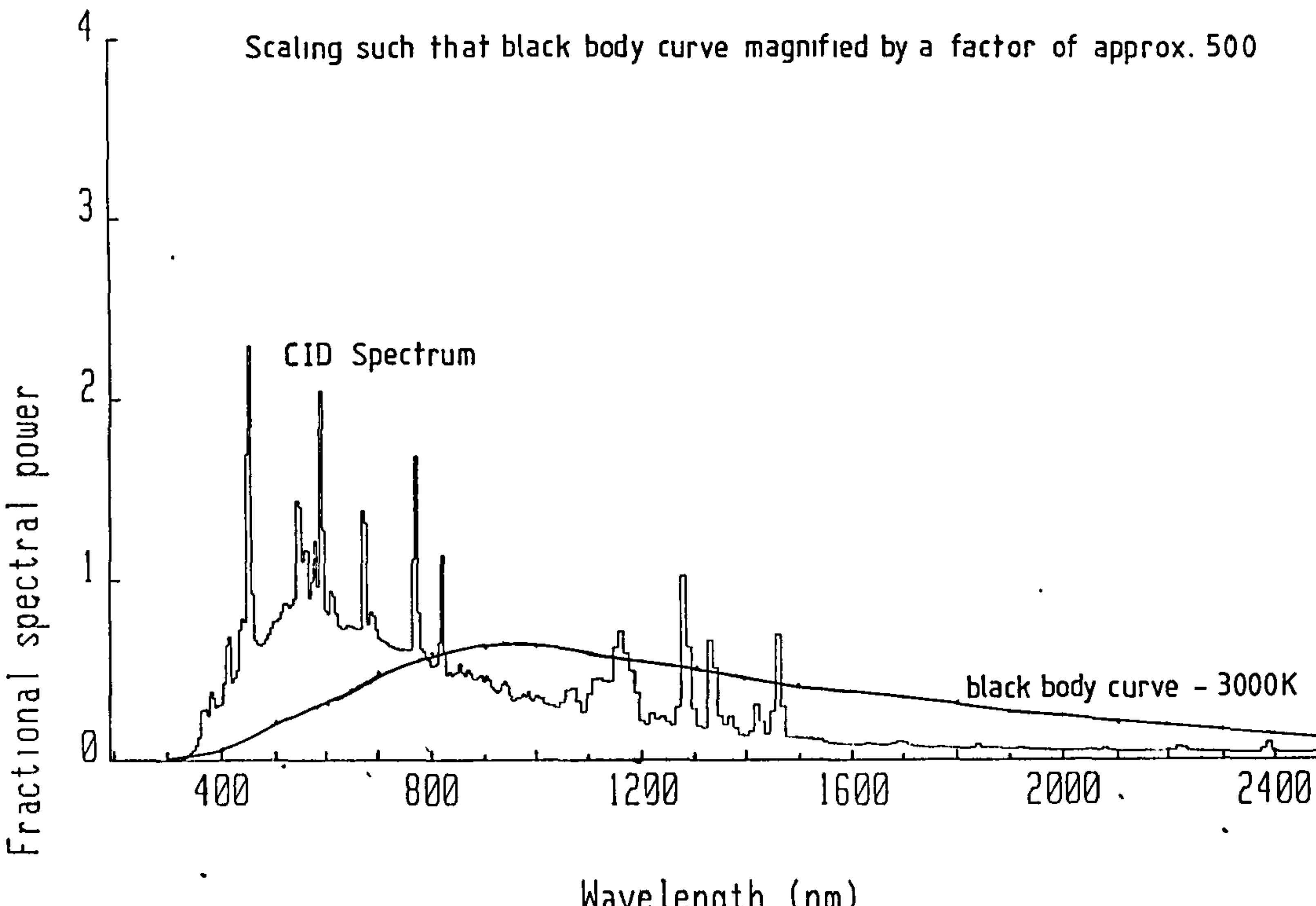


Figure 14 Spectrum of black body at 3000K and 2·5kW CID lamp

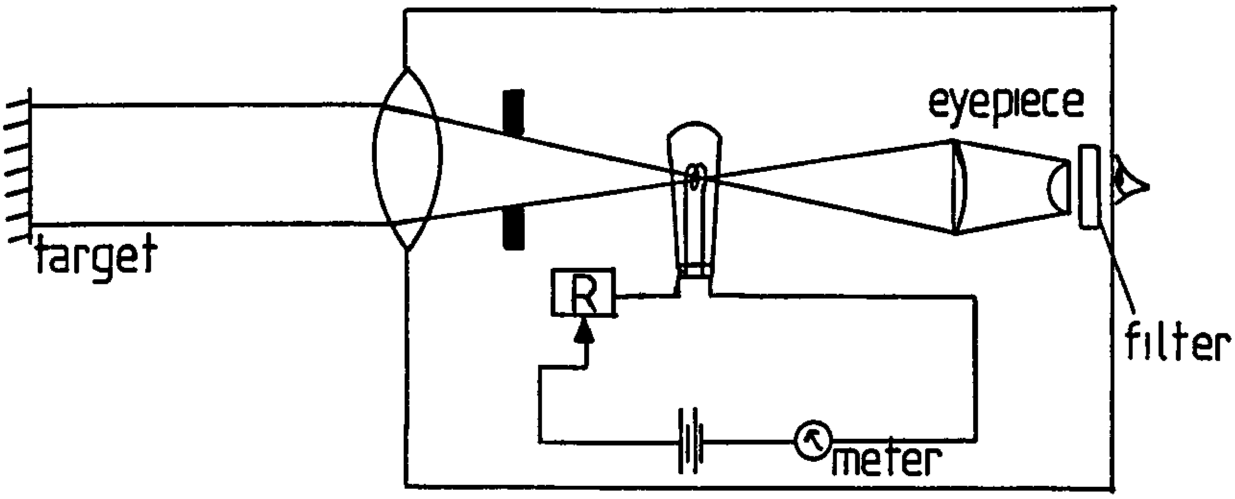


Figure 15. Simple optical (disappearing filament type) pyrometer.

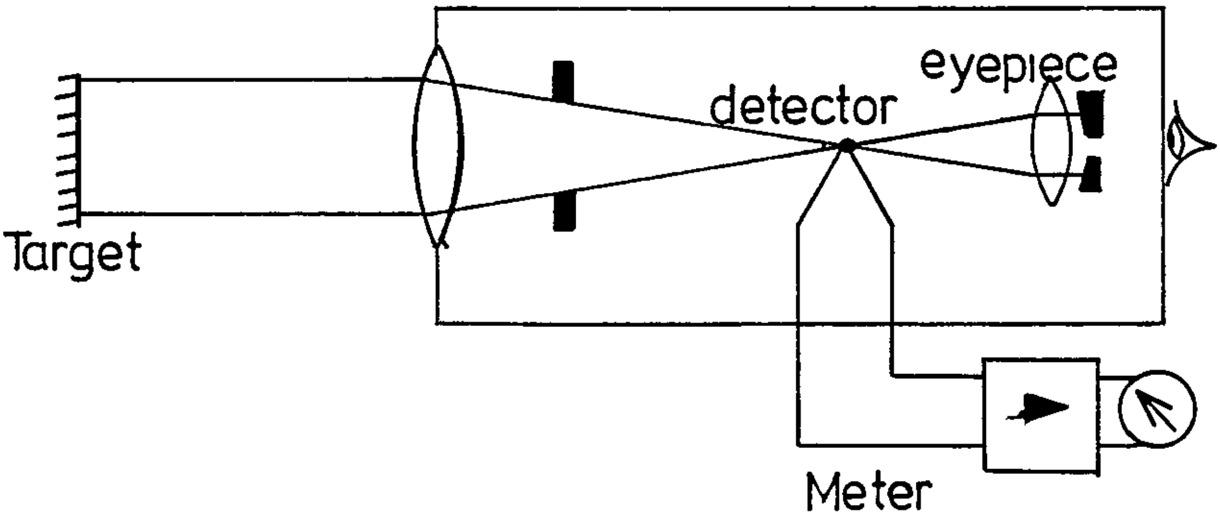


Figure 16. Band Radiation Pyrometer

brightness of the target with that of a radiation source calibrated to black body temperature. A narrow spectral response is provided by an optical filter. The optical system is such that the image plane of the target coincides with the radiation source which is commonly a tungsten filament and both can be viewed simultaneously through the eye-piece. The radiance of the tungsten filament is varied by altering the current passing through it by means of a variable resistor R until the filament disappears in the image of the target. At this point the radiances are identical in the spectral region determined by the filter and the spectral response of the eye. The indicating meter, which measures lamp current, is calibrated with the reference lamp such that the spectral radiation temperature of the target can be read directly from the scale.

Such an instrument has several advantages for an investigation of this type. The optical system is very versatile, incorporating several interchangeable lenses enabling a range of magnifications and pyrometer target distances to be used. Several instruments were available which have a considerable temperature measurement range, 650^{o} - 5000^{o}C achieved by insertion of neutral density filters into the optical path. The filter used on the pyrometers available are narrow band filters centred on 650 nM and consequently errors caused in making measurements with the lamp burning will be reduced as in this region the CID lamp output is not as high as in some regions of the spectrum. Errors caused by measurements made with the lamp running are very difficult to eliminate or quantify and will be discussed in more detail in a later section.

The instrument also has certain limitations such as the fact that measurement is based on a subjective comparison of the target and reference filament which can cause an uncertainty in the measurement.

The instrument is calibrated to a black body temperature which will, for a real material, give a temperature lower than true temperature because the target material will have an emissivity less than unity and, consequently, the radiance of the material will have a value below that of the black body by a factor of the emissivity of the material. To correct to true temperature a value for the emissivity of the material must be obtained. Emissivity can vary with temperature and surface condition and it consequently incurs a further source of uncertainty. The error incurred as a result of taking measurements with the arc running is also a limitation of the system and the response time of course is very slow, therefore, any rapid changes in temperature would be impossible to observe.

ii) Photoelectric Pyrometry

Alternative configurations of radiance pyrometer utilise some form of radiation detector to measure values of radiance instead of the eye as in the disappearing filament instrument. A number of possible detectors can be used such as a photomultiplier tube, the output of which is calibrated against a standard lamp to give spectral radiation temperature. A detector of this type has some major advantages such as its rapid response time enabling transient temperature changes to be observed and also the ability to observe the temperature decay on switch off if the output is taken to a suitable recorder. The broad spectral response of many available PM tubes means the spectral band can be chosen to minimise the effects of measurement with the lamp burning.

The disadvantages of a photomultiplier tube based system are as with the previous radiance pyrometers a value must be obtained for emissivity in order to convert measured temperatures to true surface temperature and the photomultiplier tube tends to be dependant on input voltage and a very stable PM supply would be necessary if constant calibration checks were to be avoided.

A further type of radiance pyrometer utilizing a narrow spectral band is a lithium tantalate detector system. In terms of performance a lithium tantalate detector is very similar to the photomultiplier in that it can be calibrated to give an output in terms of spectral radiation temperature. Lithium tantalate detectors have very rapid response times typically approximately 7msec and a very wide flat spectral response (.001μ to1,000μ). This gives a large choice of spectral window to enable a region where the arc radiation is at a minimum and the response time is sufficiently rapid to enable transient temperature effects to be viewed and decay of temperature at switch off to be monitored.

These detectors only respond to pulsed, modulated or chopped radiation with a typical response .01Hz to 100MHz so some form of radiation chopper is required. As with the majority of radiation pyrometers in order to convert a measured radiation temperature to true temperature a value of emissivity must be known.

iii) <u>Photoelectric Band Radiation Pyrometry</u>

Figure 16 shows schematically a typical band radiation pyrometer which is simply a radiance pyrometer viewing a wide range of wavelengths. The pyrometer of Figure 16 collects radiation through a lens onto the radiation detector. The optical system allows simultaneous viewing of the target and detector enabling reliable targeting of the detector to be achieved.

The advantages of all types of such detectors are similar i.e. their simplicity to use and positive focussing. The drawbacks of the system are that the wide spectral region observed makes the measurement with the lamp running unreliable as the arc radiation contributes considerably to the signal and all of the materials mentioned have their peak sensitivity well into the visible region. In addition the instruments available have a minimum target size of approximately 5mm radius spot which is rather large for this particular investigation. Finally, these instruments also suffer from the necessity to know the emissivity of the target materials in order to correct measured temperature to true temperature.

The types of detector used in a typical band radiation pyrometer are quite varied such as cadmium sulphide, silicon, germanium and lead sulphide and the band is determined by the spectral response of the detector. These detectors are much less sensitive than the photoelectric or pyoelectric detectors (such as the PM tube or lithium tantalate detector) and consequently for a small target size require a wider spectral window to realise useable output. Two such instruments are available for use; both incorporating silicon detectors.

A number of alternative band radiation pyrometers exist such as thermal imaging or photographic based techniques which were not considered for reasons of cost and complexity.

3.3.b. Colour Pyrometers

The two colour or ratio pyrometers measure the ratio between amounts of radiation emitted from the target in two limited wavelength bands. If the emissivity of the target for the two bands used is the same (i.e. emissivity is independent of wavelength - the material is a grey body) then the output of the instrument will depend only on the temperature of that material as is illustrated in Figure 17 and so the emissivity does not need to be known to obtain a value of true temperature for the target material. One ratio pyrometer was available which could be used for this investigation which operates by the comparison of radiation emitted in narrow bands centred on 550 and 650 nm. For the wavelength bands involved in this particular instrument the emissivity for tungsten varies by less than 3% (12) which is possibly more accurate than the determination of an absolute value for the emissitivity of the electrodes. The instrument employs a direct viewing focussing arrangement, an internal calibration standard, a direct digital readout in degrees centigrade and can be linked to a pen recorder.

The drawbacks of the system are with its optical arrangement, the target size is rather too large and to run with the smallest target size, the detector head is so close to the lamp that cooling the detector becomes a problem. The major problem with this instrument though is the proximity of the 550 nM band to the mercury resonance line in the spectrum and as clouds of gas absorbing and emitting in this band are passed in the field of view the interference caused gives poor results.

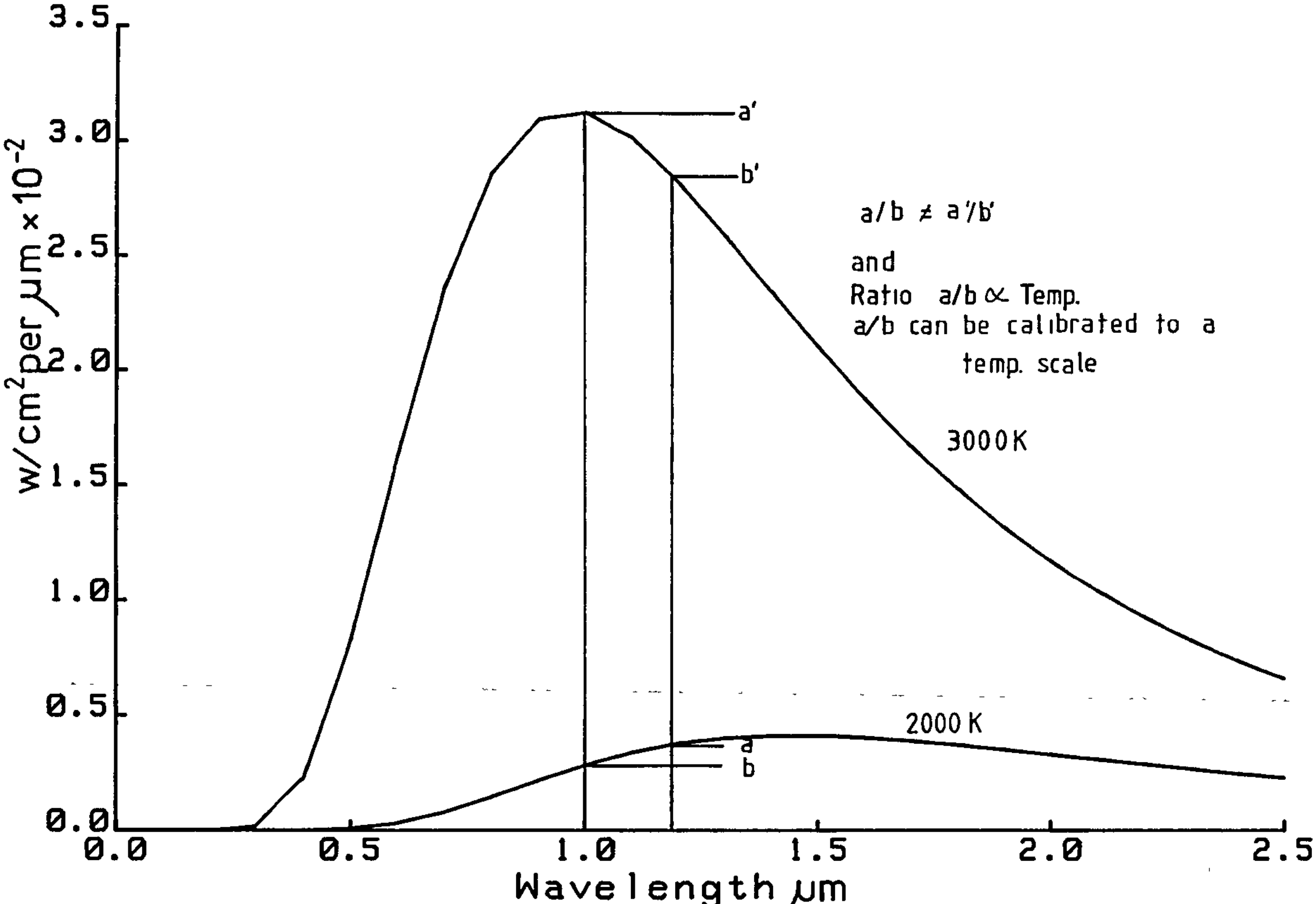


Figure 17. Black-body radiation curves for a source at 2000 K and 3000K showing operating principle of two colour pyrometer

3.4 Evaluation of Available Techniques

Having reviewed the main techniques available for making the measurements required for this investigation, certain external constraints limit the choice in addition to the technical considerations. Firstly cost is a limitation as the project has a limited budget and the purchase of expensive equipment is not possible. Time is also a major constraint and in view of the measurements to be made not too much time should be dedicated to developing a measurement technique if a simpler alternative existed.

Two pyrometers incorporating silicon detectors were tried in a limited number of measurements and were found to be unstable on readout i.e. the output was not steady but fluctuating constantly. The fluctuating temperature measurements were attributed to interference of the arc radiation and in particular clouds of mercury vapour which can be seen moving around within the arc tube. (This problem is discussed in more detail in Appendix 2). Large target size was also a drawback of the instruments used.

Other detector materials used in this type of band radiation pyrometer would suffer similar setbacks and the possibility of using this type of instrument was not pursued.

An attempt was made to set up a system using a monochromater system and a photomultiplier tube as the detector but it was very difficult to maintain a stable calibration when moving lamps to scan the electrodes and maintaining the tight control over the optical system targeting the electrode on the entrance to the monochromater. If a simpler system could be employed it would be better for this project but for any further work involving more accurate or detailed temperature measurements this system could probably be made to work.

The two colour or ratio pyrometer was adopted initially as a possible convenient measuring instrument and the performance and limitations of the instrument are discussed in more detail in Appendix 2. The two colour instrument was eventually found to be unsuitable for use as a measuring instrument in this investigation due mainly to problems of arc interference and too large a measuring field.

Finally, the instrument chosen to make the measurements was the disappearing filament pyrometer which was considered sufficiently accurate, probably the simplest instrument to use, very versatile and has very good spatial resolution. The use of the instrument and discussion of its limitations will be discussed in greater detail in sections 4 and 6.

4. EXPERIMENTAL PROCEDURE

4.1 Temperature Measurement Technique

As has been established the instrument chosen to make the temperature measurements is the disappearing filament pyrometer. To restate the reasoning behind the choice a number of factors influenced the selection:-

a) Availability - at least two instruments were available for use.

b) The simplicity of operation and versatile optical system mean that setting up the measurement system can be done very quickly and measurements can be performed rapidly.

c) The very large temperature range of the instrument means that extremes of temperature encountered by over-running or under-running lamps can be easily accommodated.

d) Good spatial resolution can be achieved enabling detailed thermal profiles to be obtained.

e) The use of the red filter helps minimise the errors caused by measuring temperatures with the lamp running.

f) These instruments have been used extensively to give satisfactory results at similar temperatures in investigations into temperatures of tungsten filaments in incandescent lamps.

The instrument does have some limitations and an attempt is made to quantify the errors of the measurement system and those limitations are considered in the treatment of the results.

One problem which is encountered with any form of radiance pyrometry is the necessity to obtain a value for the emissivity of the material being measured in order to correct to true temperature. The difficulty arises because emissivity is dependant on the surface texture of the material and can be affected by the method of manufacture and to obtain a definite value is obviously very difficult.

A further source of error is the subjective nature of the colour matching of the filament to the target although this can be minimised by the use of a single operator for all measurements and by calibration checks against a standard lamp. Finally, the narrow spectral region observed does reduce errors caused by arc radiation but it cannot be totally eliminated. Attempts were made to evaluate quantitatively the error introduced.

4.2 Pyrometer Calibration Procedure

Due to a problem of availability of the disappearing filament pyrometers two instruments had to be used to make the measurements. Both instruments were of the same type and model and both were checked against our N.P.L. calibrated tungsten strip lamp radiance temperature standard for the accuracy of their calibration.

The instruments used are Pyro-WERK GMBH micro-pyrometers, Serial Numbers 3161 and 3342. All measurements used a standard supplementary lens designated D by Pyro-WERK which gives a magnification of 33 times. (This lens was subsequently used for all measurements).

corrections were made to measured temperatures to compensate for the lens used as given in the manufacturers literature. (Table 2).

The instrument is shown schematically in Figure 15 and its layout is shown in Figure 18. The operating procedure is as follows:-

The filament is set to maximum sharpness by turning the eyepiece lens. Once the target is in approximate line of sight the measurement point is brought into focus by adjustment of the focusing screw. The red filter is now turned into the optical path and the instrument is ready to make a measurement. The battery supply to the pyrometer is switched on and whilst observing via the eyepiece the coarse and fine resistances located on opposite sides of the instrument are adjusted until the filament tip is no longer visible against the target i.e. both have the same radiance. At this point the measured temperature can be read from the milliameter which is calibrated in black body radiance temperature in degrees centigrade. To this temperature must be added the lens correction and a measured radiance temperature is obtained.

The required lens correction is specified by the manufacturer as is shown in Table 2 and was plotted as shown in Figure 19. This plot was used to obtain the correction to add to convert the reading obtained from the pyrometer to an indicated radiance temperature.

INDICATED TEMP. ^{o}C	CORRECTION + ^{o}C
1300	4.0
1400	7.6
1500	10.5
1600	14.4
1700	17.5
1800	20.0
1900	22.0
2000	24.0
2500	30.0
3000	36.0
3500	42.0
4000	48.0
4500	54.0
5000	60.0

TABLE 2

ABSORPTION CORRECTION FOR PYROMETER READINGS WHEN USING LENS D. Obtained from manufacturers literature.

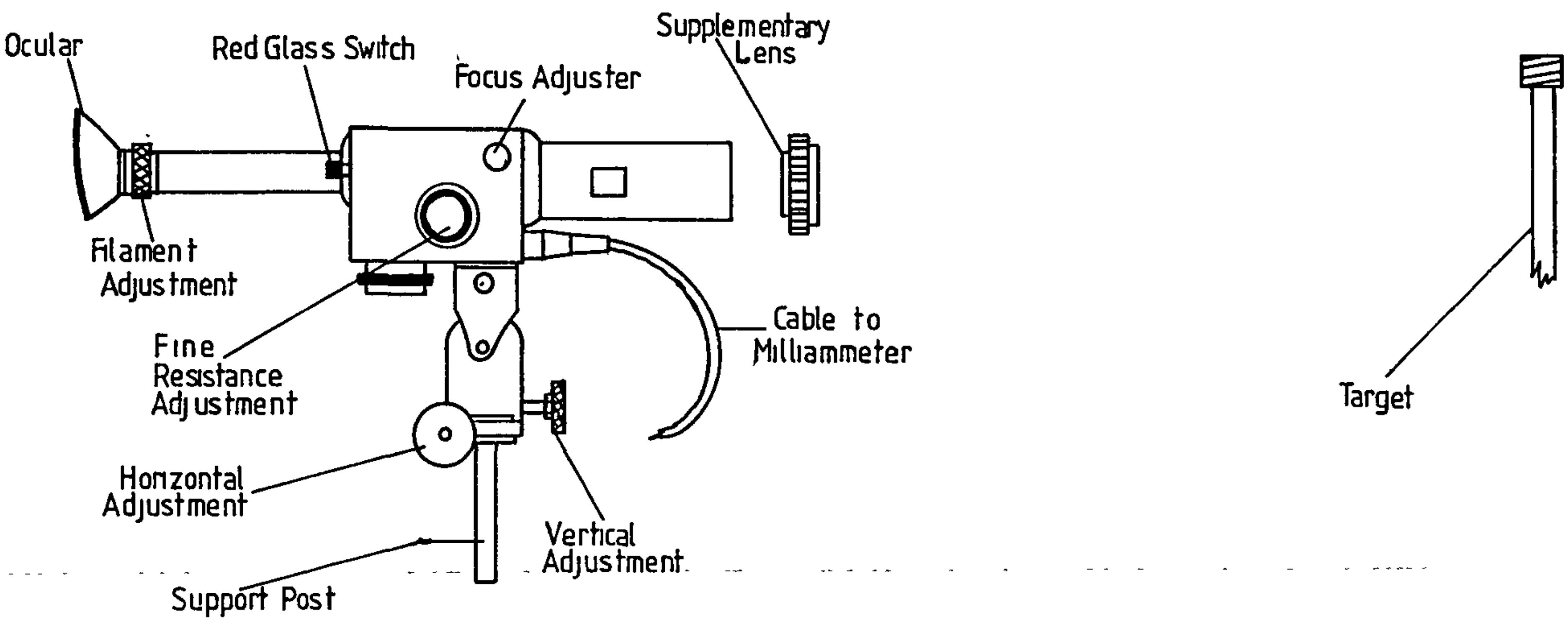


Figure 18. Disappearing Filament Pyrometer

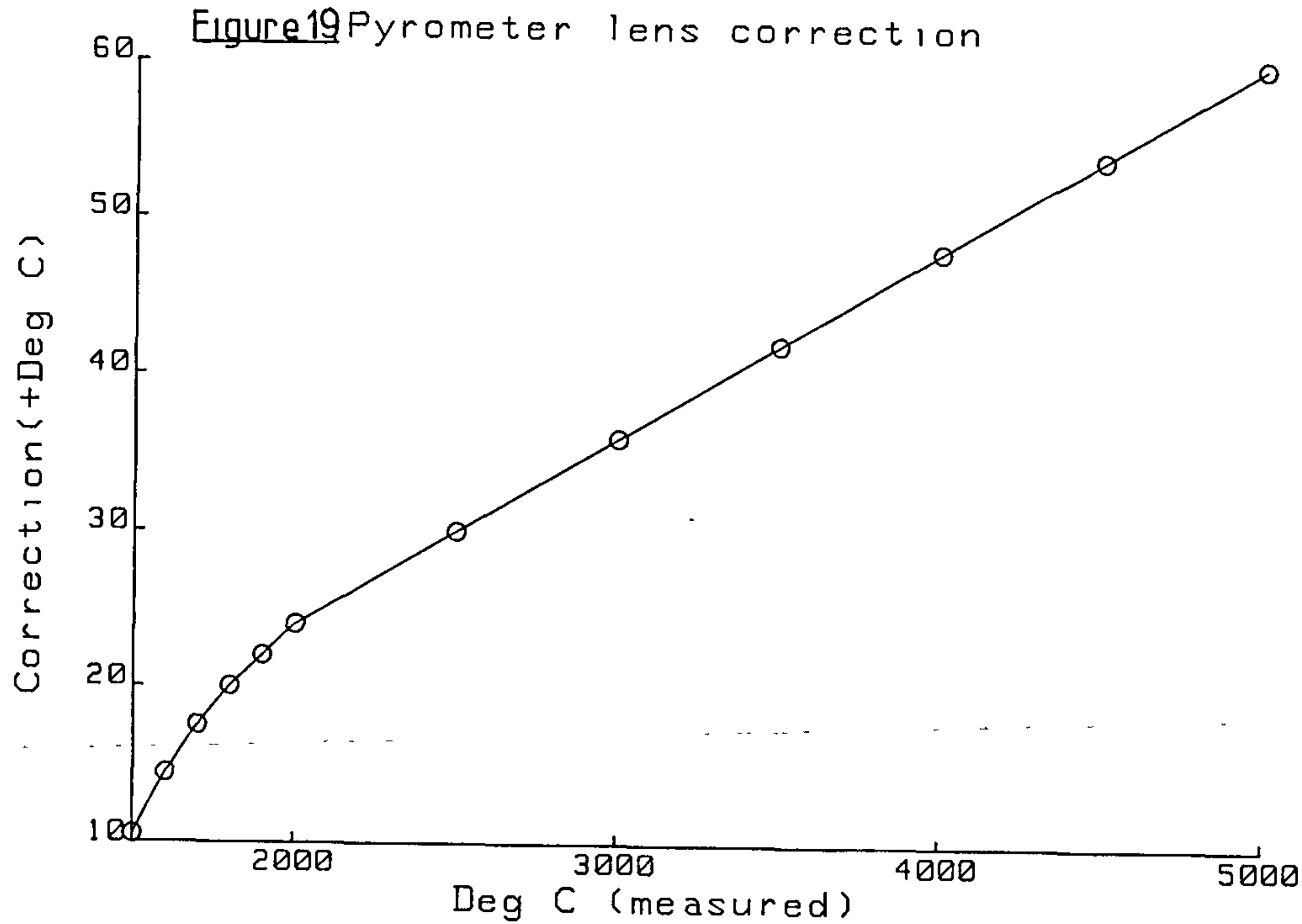


Figure 19 Pyrometer lens correction
60
50
40
30
20
10
Correction (+Deg C)
2000
3000
4000
5000
Deg C (measured)

In order to verify the calibration of the instruments to be used, they were checked against an N.P.L. radiance temperature standard tungsten strip lamp. Unfortunately the available standard lamp is only calibrated in the range 1,300 to 2,300 degrees centigrade and consequently any modification to the calibration above 2,300^{o}C must be an extrapolated figure.

The calibration measurements were carried out with the pyrometer mounted as for all measurements in a micromanipulator on an optical bench with the lamp supported by a clamp onto the lampholder. With the pyrometer set horizontally and targeted on the central portion of the strip lamp, a series of measurements were taken at 50 degree steps from 1,300 to 2,300 degrees centigrade. The pyrometer was used with the lens used for the regular measurements and the relevant lens correction was added to the measured temperature. The results are shown in Table 3.

A linear regression straight line fit was applied to the calibration data and the following relationships were found to hold better than $\pm$ 0.5% at all measured points:-

	Pyrometer No. 3161	No. 3342
Scale 1:	True = 63 + 0.975 Tmeas	True = 63 + 0.966 Tmeas
Scale 2:	True = 64 + 0.983 Tmeas	True = 48 + 0.981 Tmeas
Scale 3:	True = 1.065 Tmeas-45	True = 1.091 Tmeas -147

Where Tmeas = measured temperature corrected for lens and True = True radiance temperature, the above relationships were used to convert all measured temperatures to radiance temperatures.

TRUE TEMPERATURE °C	PYROMETER SCALE	No.3161 MEASURED TEMPERATURE °C	No.3342 MEASURED TEMPERATURE °C
1300	1	1269	1279
1350	1	1320	1335
1400	1	1371	1387
1450	1	1423	1434
1450	2	1407	1429
1500	2	1459	1480
1550	2	1511	1532
1600	2	1563	1583
1650	2	1614	1630
1700	2	1666	1687
1750	2	1717	1738
1800	2	1774	1784
1850	2	1820	1841
1900	2	1871	1886
1950	2	1917	1937
2000	2	1968	1988
2050	2	2014	2044
2100	3	2024	2064
2150	3	2054	2105
2200	3	2105	2146
2250	3	2156	2196
2300	3	2206	2247

TABLE 3

CALIBRATION DATA FOR PYROMETERS No. 3161 and 3342
(Measured temperature includes lens correction)

A further calibration check was performed using the standard lamp to evaluate the effect, if any, of the angle of measurement i.e. if the pyrometer is not sighted normal to the target. This was checked both horizontally and vertically.

The standard lamp was set to 1900^{O}C and the pyrometer targeted on the tungsten strip as for the calibration measurements at right angles to the source and a measurement taken. The pyrometer was then lowered 5mm using the micro-manipulator and by rotating the pyrometer upwards using its vertical adjuster, the source resighted and a further measurement taken. This procedure was repeated in 5mm steps to the limit of adjustment on the micro-manipulator which in the vertical plane is 20mm. The procedure was then reversed with measurements being taken from the maximum displacement 20mm back to 0.

A similar exercise was performed but moving in the horizontal plane with 5mm steps from 0 to 25mm and returning as before. The results are shown in Table 4 and show that within the range tested the measured temperature is not affected by the target-pyrometer angle. This suggests that maintaining the pyrometer perfectly normal to the measurement surface is not essential to obtain reliable results.

4.3 Experimental Procedure

The lamps used for the measurements were operated on the control gear specified in Sections 2.2.a and 2.2.b for alternating and direct current respectively. As Figures 10 and 11 show, both circuits utilise meters to monitor the voltage

SET TEMPERATURE °C	VERTICAL DISPLACEMENT mm	HORIZONTAL DISPLACEMENT mm	MEASURED TEMPERATURE* °C	
			1	2
1900	0	0	1881	1881
1900	5	0	1881	1881
1900	10	0	1886	1881
1900	15	0	1886	1886
1900	20	0	1881	1886
1900	0	0	1881	1881
1900	0	5	1886	1881
1900	0	10	1881	1881
1900	0	15	1881	1886
1900	0	20	1886	1886
1900	0	25	1881	1881

* 1 is temperature measured on first run starting displacement = 0

2 is temperature measured on second run ending displacement = 0

TABLE 4

MEASURED v TRUE BRIGHTNESS TEMPERATURE WITH VARYING DISPLACEMENT BOTH VERTICAL AND HORIZONTAL FROM NORMAL MEASUREMENT POSITION.

across and the current flowing through the lamp. In the alternating current case this is done using a single meter, a Cambridge A.C. test set which is a moving coil instrument capable of measuring not only voltage and current but also the lamp wattage. The maximum current handling capacity of this test set is 20 amps and since at its rated wattage the 2.5kW CID lamp current is greater than 25 amps it was necessary to use a current transformer to step down the current by a factor of ten. The particular test set used, Serial No. SED 490, had its calibration verified by our standards laboratory and the calibration certificate is included in Appendix 4. For the various sets of measurements after stabilising for five to ten minutes the lamp wattage was set to the required value by varying the supply voltage by means of a variable transformer, this alters the lamp current and hence wattage.

In direct current operation measurements were made using three separate instruments, a D.C. wattmeter and ammeter for wattage and current and the same Cambridge instrument to measure the lamp voltage. Variations in the operating power of the lamps on D.C. was achieved by switching in or out elements of the ballast which is a bank of resistance elements wired in parallel. This has the disadvantage that wattage can only be varied in steps and not in a continuous manner as for the A.C. circuit.

Because these lamps are high pressure discharges and during operation have an internal pressure of several atmospheres there is a slight chance of the lamp failing in an explosive manner and consequently as a safety precaution it is necessary to operate the lamps in a wire mesh cage. The cage has a cut out section to enable the pyrometer to view the electrodes directly. The physical format of the system is shown in Figure 20. The lampholder is mounted on a table the height of which can also be adjusted.

Since, as specified earlier, this investigation is concerned only with the steady state condition achieved when the electrodes reach a stable temperature, the first problem is to determine at what point this stable condition is achieved.

In order to determine how long after switch on of the lamp this stable state is achieved a series of measurements were made at various times after switch on of a lamp and at different positions along the electrode. The results of this trial are shown in Table 5. X in Table 5 represents the displacement from the tip of the electrode at which the readings were taken and the measurement was taken central in the lateral plane. The results of Table 5 show that the electrode temperatures reach a stable value relatively quickly between 7 and 14 minutes at the longest and consequently all lamps will be allowed a minimum 15 minutes stabilisation time after switch on to achieve a temperature equilibrium before any measurements are taken.

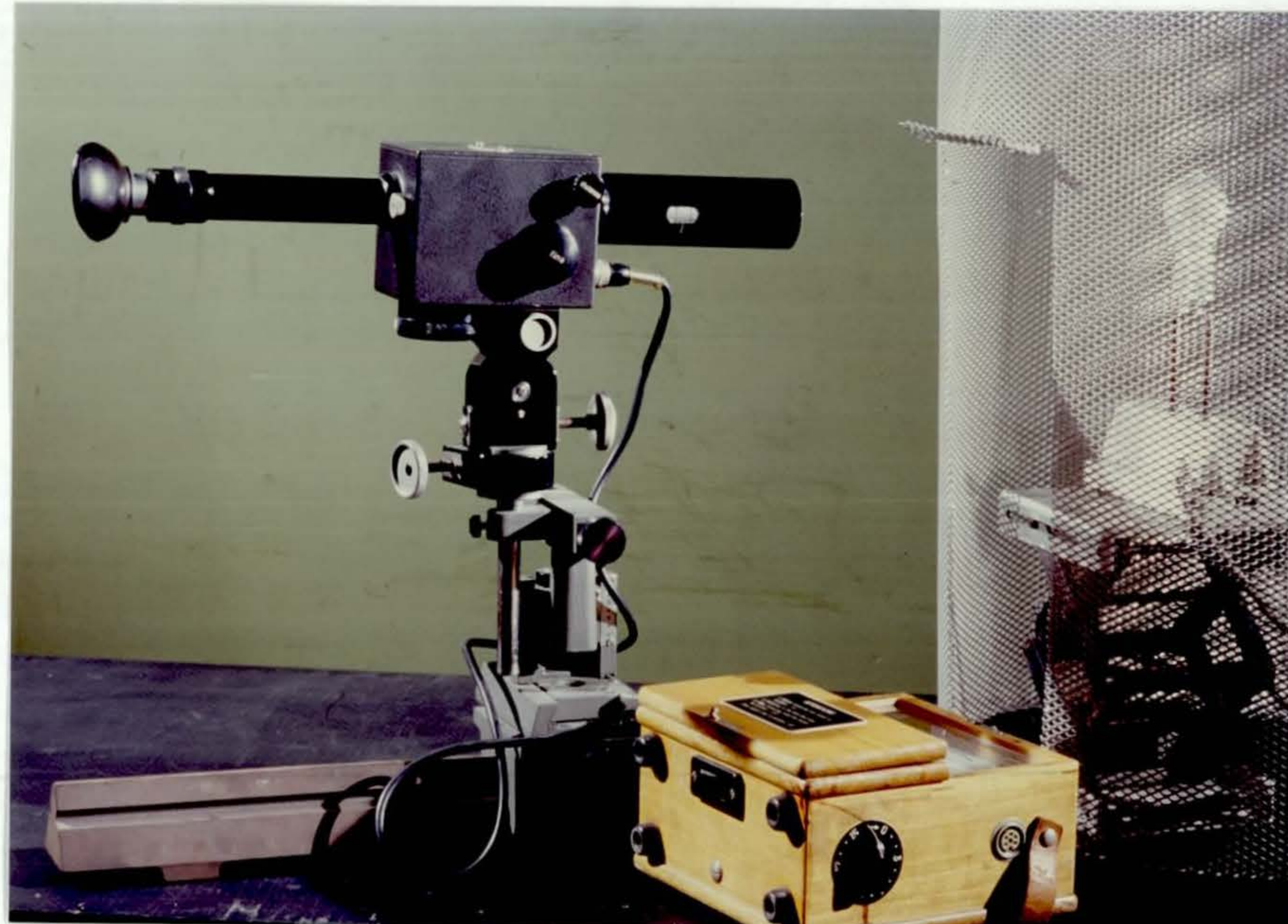


Figure 20. Disappearing filament pyrometer as used for temperature scans

X	TIME (Min)	MEASURED TEMP. °C (Including lens correction)
2.5mm	2	2429
2.5	7	2449
2.5	14	2409
2.5	17	2419
2.5	28	2409
8.0	2	1988
8.0	8	1983
8.0	21	1983
8.0	36	1983

TABLE 5

TEMPERATURE v TIME FOR POINTS ON THE RIGHT* HAND ELECTRODE OF 2.5kW CID LAMP NUMBER 1.

* CID Lamps have an identifying number stamped on the pinch seal and right and left are taken with that number facing the observer.

Having specified in the preceding sections the methods of operating and obtaining a calibration for the pyrometer and of controlling and monitoring the lamp at its required wattage, the following will deal with the method of measuring the electrode temperatures and the measurements taken.

Having set the lamp to run at the desired wattage and allowed it to stabilise for a minimum of fifteen minutes, the micro-manipulator holding the pyrometer was set to its zero position for horizontal and vertical travel and with the pyrometer set approximately horizontal, the pyrometer filament was targetted on the upper tip of the electrode coil and central in the horizontal plane. A temperature measurement is then taken at this point which is taken as the x = 0 point. Using the micro-manipulator the pyrometer is then lowered to the second measurement point and a second temperature reading taken. This process is then repeated taking measurements until the electrode shank is obscured as it enters the pinch seal region. The scan obtained is represented schematically in Figure 21 (a).

For each electrode under a specific set of conditions this process is repeated taking scans from both front and rear of the lamp (front is always specified as the side on which the lamps identification number is stamped) and a measurement from the outer side of the lamp. This process is then repeated for the second electrode. The six sets of measurements made per lamp are shown schematically in Figure 21 (b).

Measurements were taken in this way of a number of standard production 2.5kW CID lamps at 1.5, 2.0 and 2.5kW both on alternating and direct current.

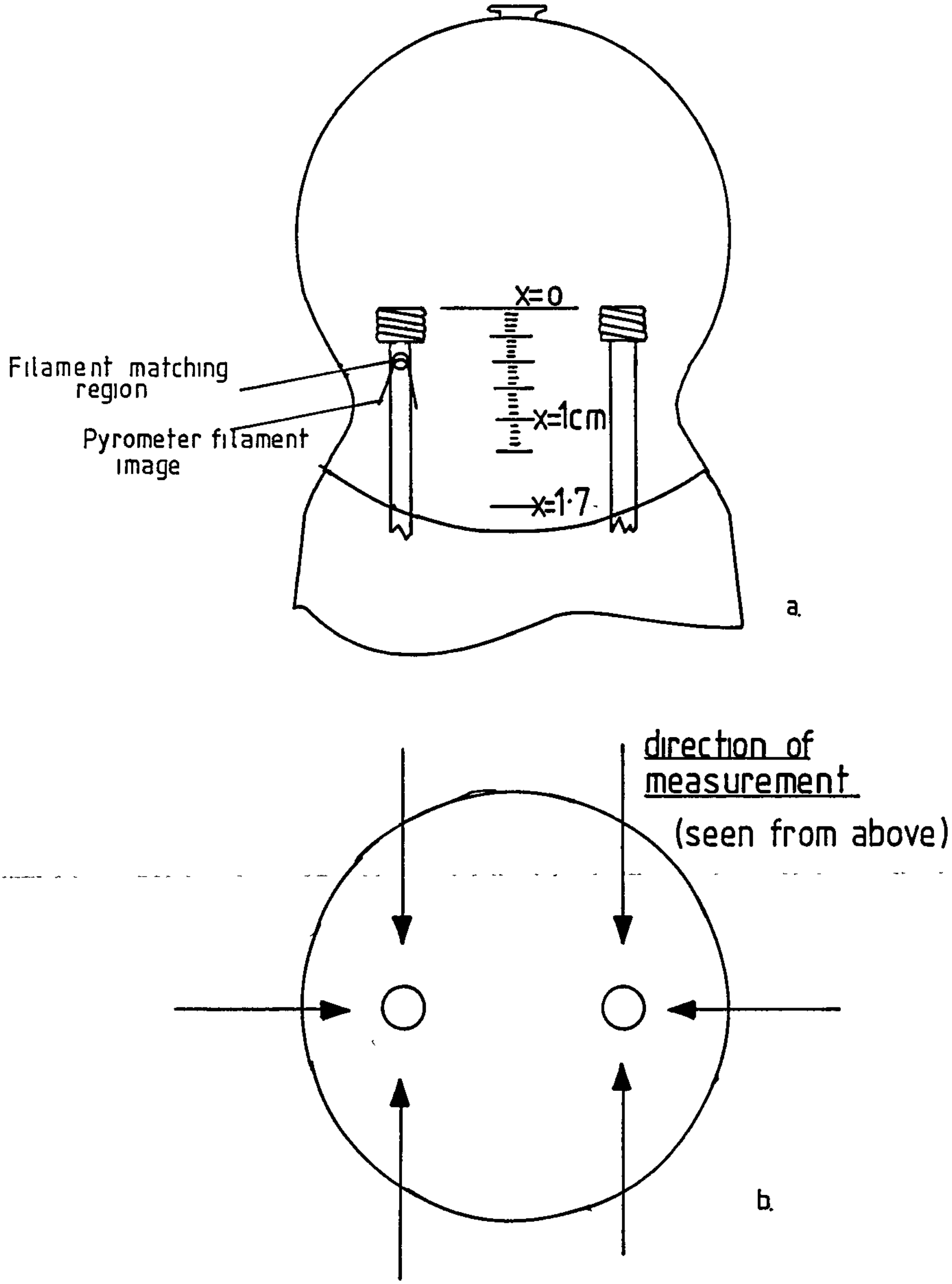


Figure 21. Illustration of temperature measurements to obtain temperature profile

Several specially constructed lamps were measured, two having no coils at the electrode tip and one lamp having odd sized electrodes for direct current operation. Also, a number of 1kW CSI/CID lamps were measured at rated wattage.

The resultant temperature profiles are, for each electrode,in the form of three sets of measurements from the three aspects. In order to establish a temperature profile for the entire electrode it is simpler to have a single value of temperature for each point along the electrode. This is achieved by simply averaging the three values at any given X point along the electrode. This gives a profile in a more easily presented form and has the advantage of removing local effects such as the arc attaching to one side of the electrode. Variations in the temperatures obtained at a single X point on an electrode from the different aspects of up to 200 degress Kelvin were obtained. These differences were more pronounced in the tip region where the arc attached to one side of the electrode leaving the opposite side cooler. With the small diameters of rod involved in this investigation such discrepancies do not cause any major problems in calculating an average profile but if much larger diameters of rod were to be used this would not be the case.

4.4 Reproducibility

A number of measurements were made and repeated with the lamp running under identical conditions after a minimum period of 24 hours in order to assess the reproducibility of the measurement technique. The measured data obtained is shown in Table 6 (data is as measured uncorrected for lens, calibrations or emissivity) and shows that the measurement system is reproducable to significantly better than ± 5%.

X	INITIAL MEASUREMENT °C	REPEAT MEASUREMENT °C	ΔT	% DIFFERENCE	INITIAL MEASUREMENT °C	REPEAT MEASUREMENT °C	ΔT	% DIFFERENCE
0	2050	2020	30	1.5	2410	2360	50	2.1
.05	2035	2010	25	1.2	2350	2370	20	0.8
.15	1985	1985	0	0	2300	2290	10	0.4
.25	1945	1945	0	0	2250	2190	60	2.7
.35	1905	1915	10	0.5	2090	2080	10	0.5
.4	1865	1870	5	0.3	2050	2030	20	1.0
.5	1840	1850	10	0.5	2000	1970	30	1.5
.6	1820	1810	10	0.5	1920	1900	20	1.0
.7	1780	1775	5	0.3	1860	1840	20	1.1
.8	1690	1735	45	2.7	1795	1770	25	1.4
.9	1680	1700	20	1.2	1755	1700	55	3.1
1.0	1680	1690	10	0.6	1680	1655	25	1.5
1.1	1640	1660	20	1.2	1610	1595	15	0.9
1.2	1600	1625	25	1.6	1550	1540	10	0.6
1.3	1605	1605	0	0	1520	1515	5	0.3
1.4	1575	1575	0	0	1490	1485	5	0.3
1.5	1550	1550	0	0	1460	1450	10	0.7
1.6	1515	1520	5	.3	1440	1435	5	0.3
1.7	1500	1485	15	1.0	1430	1430	0	0

TABLE 6

Repeated sets of measurements with lamp operating under identical conditions for initial and repeat measurement. All measurements made on lamp No. 238 under various operating conditions. X in Cm and temperatures as indicated by pyrometer uncorrected.

X	INITIAL MEASUREMENT °C	REPEAT MEASUREMENT °C	ΔT	% DIFFERENCE	INITIAL MEASUREMENT °C	REPEAT MEASUREMENT °C	ΔT	% DIFFERENCE
0	2420	2400	20	0.8	2610	2630	20	0.8
.05	2370	2330	40	1.7	2350	2350	0	0
.15	2380	2350	30	1.3	2275	2350	75	3.3
.25	2300	2310	10	0.4	2250	2280	30	1.3
.35	2220	2225	5	0.2	2175	2225	50	2.3
.4	2175	2120	55	2.5	2145	2125	20	0.9
.5	2020	2050	30	1.5	2025	2045	20	1.0
.6	1955	1990	35	1.8	1980	2030	50	2.5
.7	1885	1920	35	1.9	1925	1960	35	1.8
.8	1810	1835	25	1.4	1900	1910	10	0.5
.9	1740	1760	20	1.1	1840	1855	15	0.8
1.0	1665	1690	25	1.5	1780	1785	5	0.3
1.1	1595	1630	35	2.2	1680	1690	10	0.6
1.2	1550	1575	25	1.6	1600	1630	30	1.9
1.3	1500	1530	30	2.0	1560	1585	25	1.6
1.4	1465	1495	30	2.0	1590	1560	30	1.9
1.5	1440	1470	30	2.1	1595	1560	35	2.2
1.6	1440	1465	25	1.7	1540	1520	20	1.3
1.7	1445	1460	15	1.0	1525	1500	25	1.6

TABLE 6 (Cont)

5. RESULTS

The results obtained as described have been corrected by the use of the factor to compensate for the supplementary lens used on the pyrometer but require correction for the calibration error of the pyrometers to yield a true radiance temperature.

Having obtained this value of radiance temperature a further correction is required to obtain the true surface temperature as the target material, tungsten, is far from behaving like a black body. This correction can be derived by considering Weins Law:

$$\epsilon_\lambda C_1 \lambda_B^{-5} \exp\left(-C_2/\lambda_B T\right) = C_1 \lambda_B^{-5} \exp\left(-C_2/\lambda_B S_B\right) \qquad 5.1$$

Where S_B = apparent (measured) temperature in K

ϵ_λ = emissivity at wavelength λ

C_1 and C_2 are radiation constants

T = true temperature (K)

λ_B = effective measuring wavelength

So
$$T = \left(\frac{1}{S_B} + \frac{\lambda_B \ln \epsilon_\lambda}{C_2} \right)^{-1} \qquad 5.2$$

Consequently if the emissivity is known at the wavelength used for measurement the true temperature of the target can be calculated.

The effective wavelength for this instrument is determined by the filter used and taken to be 0.65 μm as specified by the manufacturers literature and the value of emissivity is taken from de Vos's data (12) to be 0.43 which represents an average value for the temperature range under consideration. Variation of emissivity with temperature over the measured range will cause less than $\pm$ 1% error in the resultant temperature and so is not a major source of error.

All sets of measured data were transferred onto casette tape via a Hewlett Packard 85 mini-computer for storage and so the pyrometer calibration as specified in Section 4.2 and emissivity corrections were made by the creation of a correction sub-routine in the program written to store the data on the tapes.

The temperature profiles stored on the computer tapes are now true measured surface temperatures for tungsten in degrees Kelvin v displacement from the electrode tip in centimetres. As six sets of measurements exist for each lamp measured under any particular operating conditions the total number of electrode temperature profiles is in the region of 150 - 200 and so only a summary of those results will be presented here.

Table 7 shows the temperature profiles obtained for each electrode of three standard production 2.5kW CID lamps operated on A.C. The results obtained show a good degree of similarity in temperature profiles for lamps of nominally identical construction operating under identical conditions. This similarity in profile for lamps of nominally identical construction operating under similar conditions is typical of all the results obtained in the investigation.

Figure 23 shows the variation in the average temperature profile of the three production 2.5kW CID lamps measured at 2.5kW, 2.0kW and 1.5kW on A.C. and shows that the basic profile shape remains unaltered

X	LAMP No. 238 T(K)		LAMP No. 339 T(K)		Lamp No. 301 T(K)	
	LEFT ELECTRODE	RIGHT ELECTRODE	LEFT ELECTRODE	RIGHT ELECTRODE	LEFT ELECTRODE	RIGHT ELECTRODE
0	3335	3252	3312	3273	3241	3197
.05	3190	3129	3230	3139	3177	3150
.15	3118	3097	3162	3055	3038	3114
.25	3075	3032	3114	2994	2906	3060
.35	2929	2965	2887	2934	2845	2890
.4	2853	2831	2814	2781	2723	2745
.5	2689	2761	2711	2663	2586	2662
.6	2620	2676	2634	2620	2526	2538
.7	2533	2571	2532	2546	2464	2477
.8	2476	2501	2473	2479	2387	2417
.9	2396	2436	2385	2375	2304	2337
1.0	2325	2355	2298	2331	2213	2253
1.1	2241	2292	2241	2269	2143	2168
1.2	2172	2232	2180	2220	2091	2128
1.3	2132	2172	2141	2153	2036	2084
1.4	2116	2108	2166	2093	1982	2041
1.5	2093	2068	2108	2050	1978	1991
1.6	2057	2019	2003	2051	1931	1974
1.7	2023	1953	-	-	1937	1923

TABLE 7

MEASURED TEMPERATURE PROFILES OF THE ELECTRODES OF STANDARD PRODUCTION 2.5kW CID LAMPS OPERATED AT 2,500W ON A C.

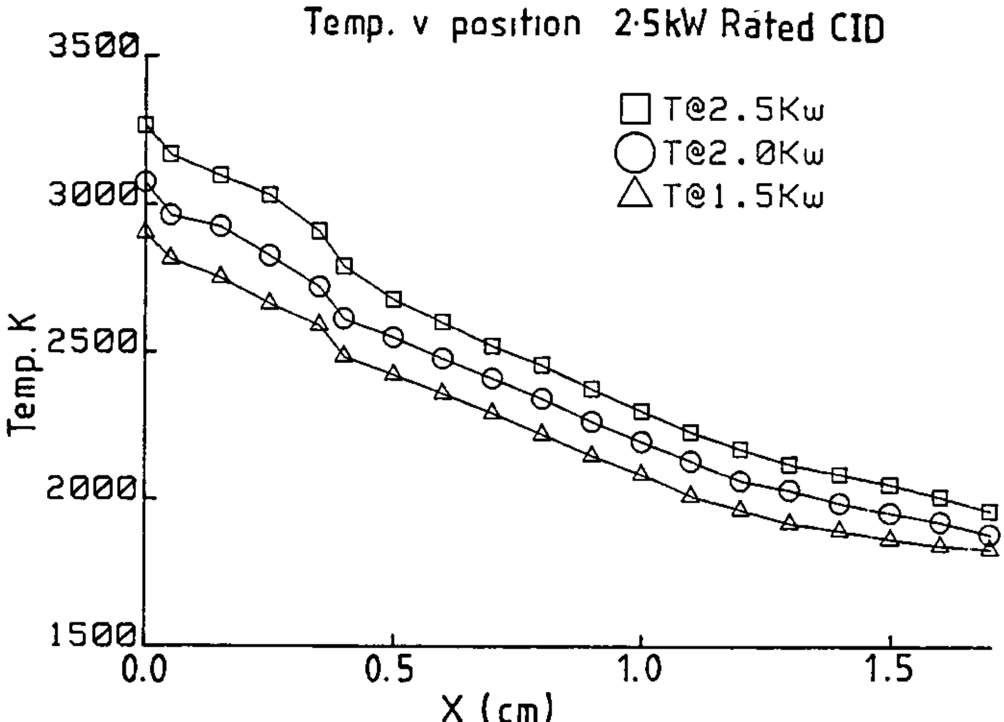


Figure 23 Average temperature profiles for standard 2·5kW CID lamps

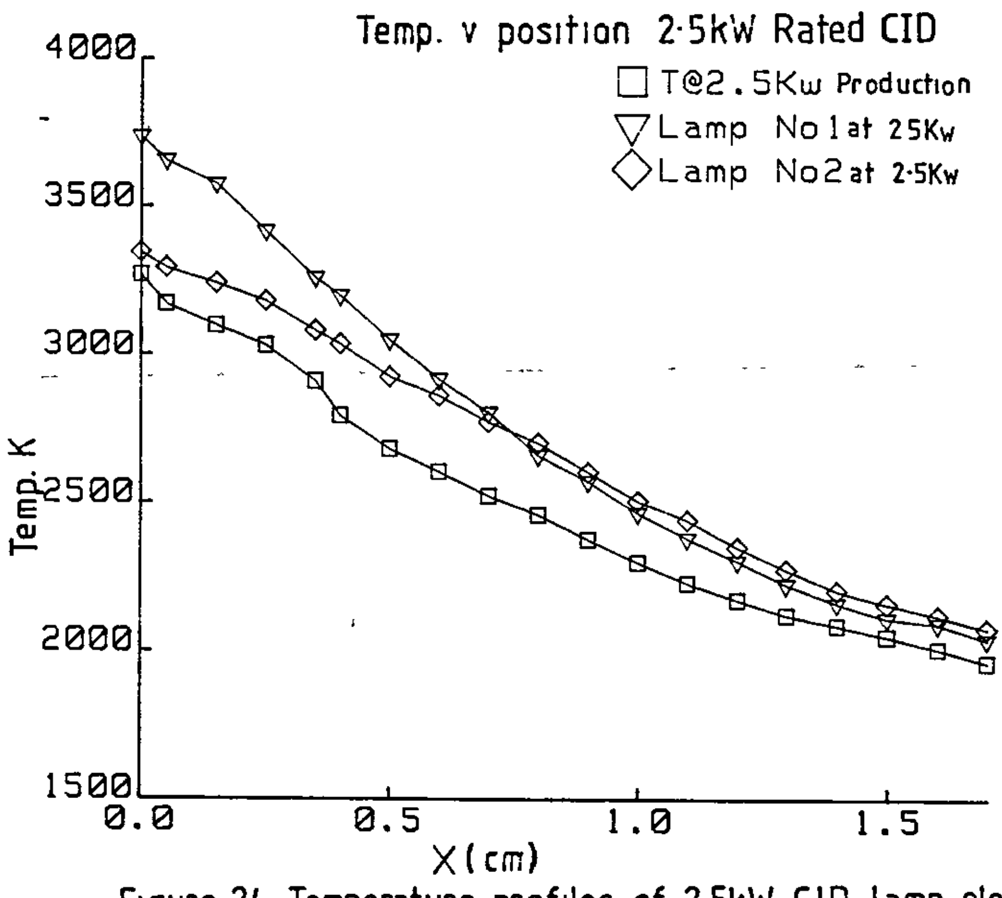


Figure 24. Temperature profiles of 2 5kW CID lamp electrodes of various geometries

as the lamp power is reduced but is displaced to lower temperatures.

Figure 24 shows the comparison between the average 2.5kW CID production lamp operated at rated power (2.5kW) on A.C. and the two specially constructed lamps having no overwind coils on the electrodes when operated under similar conditions. Lamp 1 has electrodes which are effectively standard shanks but with the overwind omitted and shows the considerable difference made by the overwind to the electrode performance. Lamp 2 has a larger than standard electrode shank and no overwind but still runs hotter than the standard electrode configuration.

One standard 2.5kW CID lamp operating at rated wattage on A.C. supply was measured at intervals during life testing in order to observe whether any change occurs in the temperature profile as a result of prolonged operation. The results are presented in Table 8 and show no significant change between the sets of measurement as the lamp is aged to 200 hours.

The profiles obtained operating a 2.5kW CID lamp on D.C. show a major difference between electrodes with the anode running at much higher temperatures than the cathode.

Figure 25 shows the profiles obtained at various wattages, D.C. operation, for lamp No. 339 and shows, as for the A.C. case, the profile shape is maintained but shifted to lower temperatures as the operating power is reduced.

X	LEFT ELECTRODE T(K)			RIGHT ELECTRODE T(K)		
	0 hrs	100 hrs	200 hrs	0 hrs	100 hrs	200 hrs
0	3342	3231	3231	3188	3034	3218
.05	3272	3273	3237	3237	3072	3211
.15	3188	3199	3197	3141	3062	3199
.25	3082	3215	3029	2974	2940	3023
.35	2953	2980	2976	2863	2820	2858
.4	2820	2843	2798	2675	2662	2706
.5	2715	2750	2750	2597	2609	2603
.6	2645	2702	2683	2540	2547	2551
.7	2574	2601	2597	2490	2485	2454
.8	2493	2545	2493	2403	2424	2415
.9	2430	2473	2403	2311	2342	2329
1.0	2341	2379	2310	2234	2278	2271
1.1	2272	2305	2261	2194	2228	2209
1.2	2234	2257	2198	2132	2182	2165
1.3	2184	2195	2148	2092	2100	2106
1.4	2134	2122	2085	2071	2057	2061
1.5	2082	2078	2059	2027	2040	2089
1.6	2060	2074	2070	1966	2029	2050
1.7	2013	2040	2056	1914	1973	-

TABLE 8

Variation of temperature with position for the electrodes of 2.5kW CID lamps run at 2.5kW and measured at intervals through the lamps life.

Temperatures in K, X in Cm.

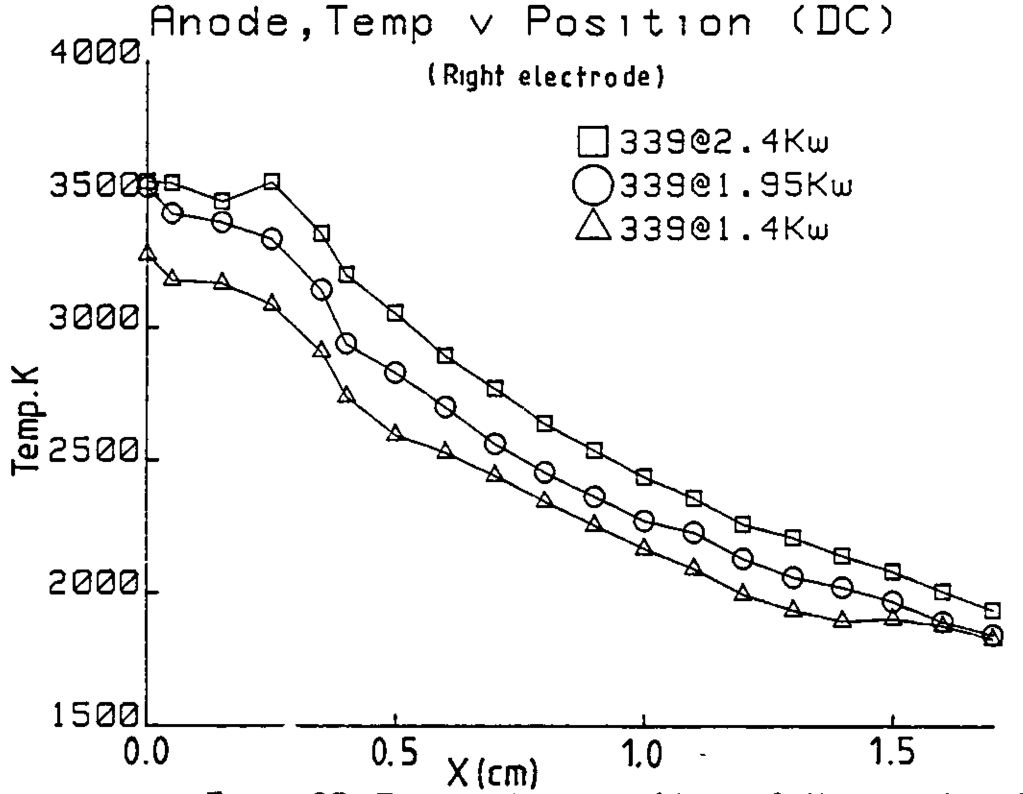


Figure 25 Temperature profiles of the anode of 2·5kw CID lamp no. 339 D.C. operation

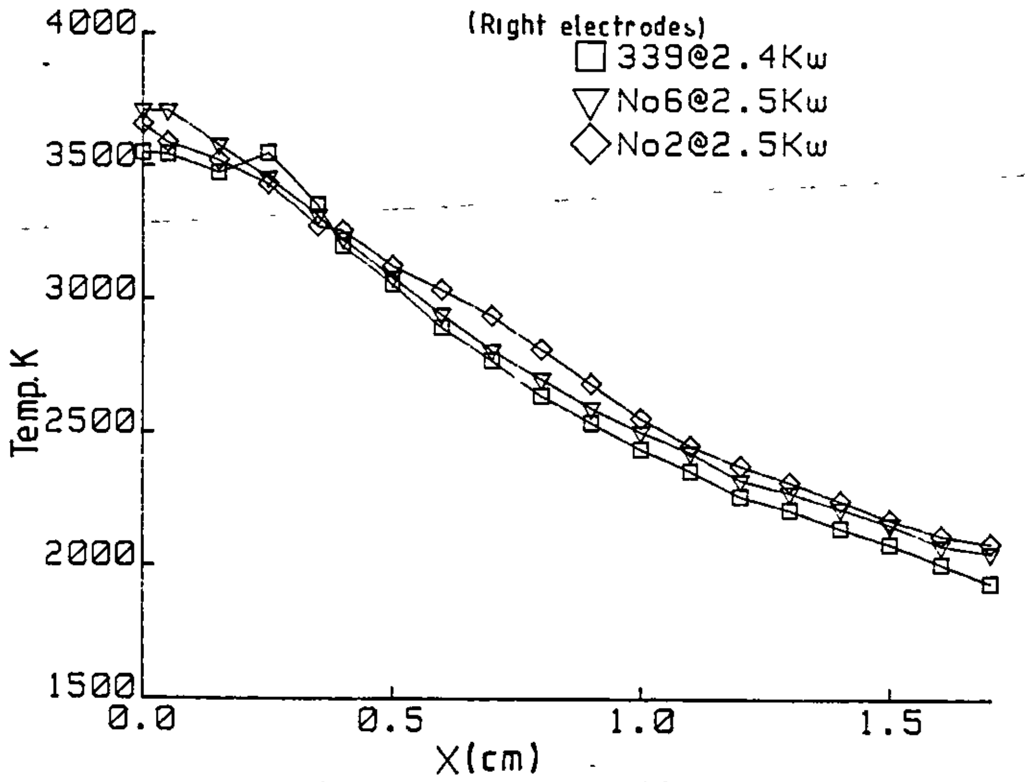


Figure 26 Temperature profiles of 2·5kW CID lamp anodes of various geometries D.C. operation

Figure 26 shows the profiles of the anodes of lamp Nos. 2 and 6 compared to No. 339 when operated at similar powers. The profiles for Nos. 2 and 6 are of particular interest as they have anodes of the same size but considerably different cathode sizes, see Table 1, and the anode profiles are similar indicating that the anode profile is independent of cathode geometry. The cathodes of these lamps show a markedly different profile as can be seen in Figures 27 and 28. The profiles of Lamp No.339 at varying powers, Figure 27, again shows the similar shaped profile shifting to lower temperatures as lamp power is reduced.

Figure 28 shows the considerable difference a change in geometry can make to an electrode profile.

Comparison of Figures 25 and 27 shows the considerable difference in temperature between anode and cathode of lamps operated on D.C. and also from Figures 26 and 28 that the difference can be narrowed by a change in geometry of one or both of the electrodes.

The measured profiles for the 1kW CSI/CID lamps are shown represented graphically in Figure 29. The results are for A.C. operation at rated wattage and represent the average of both electrodes of one lamp for the CSI and of two lamps for the CID figures. Although the CID does display slightly higher electrode temperatures it is possible that it could simply be accounted for by lamp to lamp variation as it is a relatively small difference.

Two 2.5kW CID lamps Nos. 1 and 2, were also measured for tip temperature ($x \simeq 0$) with change in current (A.C. operation) and the results are shown in Table 9.

The measured values as presented in Figures 23 to 29 are shown tabulated in Appendix 3.

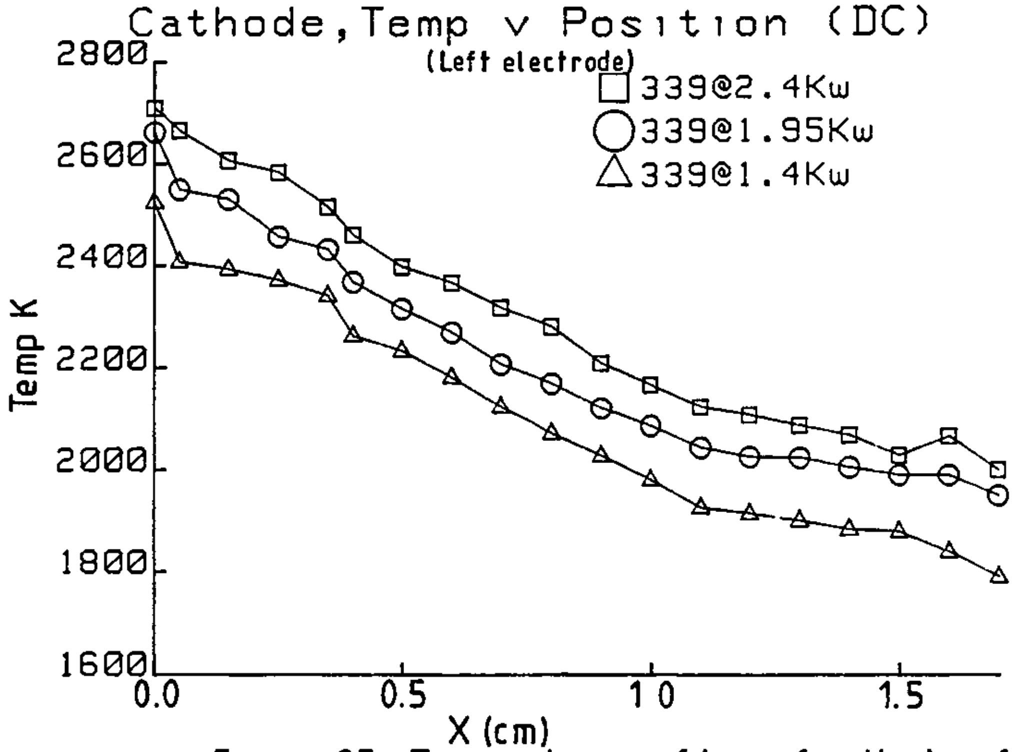


Figure 27. Temperature profiles of cathode of 2·5kW CID lamp no.339 operated on DC

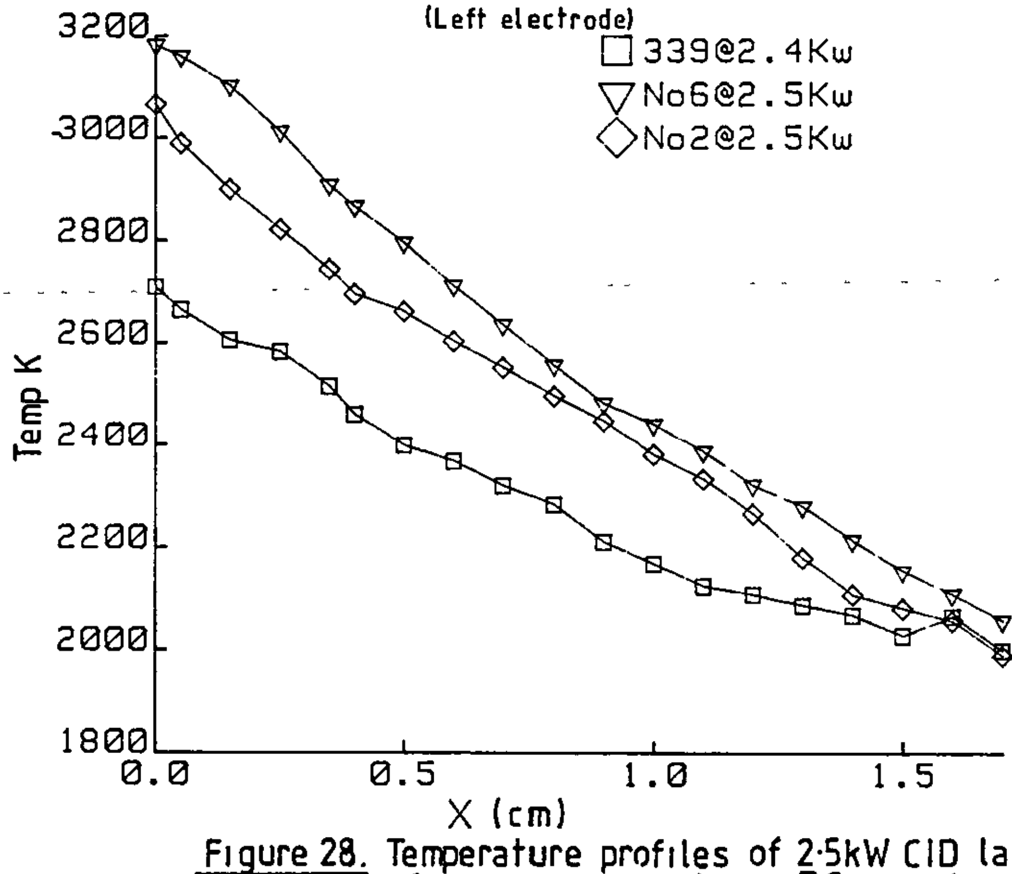
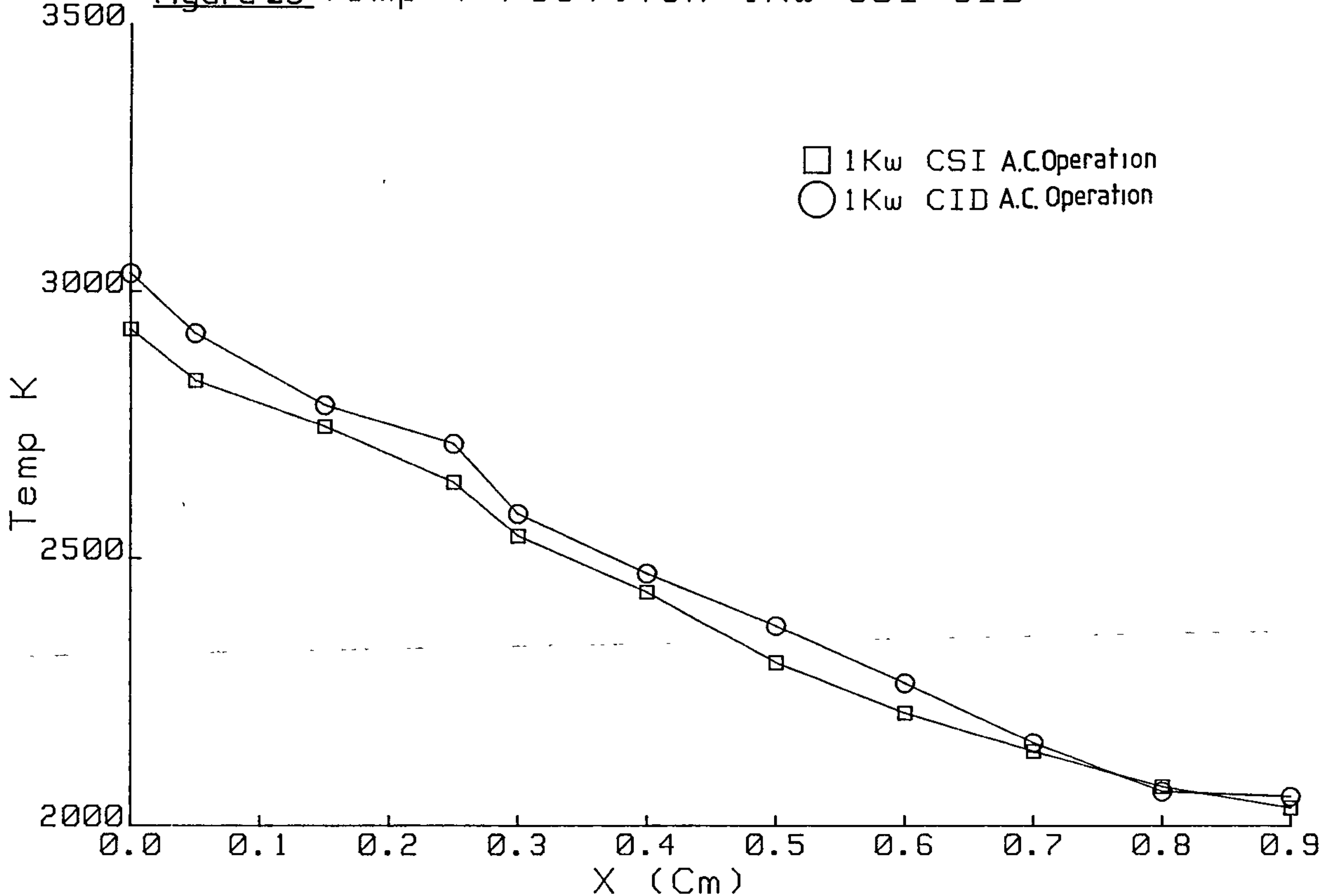


Figure 28. Temperature profiles of 2·5kW CID lamp cathodes of various geometries DC operation

Figure 29 Temp v Position 1Kw CSI/CID



	No.1		No.2	
I amps	T(K) LEFT ELECTRODE	T-RIGHT ELECTRODE	T-LEFT ELECTRODE	T-RIGHT ELECTRODE
27.5	-	-	3378	3308
25.0	3607	3575	3282	3163
22.5	3443	3455	3172	3112
20.0	3296	3358	3053	2932
17.5	3160	3182	2941	2823
15.0	2948	2999	2840	2627

TABLE 9

Tip temperature (i.e. $x = 0$) variation with lamp current for lamps No. 1 and 2. A.C. operation.

Temperatures K and Current I amps.

6. DISCUSSION

6.1 Development of Mathematical Model

The measured temperature profiles have shown that for lamps of similar construction running under similar conditions the resultant temperature profiles are comparable. If the relationships determining the interaction of lamp dimensions, running conditions and any other variables could be related to the resultant performance of the lamp this would give insight into the processes occuring in the lamp during operation and possibly provide a useful tool which could be used to design new electrode systems or make improvements in existing systems.

In order to try to build a model of what is happening in an operating electrode system we must consider in its simplest terms what is occuring in such an electrode during operation.

The electrode is conducting current and also being heated at its upper surface by the arc and dissipating that energy by conduction along its length and radiation from its surface. This picture can be simplified if we assume that no energy is transferred radially within the electrode i.e. at any point along the electrode no temperature gradients exist radially. We assume also that the only energy loss is by radiation radially from the electrode surface and by conduction along the electrode rod. That is, convection losses do not play a significant role.

Heating of the electrode is by conduction through the end face of the electrode from the arc and also by joule heating from the passage of current through the shank. In the case of the lamps under consideration the joule heating will be assumed to be negligible, the validity and implications of this assumption will be discussed in a later section.

If we now consider a very small element δx of an electrode performing as specified above, such as the element shown schematically in Figure 30 with energy Q_1 passing through surface A at temperature T and energy Q_2 leaving the element through surface B at a temperature $T-\delta T$. The balance of energy is lost by radiation, Q_R, from the surface of element.

Energy passing into the element through surface A is given by:-

$$Q_1 = K\pi r^2 \frac{dT}{dx} \qquad 6.1$$

where K = thermal conductivity of the electrode material
r = radius of the electrode

Energy passing out of the element through surface B is given by:-

$$Q_2 = K\pi r^2 \frac{d(T - \delta T)}{dx} \qquad 6.2$$

Energy dissipated from the surface of the element is given by:-

$$Q_R = 2\pi r \delta x \, \gamma T^{\nu} \qquad 6.3$$

Where the Stefan-Boltzman law is modified to

$$Q = \gamma T^{\nu} \qquad 6.4$$

Following the treatment of Schlegel, Ref. 5. For a black body $\gamma \doteq \sigma$ the Stefan Boltzmann constant and $\nu = 4$ and for a material obeying the Stefan-Boltzmann law

$$Q = \epsilon \sigma T^4 \qquad 6.5$$

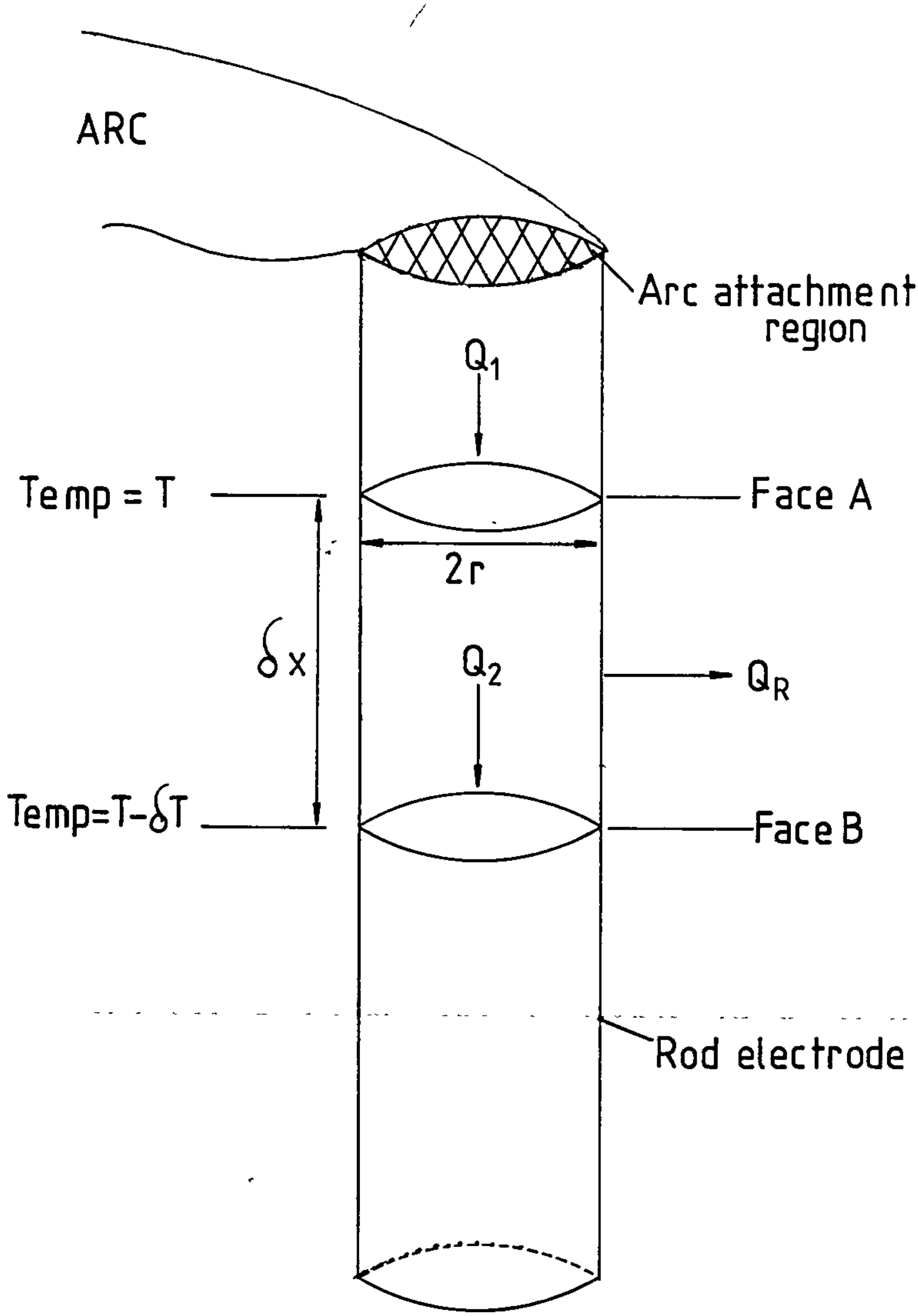


Figure 30. Schematic representation of energy flow in a small element of a rod electrode heated at one end

but for tungsten, the most common electrode material, ϵ is temperature dependant and the T^4 relationship does not hold true so it is more accurate to present the Stefan-Boltzmann equation in the modified form.

Values for γ and ν were obtained by a computer power plot performed on Forsythe and Worthings data (16) for the total radiation intensity variation with temperature of tungsten. Such a plot yields values of

$$\nu = 4.623$$

and $$\gamma - 1.281 \times 10^{-14}$$

If we now combine the three expressions governing heat flow through the element we obtain

$$Q_1 - Q_2 = Q_R \qquad 6.6$$

or $$\frac{d^2T}{dx^2} = \frac{2\gamma T^{\nu}}{Kr} \qquad 6.7$$

Values for γ and ν have already been obtained and r is the electrode radius but K, thermal conductivity, is another temperature dependant quantity and in order to obtain a value for K a computer power plot was performed on Forsythe and Worthings data (16) for the thermal conductivity of tungsten at various temperatures and a value of $K = 0.0543T^{0.397}$ is obtained.

So expression 6.7 now becomes

$$\frac{d^2T}{dx^2} = 4.7182 \times 10^{-13} r^{-1} T^{4.226} \qquad 6.8$$

A general solution to this differential equation would be extremely complex and so to achieve a useable solution we assume that the electrode behaves as an infinitely elongated one sided rod.

With the above assumption then as x tends to infinity then the temperature will approach 0 and $\frac{dT}{dx}$ also tend to 0.

If we make the substitution $u = \frac{dT}{dx}$

so $\frac{du}{dx} = \frac{d}{dx}\left(\frac{dT}{dx}\right)$ 6.9

$$\frac{d^2T}{dx^2} = \frac{d}{dx}\left(\frac{dT}{dx}\right) = \frac{du}{dx} = \frac{du}{dT} \cdot \frac{dT}{dx} = \frac{udu}{dT} \qquad 6.10$$

and $u\,\frac{du}{dT} = 4.7182 \times 10^{-13} r^{-1} T^{4.226}$ 6.11

$$\text{so } \tfrac{1}{2}u^2 = \int 4.7182 \times 10^{-13} r^{-1} T^{4.226}\, dT + C \qquad 6.12$$

$$\text{or } \quad u = \frac{dT}{dx} = \left[\frac{2 \times 4.7182 \times 10^{-13} r^{-1} T^{5.226} + C}{5.226}\right]^{1/2} \qquad 6.13$$

but $\frac{dT}{dx} = 0$ and $T = 0$ at $x = \infty$

So C must be 0 and

$$\frac{dT}{dx} = \left[\frac{2 \times 4.7182 \times 10^{-13} r^{-1} T^{5.226}}{5.226}\right]^{1/2} \qquad 6.14$$

$$\text{therefore} \quad x = \int_{T_0}^{T} \left[\frac{2 \times 4.7182 \times 10^{-13} r^{-1} T^{5.226}}{5.226}\right]^{-1/2} dT \qquad 6.15$$

Where x is the distance separating two points at temperatures T_0 and T. For $x = 0, T = T_0$ and for $x = x$, $T = T$,

$$\text{so} \quad x = \left[\frac{2 \times 4.7182 \times 10^{13} r^{-1}}{5.226}\right]^{-1/2} \frac{1}{1.613} \left[T^{-1.613} - T_0^{-1.613}\right] \qquad 6.16$$

$$\text{or} \quad T = \left[6.854 \times 10^{-7}(x) r^{-0.5} + T_0^{-1.613}\right]^{-1/1.613} \qquad 6.17$$

So given the radius of an electrode and the temperature of its tip, at $X = 0$, we have an expression which relates the distance from the tip of the electrode to the temperature at that point.

Since we are assuming all power supplied to the electrode is conducted through its end face then N, the power loss to the electrode, is given by

$$N = K \quad A \left(\frac{dT}{dx}\right)_0 \qquad 6.18$$

where A is the cross sectional area of the electrode.

So from 6.14

$$N = 2.307\pi \times 10^{-8} r^{1.5} T^{3.01} \text{ Watts} \quad \text{using } K = 0.0543T^{0.397} \qquad 6.19$$

and we can therefore relate the power loss to the electrodes to the measured tip temperature for a given rod diameter.

6.2 Errors in Measurement

The errors involved in the temperature measuring technique are very difficult to quantify accurately. The major source of error being the presence of the arc in such close vicinity to the material, the temperature of which is being measured. Radiation from the electrode must pass through clouds of absorbing and emitting gases along the optical path to the pyrometer. The red filter helps to reduce this effect but cannot be relied upon to totally eliminate such errors.

Differences in the curvature of the arc tube wall, through which the electrode is being viewed, may also lead to errors caused by reflections at the curved surfaces. These uncertainties in the accuracy of the temperature measuring technique suggest one aim of any work on extending this investigation would be to develop a method of establishing the size of these errors.

Attempts were made to quantify the errors caused, if any, by making temperature measurements with the lamp operating i.e. in the vicinity of the arc. This was done by making temperature measurements of a filament through a 2.5kW CID lamp i.e. with the pyrometer viewing the filament through the lamp bulb. This was done with the lamp off and repeated with the lamp operating. This trial did not yield any useful results as reliable colour matching with the filament was not possible even with the lamp not running. This was due to the reflections at the several quartz and glass surfaces through which the filament was being viewed and the condensed halides on the CID lamp wall when switched off causing obscuration of the filament.

An estimate of the accuracy obtained in the measurements is indicated by the measurements on lamp Number 1 on alternating current and Number 339 operated on Direct Current. The electrodes of both lamps when operated at 2.5kW show signs of the tungsten in the tip region becoming molten indicating a temperature in the tip area of 3655 K (melting point of tungsten). Examination of the measured temperatures for the electrode tips of these lamps show them to be within 150 K of the tungsten melting point.

If an accuracy of $\pm$ 150 K were maintained for all measurements then in the worst cases (i.e. measurements of low temperature areas) an error of $\pm$ 7.5% is obtained.

6.3 Comparison of Model With Experimental Results

Before any attempt to compare the theoretical profiles to those obtained in the measurement of the electrodes we have to obtain a value for r, the radius of the electrode rod. This, in the case of a simple rod electrode is straightforward, and can be obtained by measurement using a travelling microscope. For the case of a standard production lamp electrode the picture is slightly more complex as the rod of the electrode has, as was shown in Figure 6, a coil at its upper end thus increasing the effective diameter of the shank. In this case for the coil Section 6.17 becomes

$$T = (6.854 \times 10^{-7}(x)r_c^{-0.5} + To^{-1.613}) \qquad 6.20$$

where rc = radius of the coil section of the electrode.

For the section of the electrode having no coil expression 6.17 becomes

$$T = (6.854 \times 10^{-7} (X - Lc)S^{-0.5} + T_{Lc}{}^{-1/1.613} \qquad 6.21$$

where s = shank radius

Lc = length of the coil section

T_{Lc} = temperature predicted by expression 6.20 for the end point of the coil i.e. X = Lc.

6.3.a. A.C.Operation

Using such a model temperature profiles were computed for a 2.5kW CID lamp having dimensions of the average of the electrodes of lamps 238, 339 and 301 (shown in Table 1 as measured using a travelling microscope) and using the average temperature at $x = 0$ for T_O. Comparison of the computed values with the average measured values at 2.5, 2.0 and 1.5kW are shown in Figure 31 and show how the model predicts the general shape of the profile showing the change in gradient at the end point of the electrode coil. The model does tend to underestimate the temperature values particularly at the higher X values (lower temperature region).

Over 80% of the measured points are predicted to better than $\pm$ 5% and $\pm$ 10% includes all points.

For lamps having no electrode coil then expression 6.17 can be used without any modification to produce a theoretical temperature using the measured temperature at $X = 0$ and the electrode radius as shown in Table 1. These were specially constructed lamps and the predicted profile is shown in Figure 32 plotted with the measured profile for operation at 2.5kW. The results are the average of both electrodes. The agreement is not as close as was achieved for the standard lamps with the model again tending to underestimate the temperatures. Agreement of the model is still within $\pm$ 10% of the measured profiles and does predict the differing gradients of the curves of lamps 1 and 2 which is shown by the measured values.

Figure 33 shows a comparison of predicted and measured values for 1kW CSI (average of two electrodes of one lamp) and 1kW CID (average of two lamps) operated at 1kW. The predicted profile is calculated using the separate coil and shank radii

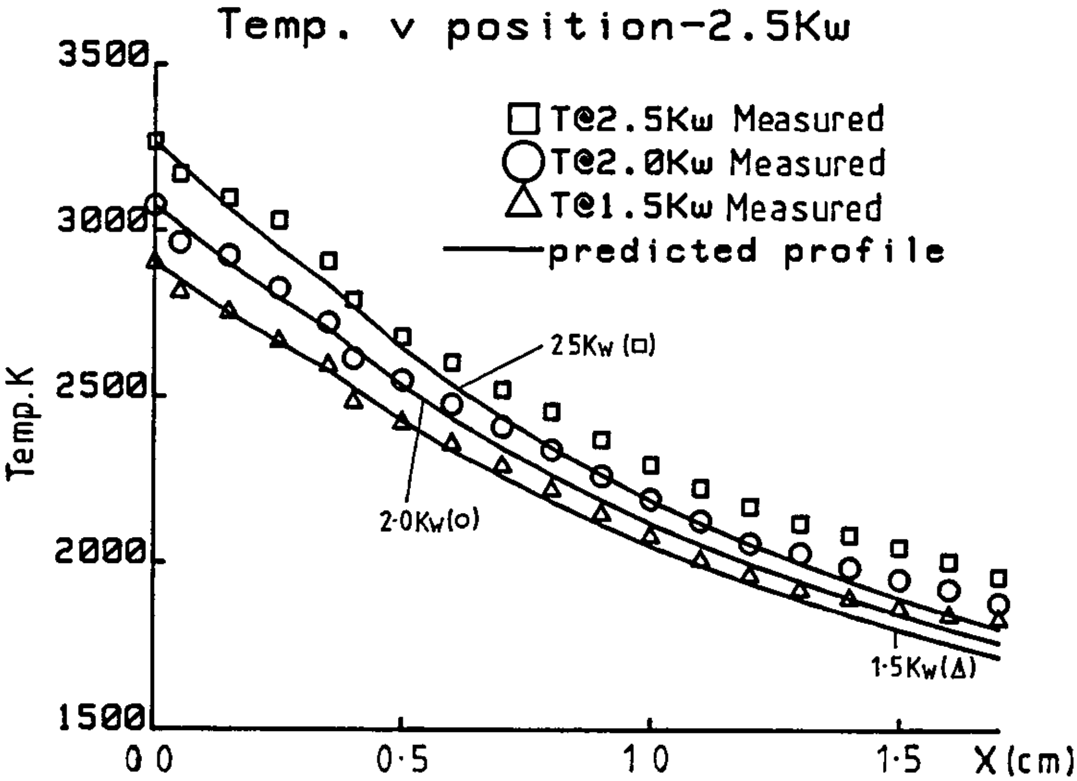


Figure 31. Measured and predicted temperature profiles of average 2·5Kw CID lamp, A.C. operation

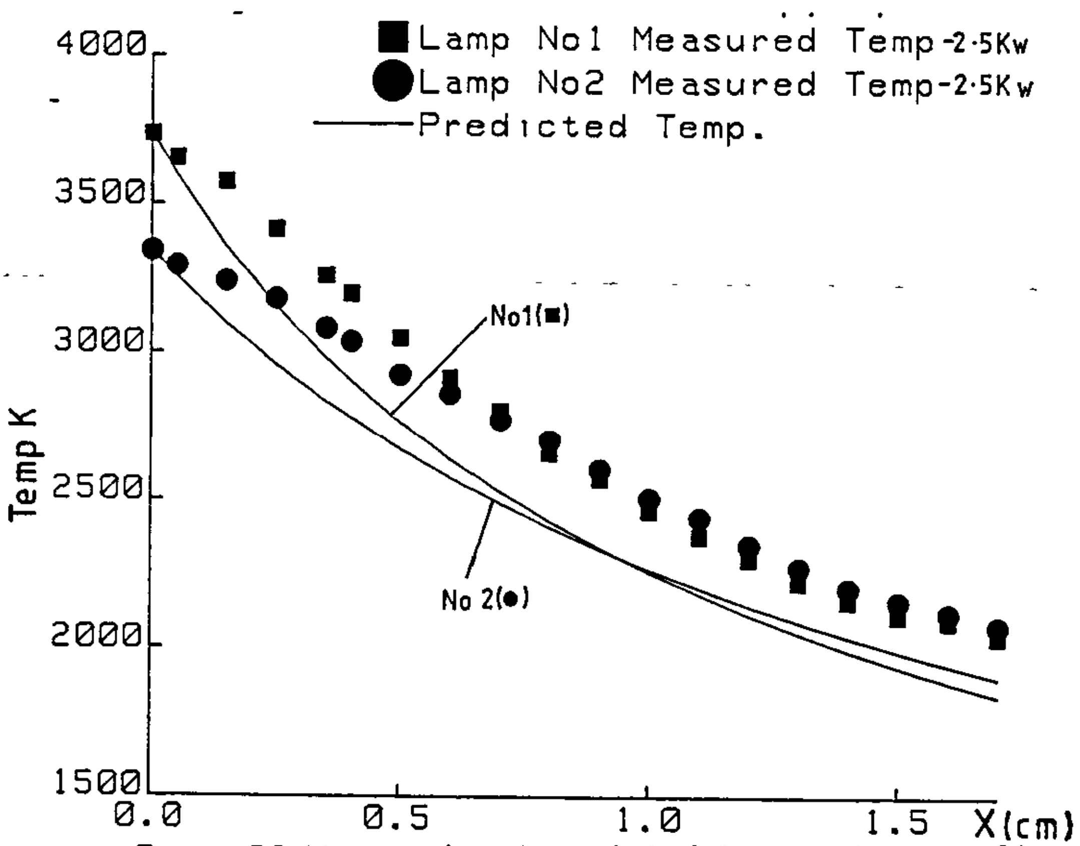


Figure 32. Measured and predicted temperature profiles of 2·5Kw CID lamps with none standard electrodes A.C. operation

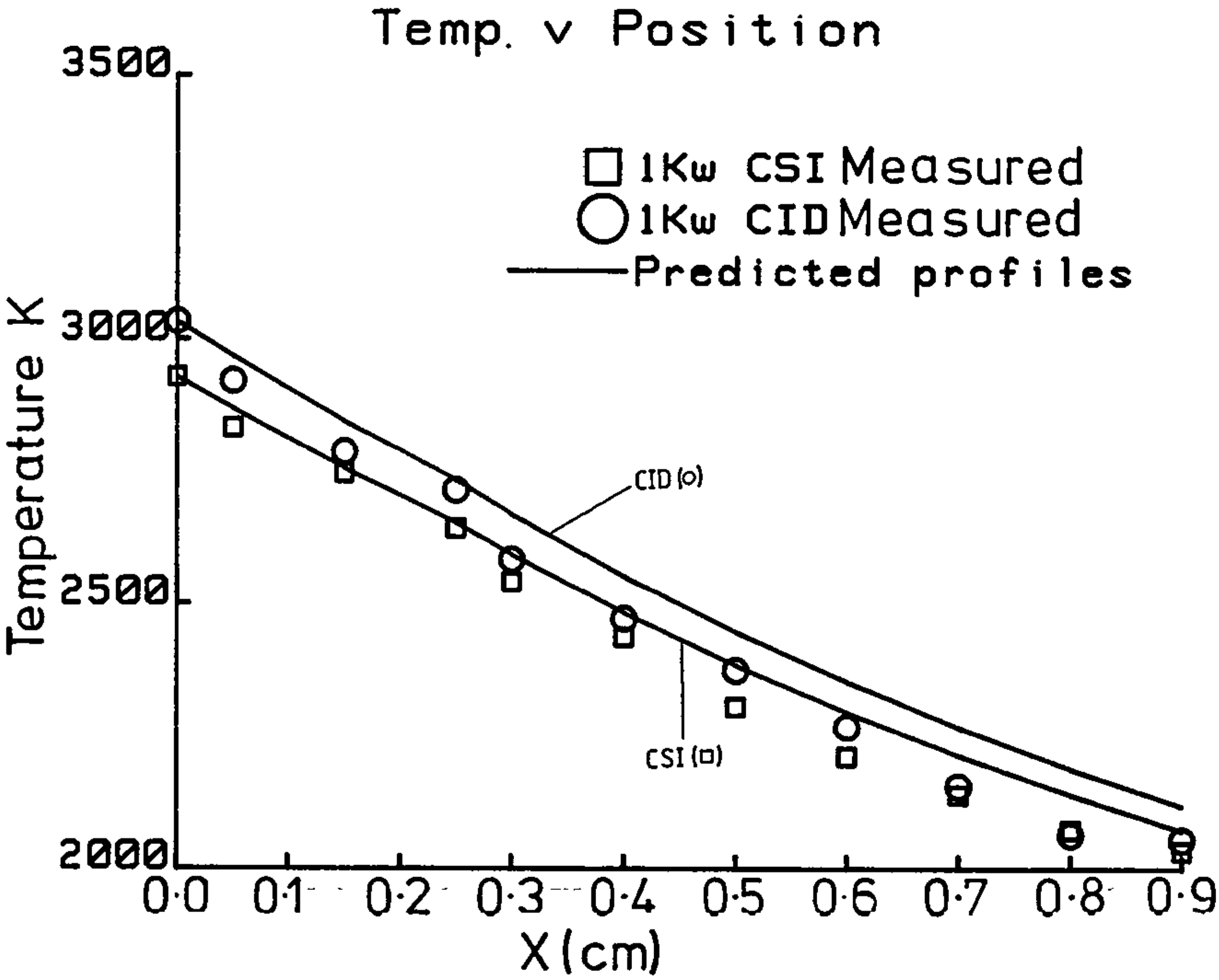


Figure 33. Measured and predicted temp. profiles of 1Kw CSI and CID lamp electrodes A.C. operation

in expressions 6.20 and 6.21. Values of To and radii are average measured values for the lamps concerned. The change in gradient at the coil end is predicted and agreement with measured temperatures is good, 90% of the measured points within $\pm$ 5% of the model and 100% within $\pm$ 6%.

A difference between the 2.5kW lamp and the 1kW occurs in the lower wattage case where the model tends to overestimate the temperatures whereas the model tends to underestimate for the larger lamp.

6.3.b. D.C. Operation

Having studied the lamps when operated on alternating current we now see if the model holds for lamps operated on direct current. No 1kW lamps were measured on D.C. operation so in this case only CID lamps are being considered.

For standard production 2.5kW CID lamps the model incorporating the shank and coil radii and using expressions 6.20 and 6.21 were used to obtain a predicted profile for a measured tip temperature. The predicted temperature profiles compared to measured values for the anode of 2.5kW CID lamp number 339 operated at various wattages are shown in Figure 34. The general shape of the curve is predicted with 80% of the values falling within $\pm$ 5% of the measured values and with only a single value outside the range $\pm$ 10%.

The predicted and measured temperature profiles for the cathode of lamp number 339 at various wattages are shown in Figure 35. Agreement for the cathode of this lamp is not as close between predicted and measured values as for the previous cases. As in the earlier electrode systems the general shape is obtained and reasonable agreement is obtained as far as the X = 1.0cm point but beyond that the theoretical values appear to severely underestimate the measured

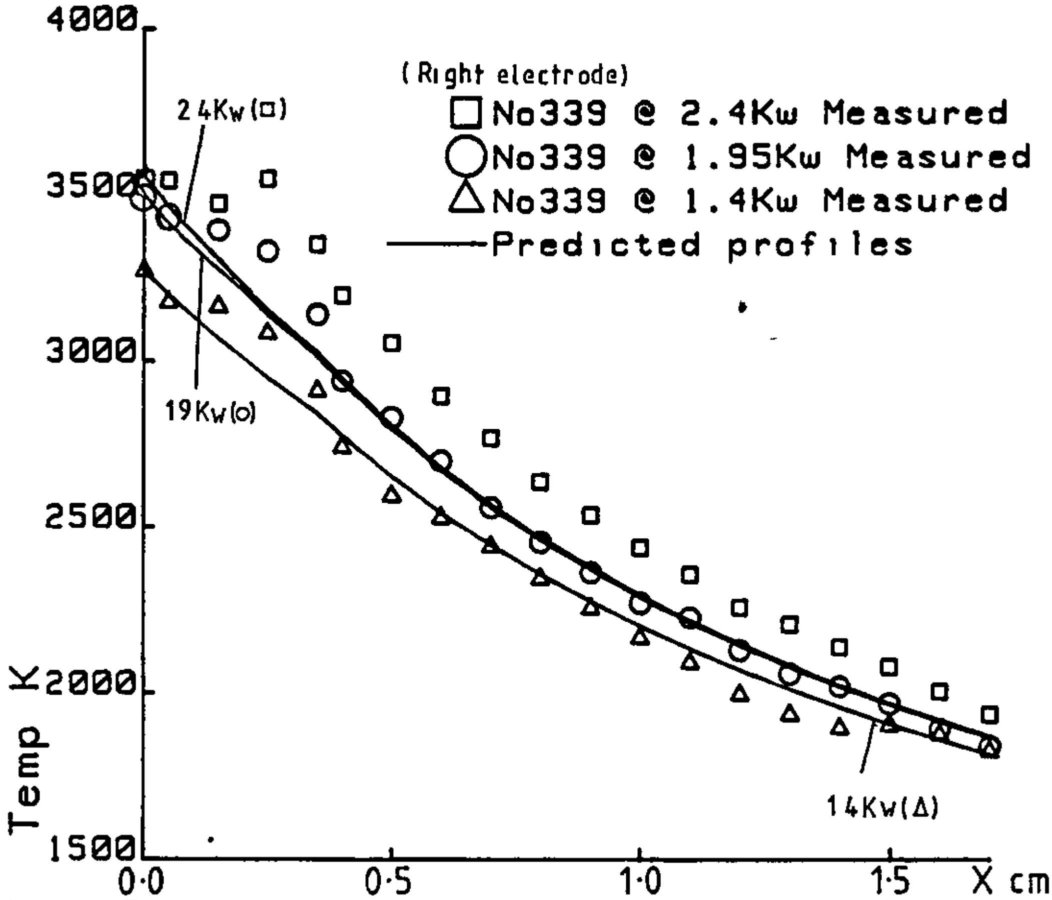


Figure 34. Temp. profile for the anode of 2·5Kw CID lamp no.339, DC operation.

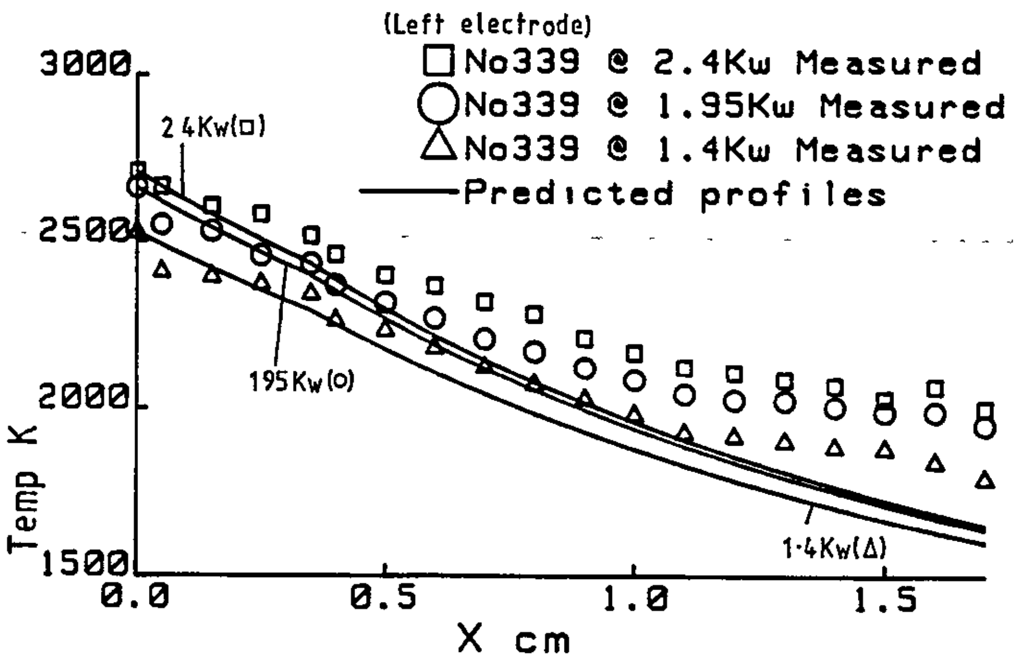


Figure 35. Temp. profile for the cathode of 2·5Kw CID lamp no. 339, DC operation

values. These discrepancies are likely to be caused by the fact that the model assumes that all of the energy will be radiated within the length of the rod but in this instance where the temperatures involved are significantly lower than the previous electrode profiles radiation will become a less dominant energy loss mechanism and particularly in the region of the pinch seal area conduction will begin to play a significant role.

The specially constructed 2.5kW CID lamps having no overwind coils and/or different sized anode and cathode when operated on D.C. yield some significant results. Predicted profiles can be obtained from expression 6.17 directly using the radius of the electrode shank as measured.

Figures 36 and 37 show the measured against predicted temperatures for the two specially constructed lamps, Number 6 having different sized anode and cathode and Number 2 having both electrodes of similar size to the anode of Number 6. The cathode of Number 6 is smaller in diameter than the anode (see Table 1).

As can be seen from these results, the three larger electrodes show an agreement between theoretical and experimental temperatures to within $\pm$ 10% in the worst instances, whereas the small cathode of lamp Number 2 shows a much more marked discrepancy, the majority of points underestimating the temperature by 10 to 15%. Some difference appears evident in this particular case and the most likely cause of this is the mode of arc attachment to the electrode. Generally the arc will attach itself in a diffuse mode to the electrode where the arc termination almost smothers the electrode tip and the assumption made in the model that the power loss to the electrodes is conducted through the end face is a

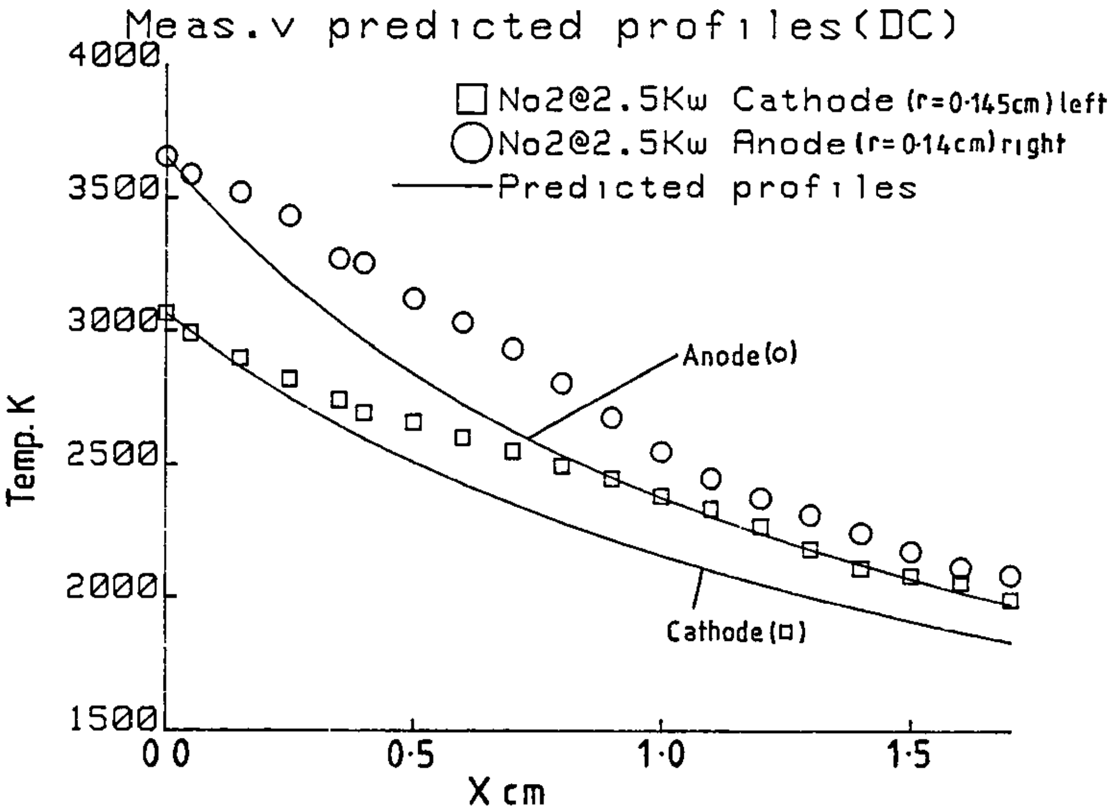


Figure 36. Electrode temperature profiles for 2·5Kw CID lamp no.2, D.C. operation

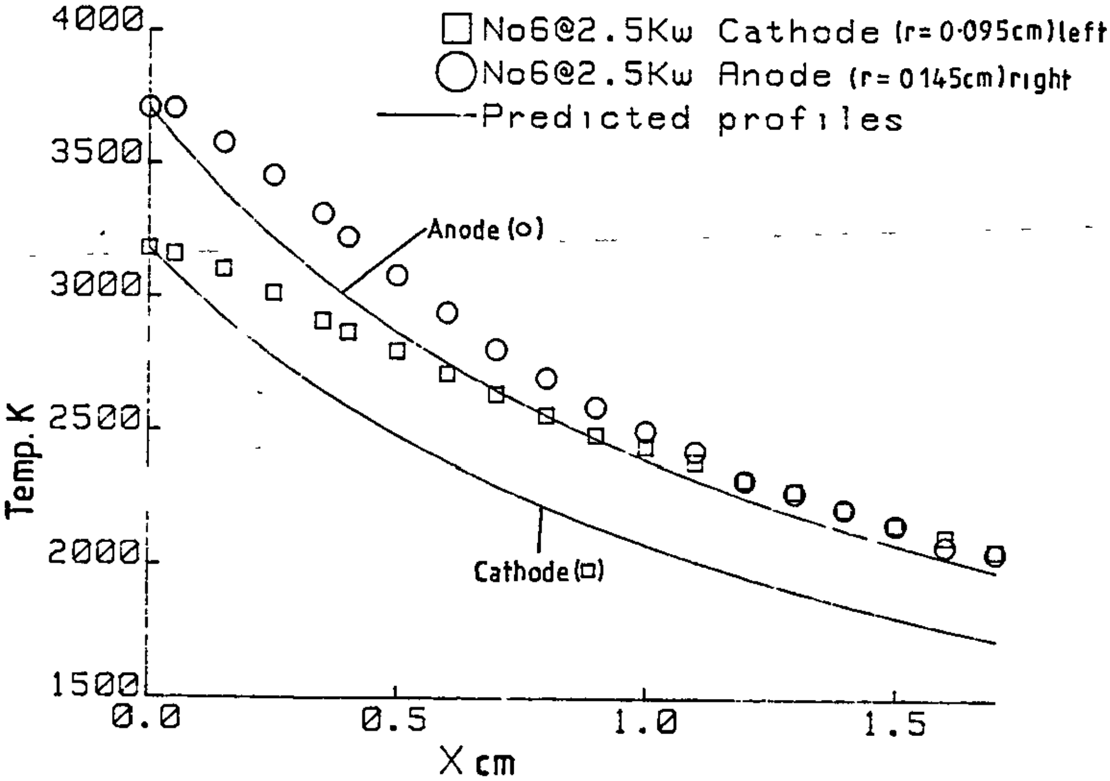


Figure 37. Electrode temperature profiles for 2·5Kw CID lamp no.6, D.C. operation

good approximation but under certain conditions of field, temperature and electrode surface that attachment can revert to spot mode where attachment is via a very small hot spot giving unreliable temperature measurements due to large local temperature gradients in the tip region. (Such phenomena is documented in the literature (10)). This was the only case where a noticeable transition to hot spot attachment occured.

The predicted profiles shown in Figures 31 to 37 compared to measured values are also presented in tabulated form in Appendix 3.

Having established that the model can be used to predict temperature profiles to ± 5% for the majority of cases but to ± 11% encompassing almost all points it is now possible to investigate the possibility of using the formula derived (6.18) to calculate the power transferred to the electrode.

Values of the radius of the coil section are used for the lamps having overwind coils and the tip temperatures are as measured. Inserting these values into expression 6.18 gives the values for power transferred to the electrodes shown in Table 10.

As can be seen from the table variations in current, to alter lamp power, have a significant effect on the power loss to the electrode as does variation in electrode diameter. In order to evaluate the change of electrode loss with lamp current when operating on A.C. a number of measurements were made on single lamps (lamp Numbers 1 and 2), varying the current and making temperature measurements on the electrode tip so as to be able to calculate the power loss to the electrode.

Values for the electrode power loss in the lamps having overwind coils (standard lamps) does appear surprisingly high in comparison to those for plain rod electrodes. To a limited extent this is expected as the coil is in a region of the arc tube where the ambient temperature created by the close vicinity of the arc will reduce the amount of energy radiated by the coil and consequently less power than the model calculates would be required to maintain the measured tip temperature. This is particularly relevant for the coil terminated lamps as they have a greater mass of their electrode in this 'hot' region.

Electrodes with overwind coils would also be expected to have a greater amount of power transferred to it to maintain a similar temperature profile to a rod of similar size and therefore the result is not unexpected but simply of a greater magnitude than might be expected. Table 10 shows the resultant variation of electrode loss with current changes.

If this data is subjected to a linear regression straight line fit then in both cases a good straight line fit is obtained with a correlation co-efficient of 0.998 or better. The data and resultant line fit are shown in Figure 38.

The lines are represented by:

$$Pe = -7.08 + 4.86i \qquad 6.22$$

where Pe = electrode power loss

i = lamp current (r = 0.0995)

for lamp Number 1

and

$$Pe = 3.02 + 5.65i \qquad 6.23$$

(r = 0.1435)

for lamp Number 2.

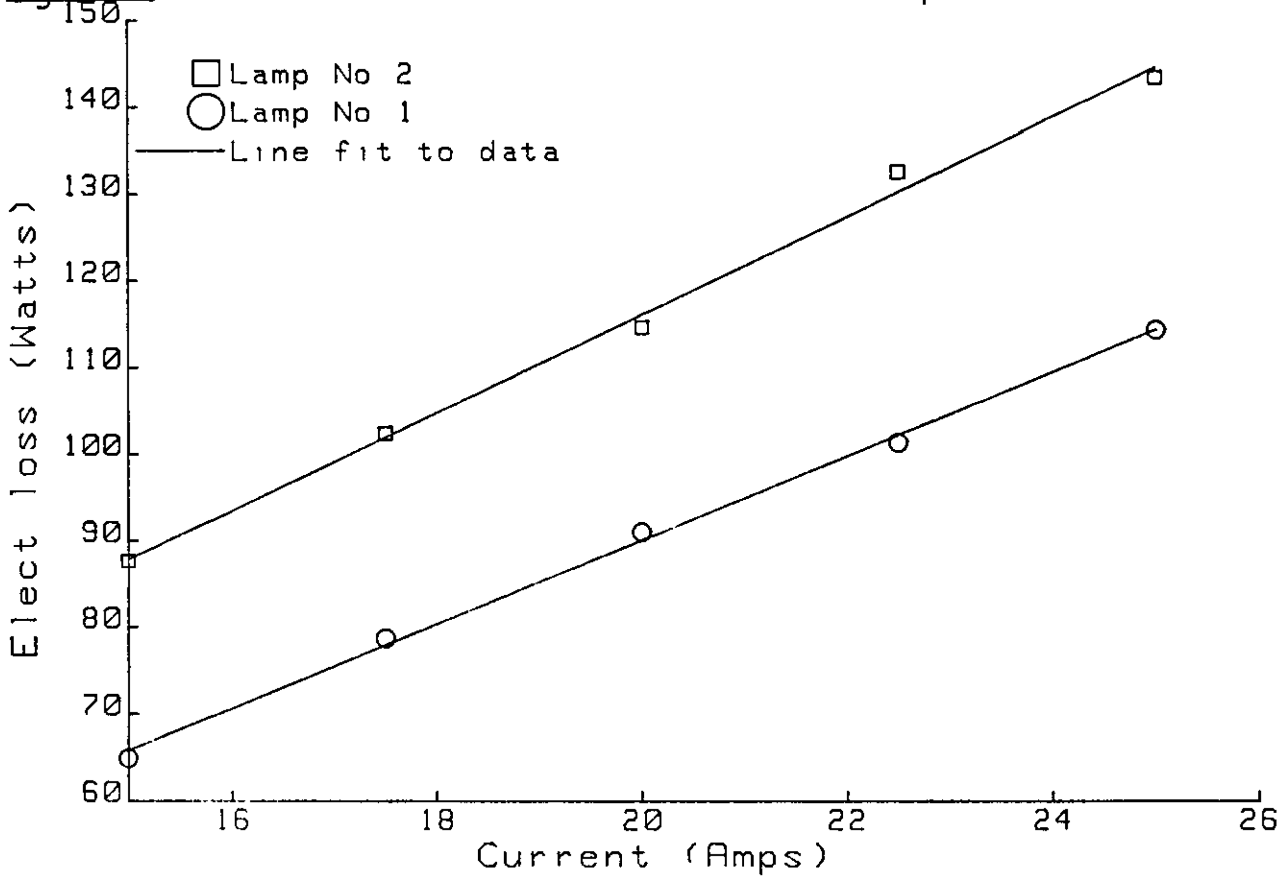
This shows that for those electrode geometries the power lost by the system to the electrodes varies linearly with lamp current over the region studied.

LAMP No.	TYPE	OPERATED ON	I (AMPS)	KW	AVE.ELECT LOSS (W)
238			29.75	2.5	223.5
238	2.5kW CID	A C	24.5	2.0	186.8
238			19.4	1.5	146.9
339			28.5	2.5	232.6
339	2.5kW CID	A C	21.0	2.0	198.8
339			17.25	1.5	165.9
301			27.5	2.5	230.1
301	2.5kW CID	A C	23.0	2.0	185.9
301			17.0	1.5	168.6
1			25.0	-	114.3
1			22.5	-	101.3
1	2.5kW CID	A C	20.0	-	91.0
1			17.5	-	78.7
1			15.0	-	64.9
2			27.5	2.5	159.8
2			25.0	-	143.2
2	2.5kW CID	A C.	22.5	-	132.5
2			20.0	-	114.6
2			17.5	-	102.4
2			15.0	-	87.6
5180	1kW CSI	A C	15.0	1.0	114.7
3847	1kW CID	A C	13.75	1.0	121.4
5654	1kW CID	A C	15.0	1.0	130.2
339		D C	24.0	2.4	314.5
339	2.5kW CID	Anode	19.75	1.95	309.0
339			14.27	1.4	246.5
339			24.0	2.4	119.6
339	2.5kW CID	D C	19.75	1.95	113.5
339		CATHODE	14.27	1.4	96.8
2	2.5kW CID	D C	24.5	2.45	212.5
6		ANODE	27.5	2.44	221.6
2	2.5kW CID	D.C.	24.5	2.45	121.3
6		CATHODE	27.5	2.44	74.1

TABLE 10

Electrode losses for various lamps under various operating conditions.

Figure 38 Power lost to electrodes v lamp Current



Expression 6.18 also predicts electrode power loss should vary linearly with electrode radius raised to the power 3/2.

With the electrode geometries used in this investigation it is not possible to test this accurately as a specific radius can only be obtained for a rod electrode (i.e. without overwind coil) and only two electrode sizes in this format were used. An extension of this work would be to test this relationship with a wide range of radii operating at fixed currents.

6.4 Application and Limitation of the Model

6.4.a. Agreement with Measured Values

If the discrepancies between the measured and predicted temperatures are examined the model seems to predominantly under-estimate the measured temperatures. Several possible reasons could be considered as causing this:-
The assumption that the electrode behaves as a semi-infinite rod will contribute to this. Clearly at the end of the rod the temperature will not be O and in the pinch seal region some energy will be lost by conduction to the quartz and also by radiation from the surface. Secondly, the assumption that the ambient temperature will be negligible will give rise to such an error particularly in the cases where the electrode temperatures are lower. Finally, there will inevitably be some exchange of radiation from the arc to the electrode other than through the point at which the arc attaches to the electrode which will further give rise to temperatures above those predicted.

The discrepancy observed in the case of the 1kW lamps is more difficult to understand. The 1kW being physically smaller most of the above errors would be expected to cause under-estimation of temperature rather than over-estimation as occurs. The most likely causes of such errors are that convective losses from the electrode becoming significant factors and also the heat-sinking effect of the pinch seal area and lamp holder in the smaller lamp.

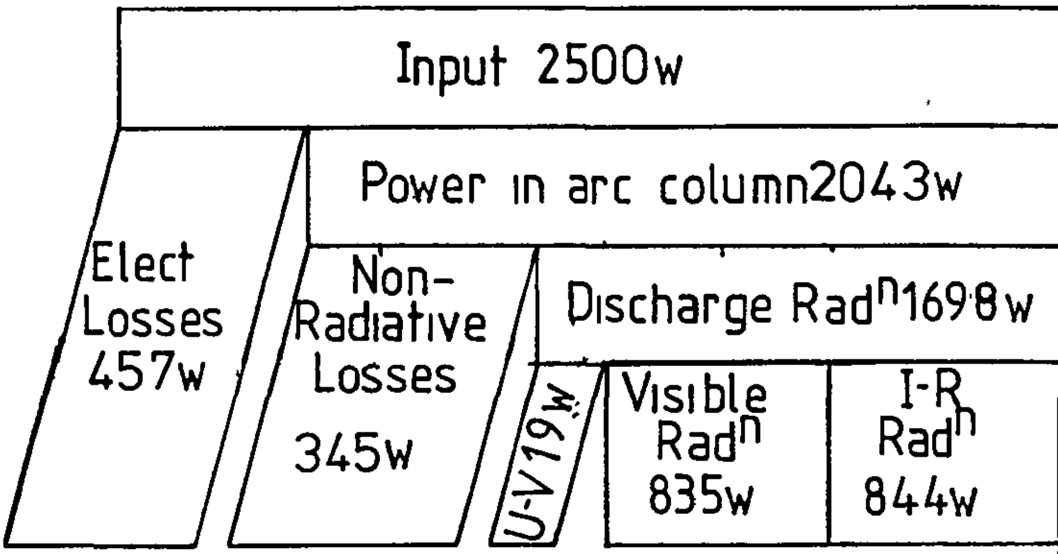
The model has been shown to hold to within ± 5% of measured values for the majority of cases but to encompass all the measured results a limit of confidence on the predicted temperatures an accuracy of ± 11% of experimental values is a more reasonable tolerance.

6.4.b Calculation of Electrode Losses

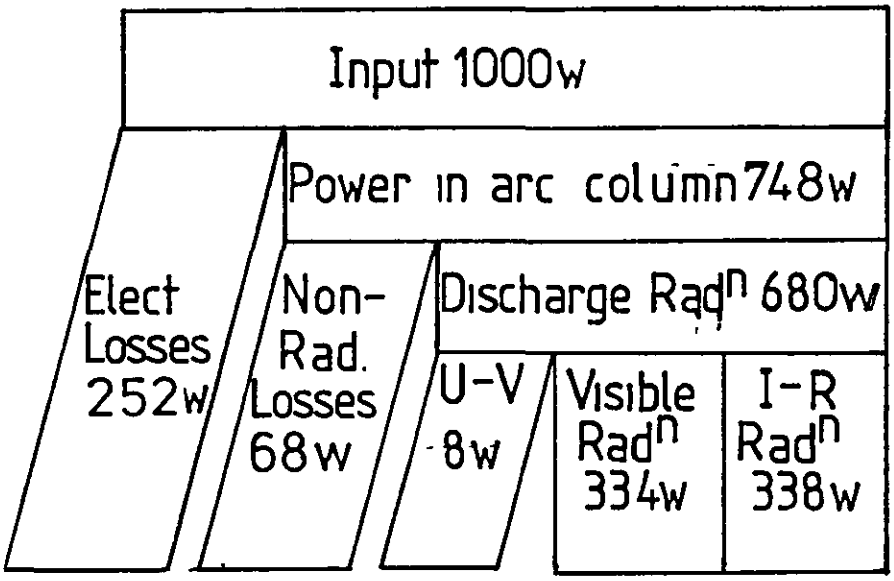
The ability to relate the measured temperatures to a figure for electrode power loss is a useful step in being able to more fully quantify aspects of the performance of electrodes in metal halide lamps. The average electrode losses, as shown in Table 10 for the 2.5kW CID, 1kW CID and 1kW CSI lamps. have been used to create a total energy balance for the three lamp types along the lines of those quoted in the introduction and are represented in the same schematic form in Figure 39.

The power in the arc column is calculated as the difference between the power input and the power transferred to the electrodes. The discharge radiation figures are data as measured by staff in the THORN EMI Lighting Research Department using a spectroradiometer system which measures relative to an NPL calibrated standard source in the range 250 to 2,500 nM.

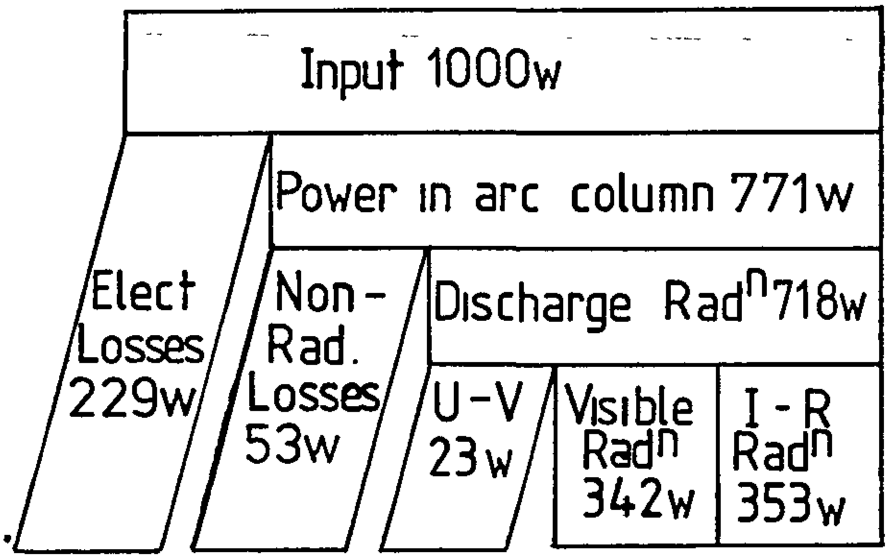
The non-radiative losses are taken to be the difference between the arc column power and the discharge radiation. This is the first time such energy balances have been calculated for CSI/CID type single ended discharge lamps.



(a) Energy balance for 2·5Kw CID lamps



(b) Energy balance for 1Kw CID lamps



(c) Energy balance for 1Kw CSI lamps

Figure 39. Energy balances for CID/CSI lamps

Although no 'easy-to-use' formulae for designing electrodes for discharge lamps have been obtained some important steps in evaluating the important parameters in electrode performance have been established. A close correlation between lamp current and electrode power loss has been established. A correlation is also suggested relating the radius of electrodes to the power lost to the electrodes. In an attempt to further evaluate this correlation and reduce electrode losses a lamp having electrodes with a small radius were made but were unfortunately too small and the upper ends of the electrodes simply melted when the lamp was operated. This shows electrode design is a compromise in limiting power loss but also maintaining acceptable temperatures.

Any further work to extend this project could usefully be directed to investigating further the dependence of power loss with respect to these two variables, electrode radius and lamp current.

6.4.c <u>Limitations of the Model</u>

The limitations of the model are mainly as a result of the assumptions made in obtaining a solution to the differential equation describing the energy flow in the electrode.

It has already been illustrated that deviation from the conditions assumed cause problems in predicting temperature profiles, i.e. when the arc adopted the hot spot mode of attachment on the cathode of lamp Number 6 deviating from the assumption that the power is conducted through the upper face of the electrode. This type of arc attachment also gives rise to large radial thermal gradients which is also contrary to one of the basic assumptions in the model.

Assuming the electrode to be a semi-infinite rod also limits the application of the solution to lamps the electrodes of which are sufficiently long and at sufficiently high temperatures to dissipate the majority of the energy supplied within their length.

The radius of the rod must also be kept small or the assumption of having no radial temperature variations will introduce errors into the model.

Neglecting any contribution from the temperatures of the gases inside the arc tube further limits the model to systems having electrodes at sufficient high temperatures that these gas temperatures do not play a significant role in limiting the dissipation of energy by the electrodes. Finally, neglecting the contribution to the heating of the electrode by the passage of current through the electrode will also have an effect but as mentioned in an earlier section if we assume an electrode (2.5kW CID) maintained at a temperature of 3500^{o}K along its length (far more severe than would be encountered) the contribution from the joule heating would be less than 1 watt and is consequently unlikely to be a major source of error unless the electrode diameters are reduced significantly or the currents increased.

7. CONCLUSIONS

After consideration of a number of possible temperature measuring techniques a system incorporating an optical disappearing filament pyrometer has been successfully used to measure the temperature profiles of the electrodes of a number of CSI/CID type single ended metal halide discharge lamps operating under various conditions such as varying wattages and both alternating and direct current circuits. The resultant temperature profiles show excellent reproduceability both with repeated measurements on a single electrode operating under nominally identical circumstances and for numbers of lamps of the same types measured under similar conditions.

In addition to making temperature measurements a theoretical model has been developed by considering the basic energy flow equations for a rod electrode heated from one end. The resultant model using electrode radius and measured electrode tip temperature to predict temperature profiles for the electrode systems is shown to match the measured values to within $\pm$ 10% for more than 90% of the measured values. The derived model also provides a value for power transferred to the electrodes by the arc and these calculated power losses are used to calculate energy balances for the 2.5kW CID and the 1kW CSI and CID lamps.

The calculated electrode power losses have been shown to vary linearly with lamp current for a fixed electrode geometry and the expression derived for power loss to the electrode suggests that the power loss to the electrode should also vary linearly with the electrode radius raised to the power 3/2 for a fixed current. This information then provides a starting point in the development of a method of predicting electrode performances under certain specified conditions.

Finally it has been shown that electrode temperature profiles remain constant through lamp life.

8. FUTURE WORK

The results established in this investigation provide several areas of interest where it would be useful and informative to expand on the work done so far.

It would be very useful to extend considerably the work on the relationship between electrode geometry, lamp current and electrode power loss as this could be developed into a comprehensive model capable of being used in the design of electrode systems.

The energy balances presented are also worthy of further investigation as the parameters other than electrode loss were calculated rather simplistically and further work on quantifying the non-radiative losses and breaking it down further would lend more credibility to the data.

It would also be interesting to try to apply the model presented to other lamp types in which the basic assumptions made in solving the differential equation are satisfied. One particular lamp type where this may give good results is the double ended xenon lamp.

Finally it would also be useful to develop further the temperature measuring technique in order to obtain a system in which the errors involved, and particularly those incurred as a result of the presence of the arc, in making the measurements could be more accurately quantified.

9. GLOSSARY

AKS TUNGSTEN - A commercial grade of tungsten widely used for discharge lamp electrodes.

ARC TUBE - Quartz body with electrodes pinch sealed into position. The term arc tube is used to describe the component before and after dosing, exhaust and sealing off processes.

CAPPED - A capped lamp is one which has some form of electrical connection (other than the arc tube pins) attached to the arc tube. The cap is also used to give additional physical support to the arc tube.

CONTROL GEAR - All elements of circuitry needed to operate a lamp. For CSI/CID lamps the control gear incorporates the ballast, ignitor and power factor correction capacitance.

CORRELATED COLOUR TEMPERATURE (CCT) - The temperature of a black body that generates light with the closest visual colour match to the specified source. Measured in degrees Kelvin.

DOSE - The materials constituting the lamp fill i.e. Mercury, metals and metal halides for the CSI/CID lamps.

DOSING - The process of adding the dose materials to an arc tube.

EFFICACY - Ratio of light output measured in lumens to the input power measured in watts.

EXHAUST - Process of, alternately, evacuating and purging, with inert gas, the arc tube after dosing and prior to sealing off.

LAMP - The light source in its finished state. It can be in any format i.e. capped or uncapped, jacketed or air burning.

LOADING - Power loading per unit area of the arc tube surface.

LUMEN MAINTENANCE - The ratio of light output at a specified life to that at 0 hours expressed as a percentage.

RADIANCE - Radiant energy emitted in a specified direction per unit time per unit projected area of surface per unit solid angle.

SEALED BEAM - A sealed beam lamp is an arc tube sealed into an inert gas filled outer jacket which also forms an integral reflector.

SEALING OFF - The final process of the exhaust schedule involving isolating the gas filled arc tube from the vacuum system by sealing the quartz tubulation with a hand torch.

SHAPE - The quartz body prior to the pinch sealing.

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APPENDIX I

COMMERCIAL LITERATURE GIVING DETAILS OF CSI/ CID LAMP RANGES

99-101

September 1972

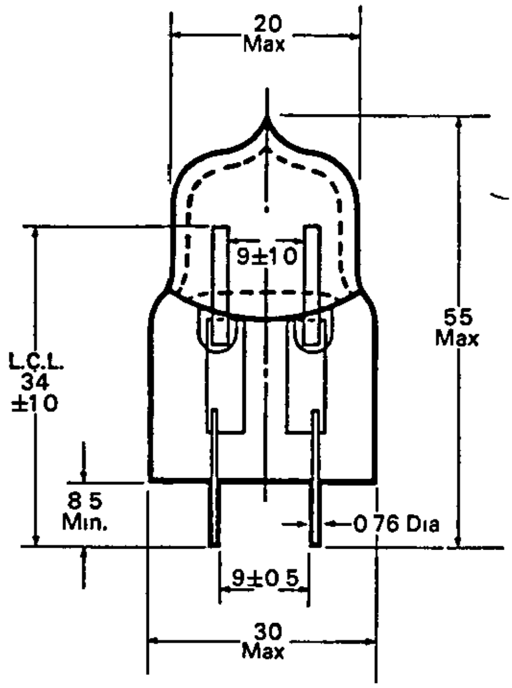
Replaces August 1972

COMPACT SOURCE MERCURY PROJECTOR LAMPS

ELECTRICAL CHARACTERISTICS

Supply Volts AC	240V
Arc Watts	400w
Arc Volts	100V
Arc Current	5A
Run up Time	30 secs.
Re-starting Time	3/5 mins.

Dimensional Diagram



The 400 watt Compact Source Iodide Lamp.

PHYSICAL DIMENSIONS

Arc Length	9 ± 1.0 mm.
Arc Size	9 x 5 mm.
Overall Length (max.)	55 mm.
L.C.L.	34 ± 1 mm.
Diameter (max.)	30 mm.
Pin Length (min.)	8.5 mm.
Pin Spacing	9.0 ± 0.5 mm.
Pin Diameter	.76 mm.

LUMINOUS CHARACTERISTICS

Initial Lum Eff (min.)	80 lumens/watt
Lumen maintenance	90%
Colour Rendering	Good
Chromaticity Co-ordinates	x = .433, y = .382

LIFE (nominal objective) 500 hours

Operating position Any

GENERAL DESCRIPTION

The 400 watt Compact Source Iodide lamp is a new design of projector lamp giving white light of good colour rendering properties at an efficiency of 80 L/W for 100 hours. The source size is approximately 9 mm. x 5 mm. and the brightness is about 8000 candelas per square cm.

The high efficiency is obtained by the use of an arc discharge. The iodide technique has been used to introduce additional elements into the arc and to keep the bulb wall clean throughout life. Careful choice of the number and quantity of these additional elements and of the loading conditions has resulted in a balanced spectral distribution which is virtually a continuum with a few widely spaced narrow absorption lines. In practical user terms this means that the light is white and the colour rendering is good.

The lamp is somewhat unconventional in appearance. It is extremely rugged. The small total physical size and the ability to operate it in any position ensures that the lamp can be readily fitted into existing equipment and simplifies the design of new equipment. The single ended construction and the degree of prefocusing provided means that lamp replacement is straightforward.

ADVANTAGES

1) The major advantage of this lamp is its high efficiency, combined with its robustness, simplicity, small size and relatively low power consumption.

2) Increased light output or reduction in input power and heat. The lamp can be used in applications which at present use 100V - 240V hard glass filament projector lamps of 250w - 1000w rating.

3) Major reduction in cost and complexity of control gear.

4) The higher screen brightness which can now be achieved means that the projection of colour pictures which are clearly visible in subdued daylight is feasible.

5) The increased performance now available may well extend the application of projection techniques.

USES

1) Considerations of source size, lamp size, lamp rating and efficiency indicates that it can be used in place of 100- 240V hard glass filament projector lamps of 250 - 1000w rating.

2) The demand will be in such fields as high power slide projectors and theatre spotlights, and in the rapidly expanding market for overhead projectors.

3) Other uses are in projection microscopes, colour printing, diazo printing, enlarging and cine projectors.

4) For photographic use it is suitable for use with daylight colour film stock.

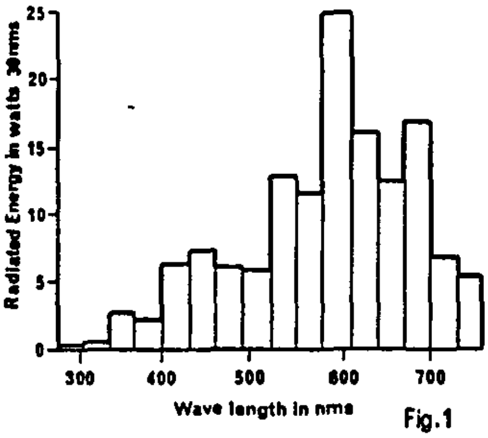


Fig.1

Typical Spectral Power Histrogram for the 400W Compact Source Iodide Lamp

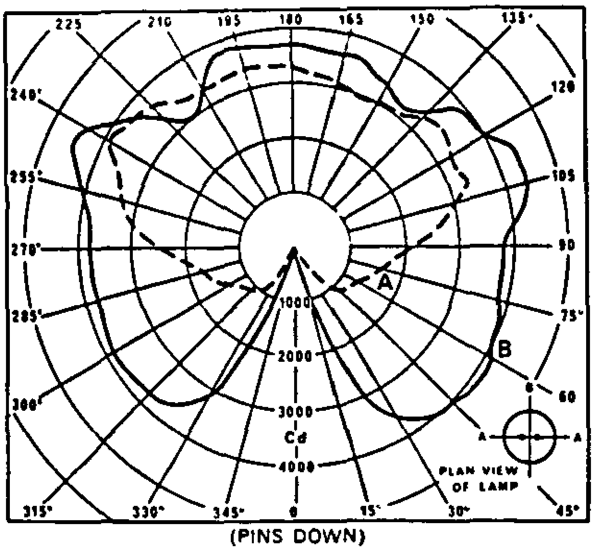


Fig.2 Typical Candlepower Distribution in vertical planes
A—through electrodes
B—normal to electrodes

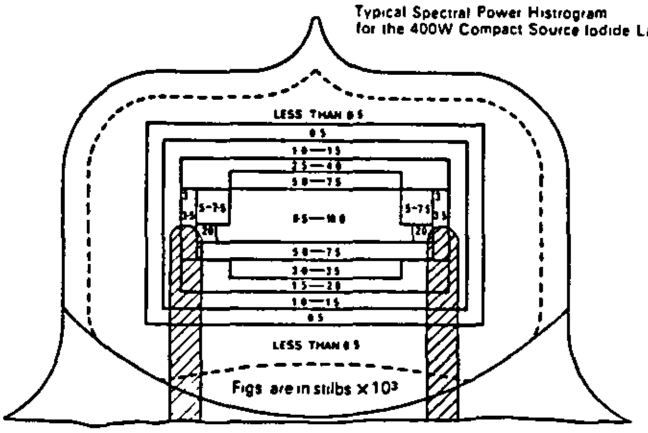
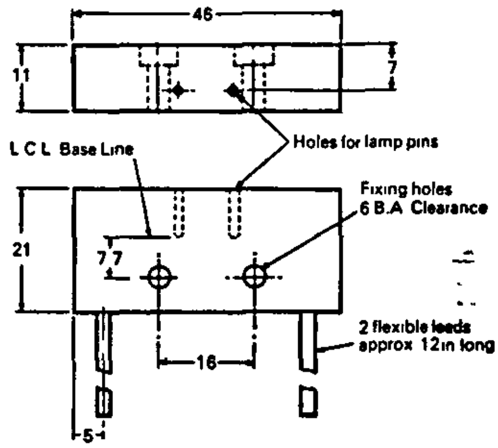
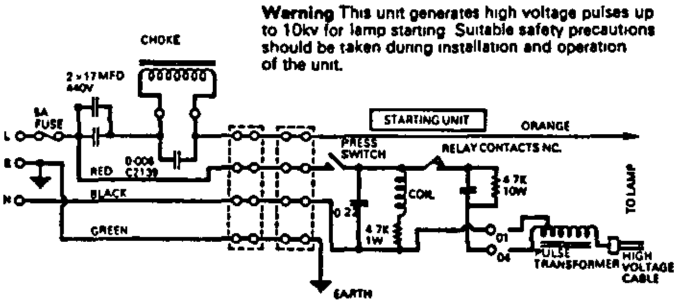


Fig 3 Typical Brightness Distribution Diagram



Lampholder ref L 1101 for use with the 400 watt Compact Source Iodide lamp

Warning This unit generates high voltage pulses up to 10kv for lamp starting. Suitable safety precautions should be taken during installation and operation of the unit.



Circuit diagrams

CHARACTERISTICS

Lamp characteristics are shown on the first page. The colour appearance is given in terms of the chromaticity co-ordinates of the C.I.E. colour chart as colour temperature is not considered a satisfactory method of defining either colour appearance or colour rendering for non Planckian radiators. The colour rendering properties can be assessed from the spectral power distribution diagram (Fig. 1). (Note: The approximate colour temperature of the lamp is of the order of 3200°K but, as indicated, this figure must be used with extreme caution.)

The candle power distribution is roughly symmetrical in the horizontal plane and an approximate figure for the candle power in any direction can be obtained from the curves shown in Fig. 2. The brightness distribution is shown in block form (Fig. 3) to assist calculation of useful areas of different applications. For example, it may be shown that approximately 80% of the light comes from an area 9mm. x 5mm. It should also be noted that the arc is partially transparent to its own radiation and its image can be superimposed to give a more square and uniform distribution. Effective gains of up to 40% can be obtained in this way.

CONTROL GEAR UNIT CAT. NO. AME 53196.4 FOR OPERATING 400 WATT MAZDA
C.S.I. COMPACT SOURCE MERCURY -IODIDE LAMP SUPPLY INPUT 240 VOLTS 50 HZ

1. The lamp connection from the high voltage terminal on the pulse transformer should be not longer than 6 ft. and suitable high tension cable should be used. (Duracable S11 - 16/012)

2. The starting unit is mounted on a detachable chassis, and may be removed and fixed separately if the 4 connecting wires are extended from the 4 way terminal block. This enables the starter unit to be mounted on the side of the lamp housing ensuring a short H.T. lead totally enclosed within the equipment for additional safety.

3. The case of the unit should be earthed.

4. The 240 volt 50 Hz supply should be connected to input terminal block marked 'L' and 'N'.

5. The input is fused with a 5 amp. fuse to BS. 1362. It can be removed by pulling the red carrier.

6. To start the lamp the side switch should be depressed for a few seconds until the lamp is burning steadily and then released. Do not operate switch whilst lamp is working.

7. It will be necessary to allow the lamp to cool before restarting.

8. WARNING:
The unit generates high voltage pulses for lamp starting. Suitable safety precautions should be taken during installation and operation of the unit.

The control unit and associated lamp house must be earthed. The H.V. cable should be protected from accidental damage. Disconnect supply before servicing. Lamp should always be totally enclosed.

THORN LIGHTING

Issue date September 1982
Replaces L5/TA January 1976

4:99.10

CSI

Compact Source Iodide Projector Lamp (Hot Restrike) 1kW

Identification

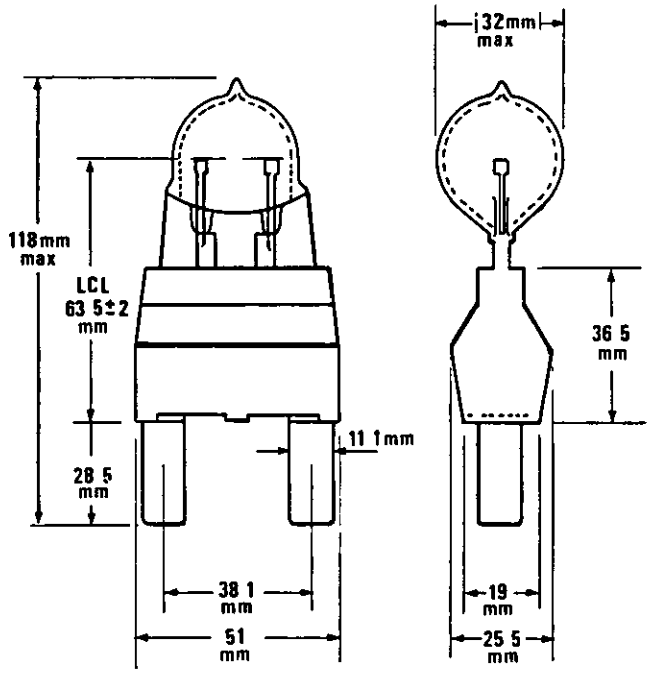
Specification Ref 99–0421

Applications

The high efficiency, robustness, and small size of this lamp makes it eminently suitable for cinema and television lighting use For photographic purposes it is suitable for use with daylight colour film stock

Description

The 1kW CSI Compact Source Iodide Lamp Ref 99–0421 is a modified form of the standard 1kW CSI Ref 99–0221 in which the lamp terminations have been modified to give better insulation so enabling the lamp to be restarted instantly when hot



Performance

Electrical Characteristics

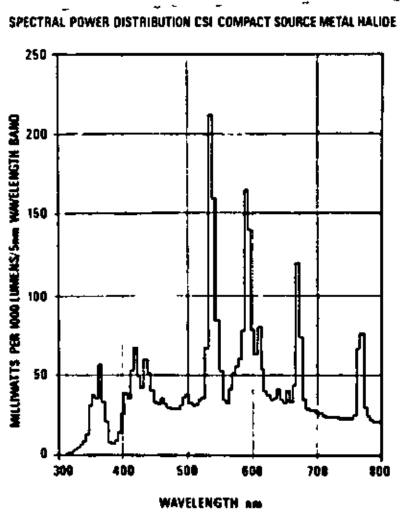
Supply voltage	220V, 240V
Arc watts	1000
Arc volts	70/85
Arc current	15 amps
Run-up time	30 sec
Restart time	Instantaneous
Starting current (cold)	17 amps approx

Dimensions

Overall length	118 mm max
L C L	63 5 ± 2 mm
Diameter	32 mm max
Arc length	14–15 mm
Cap	Bipost G 38

Luminous Characteristics

Initial efficiency	90 L/W
Lumen maintenance	85%
Centre arc brightness	8 000 stilbs
Life	500 hrs
Operating position	Universal
Chromaticity co-ordinates	x = 0 385
	y = 0 395
Colour rendering index	RA 85



Control Gear

One choke G53307 T in parallel, PF correction capacitors and 20kV minimum output starter unit

Recommended type, G53352
See circuit diagram

:lectrical Characteristics 220/240V 50Hz

upply voltage	220	240
upply frequency (Hz)	50	50
upply current (A)	5 6	5 0
'otal circuit watts (W)	1120	1140
upply power factor (lagging)	0 91	0 94
.amp voltage (V)	77	77
.amp current (A)	14 7	14 7
.amp wattage (W)	1000	1000
laximum starting current (A)		
) line current (175 μF PFC)	5	3 5
) lamp current no PFC	16	16
3rd harmonic content in line current	18	18
ecommended fuse rating	20A	20A

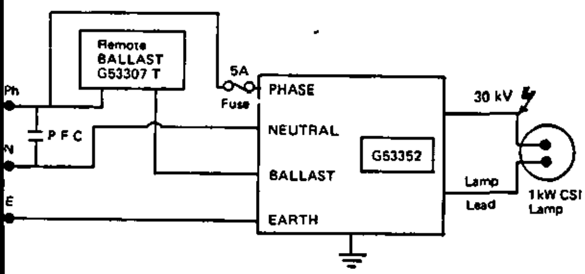
ower Factor Correction

apacitors are connected between phase and neutral for ngle phase operation The recommended value of power ctor correction is 175 μF which results in a supply power ctor of 0 94 (lagging) in the 240V circuit and 0 91 in the 20V circuit

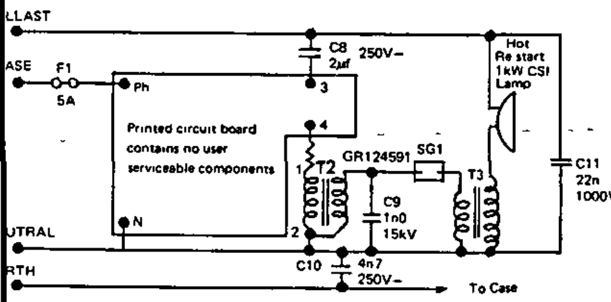
or details of Three Phase Operation and supply voltages ther than 220/240V AC 50Hz see Thorn Lighting Data neet Ref T49/T available on request

rcuit Diagram

:W Hot Re-start Circuit (for 220/240V 50Hz supplies)



Schematic wiring diagram for Hot Re-strike with G53352 ignitor



e G53352 consists of a 50/60Hz transformer (T2) high tage capacitor (C9), spark gap (SG1), output transformer 3) and control circuitry

tallation

ndard G38 lampholders should not be used with this lamp d circuit as they will not necessarily carry the high pulse tages required for hot restart. A lampholder with well ulated sockets is necessary

itable lampholders GL1198

Short well insulated leads between starter and lamp are essential to prevent actual arcing and to minimise pulse losses by 'brushing' The following minimum clearance and creepage distances between the hot lead and any adjacent metal, whether earthed or not, are recommended

Clearance distance (1) Between smooth surfaces 15 mm
(2) Between sharp projections 30 mm

Creepage distances i e bridged by an insulating surface 30 mm

Operation and Maintenance

Safety

Before Use

Always isolate the equipment from the electricity supply before inserting or replacing a lamp

Check that the replacement lamp is the correct type for the application, wattage and cap for use in the circuit and with control gear

Ensure that the lamp is correctly located in the lampholder and the quartz envelope is not scratched during insertion

During Use

High pressure mercury discharge lamps with quartz envelopes without glass outer bulbs emit short wave ultra violet radiation which is readily transmitted through quartz This radiation is harmful to eyes and skin Operators must be shielded from direct or reflected short wave ultra violet radiation

Certain metal halide lamps have operating restrictions, details of which are specified with the lamps

Disposal

These lamps should be broken in a container Precautions must be taken against flying glass or other fragments The operation should be carried out outdoors (or in a well ventilated area) Where applicable, the debris of large quantities of lamps must be disposed of in accordance with the rules of the Local Authority

Thorn Lighting reserve the right to alter the specification without prior notice or public announcement.

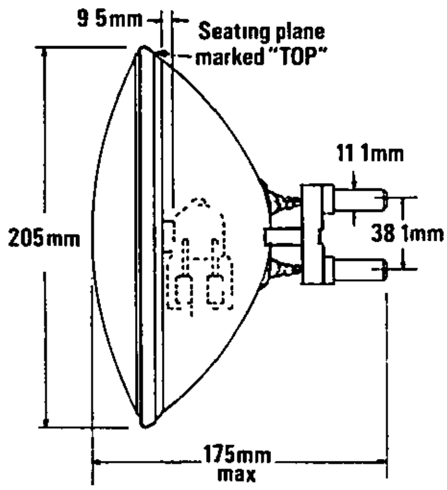
THORN LIGHTING

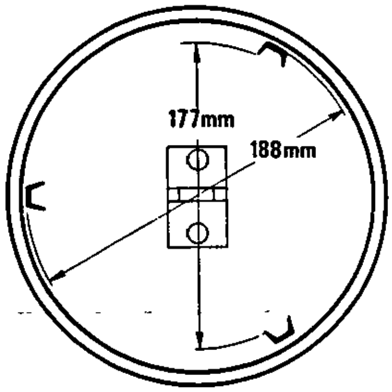
Issue date September 1982
Replaces L34 July 1976

4:99.7

CSI

Compact Source Iodide Sealed Beam Lamp 1kW





Identification

Specification Ref 99–1222

Applications

Floodlighting, especially for filming and TV outside broadcasts, suitable for use with daylight colour film stock
Also as a radiation source for solaria and allied applications

Description

The 1kW Sealed Beam Compact Source Iodide lamp consists of a high pressure discharge lamp 1kW CSI arc tube (see data sheet 4 99 9) enclosed in an 8" sealed beam reflector envelope

The 1kW CSI Arc Tube comprises a discharge in a quartz envelope operating between tungsten electrodes in an atmosphere of mercury vapour with additional metallic iodides These additives ensure a high efficiency white light source of good colour rendering, and the accurate positioning of this arc tube within the sealed beam reflector outer gives a beam candle power of some 1¼ million candelas with a total spread of 18° (to 1/10 peak)

Performance

Electrical Characteristics

Supply volts	220V, 240V A C
Arc watts	1,000
Arc volts	70/85
Arc current	15 amps approximately
Run-up time	50 secs (to 90%)
Re-starting time	10 mins (in OM 1000 floodlight)

Physical Dimensions

Diameter	205 mm
Overall length	175 mm
Cap	BIPOST G38

Luminous Characteristics

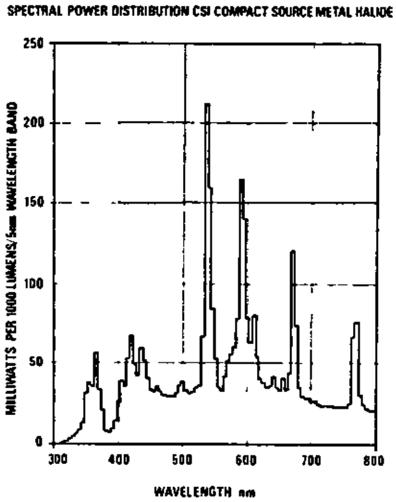
Initial beam candlepower (peak)	1 25 million cds			
Beam spread	1/2 peak	1/3 peak	1/5 peak	1/10 peak
	6°	8°	12°	18°
Lamp lumens	Initial	76,000		
	Design	67,000		
Colour rendering RA index	RA 80			
Chromaticity co-ordinates	x = 0 393			
	y = 0 395			
Life (nominal objective)	1500 hrs			
Operating position	Horizontal ± 90° (Note Preferred mounting position marked 'Top')			

Control Gear

G53307 T	220/240V 50Hz choke (1 per lamp)	19 0 kg
G53319	Ignitor unit on open gear tray	1 17 kg
GC2346	25 µF 250V capacitors (use 7 per lamp)	0 68 kg

tes

The connection from the ıgnıtor to lamp should not be onger than 6 ft and suıtable hıgh tensıon cable should be ised (Rıpaults hıgh tensıon type PV 267 7 mm PVC 16/0 012, or sımılar
The ıgnıtor components are mounted on an open tray
The ıgnıtor provides a high voltage pulse and should be otally enclosed and earthed
To start the lamp the switch (see cırcuıt dıagram) should e depressed for a few seconds untıl the lamp ıs burnıng teadıly and then released The switch should not be perated whılst the lamp ıs workıng (Swıtch ıs not upplıed)
t wıll be necessary to allow the lamp to cool before estartıng



ratıon and Maıntenance

ty

re Use

ays ısolate the equıpment from the electrıcıty supply re ınsertıng or replacıng a lamp

k that the replacement lamp ıs the correct type for the ıcatıon, wattage and cap for use ın the cırcuıt and wıth rol gear

ıre that the lamp ıs correctly located ın the lampholder the glass outer ıs not scratched durıng ınsertıon

ng Use

e outer envelope ıs broken the lamp must not be ated

e mercury dıscharge and metal halıde lamps are used rolonged perıods ın close proxımıty to eyes and skın may be a slıght possıbılıty of a low level UV radıatıon rd Suıtable protectıon should be employed

ıın metal halıde lamps have operatıng restrıctıons, detaıls ıich are specıfıed wıth the lamps

osal

e lamps should be broken ın a contaıner Precautıons be taken agaınst flyıng glass or other fragments The ıtıon should be carrıed out outdoors (or ın a well latéd area) Wıth hıgh pressure mercury lamps ıt ıs not ssary to break up the ınner arc tube Where applıcable, ebrıs of large quantıtıes of lamps must be dısposed of cordance wıth the rules of the Local Authorıty

ıng

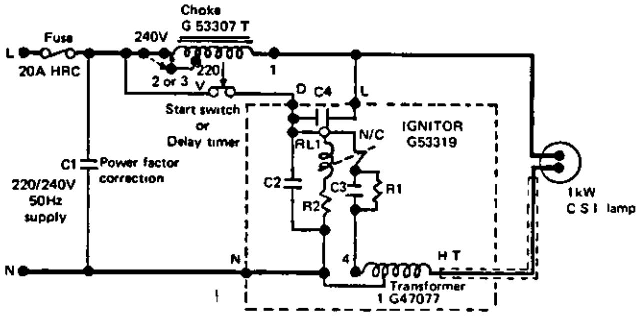
ınıt generates hıgh voltage pulses for lamp startıng ble safety precautıons should be taken durıng ınstallatıon peratıon of the unıt

ontrol unıt and assocıated lamp house must be earthed I V cable should be protected from accıdental damage upply must be dısconnected before servıcıng For oor use the lamp must be protected from raın

lıghtıng Fıttıng

ble fıttıngs ref OQ 1000 serıes avaılable for use wıth lamps, gıvıng a varıety of lıght dıstrıbutıons, and oratıng the starter unıt G53319 wıthın the fıttıng ıg

1kW CSI Cırcuıt Dıagram Usıng Choke G53307-T and Ignıtor G53319



C1 – 175 µF 250V A.C.	R1 – 4 7kΩ10W
C2/C3 – 0 22 µF 1000V	R2 – 4 7kΩ1W
C4 – 0 005 µF 250V A.C.	RL1 – Magnetıc Devıces 325/TS 14084

Thorn Lıghtıng reserve the rıght to alter the specıfıcatıon wıthout prıor notıce or publıc announcement

THORN LIGHTING

Issue date September 1982
Replaces L12/TA January 1976

4:99.8

CSI

Compact Source Iodide Sealed Beam Lamp (Hot Restrike) 1kW

Identification

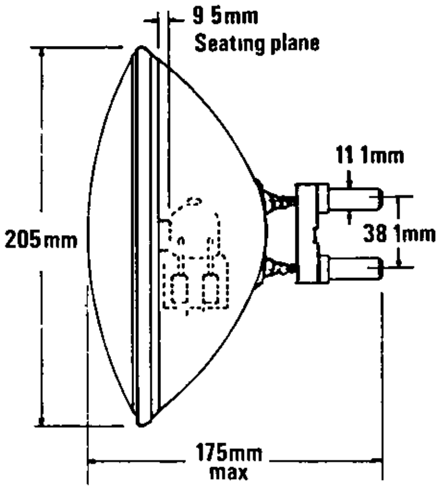
Specification Ref 99–1422

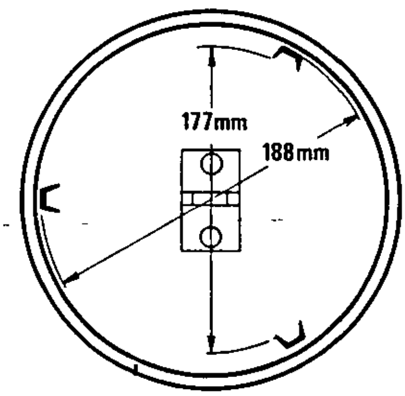
Applications

Floodlighting, especially for film and TV outside broadcasts, suitable for use with daylight colour film stock Also as a radiation source for solaria and allied applications

Description

The 1kW Sealed Beam Compact Source Iodide Lamp Ref 99–1422 is a modified form of the standard 1kW CSI Sealed Beam Lamp Ref 99–1222 (see Data Sheet 4 99 7) in which the construction has been modified to enable the lamp to be restarted immediately when hot The internal reflector is a dichroic mirror reducing the heat projected by the lamp to give a 'cool beam'





Performance

Electrical Characteristics

Supply volts	220V, 240V A C
Arc watts	1000
Arc volts	70/85
Arc current	15 amps approximately
Run up time	50 secs
Restarting time	Instantaneous
Starting current (cold)	17 amps approx

Physical Dimensions

Diameter	205 mm
Overall length (max)	175 mm
Caps	Bipost G38

Luminous Characteristics

Initial beam candlepower (peak)	1 25 million CDS			
Beam spread	1/2 peak ±3°	1/3 peak ±4°	1/5 peak ±6°	1/10 peak ±9°
Colour rendering, RA Index	RA 80			
Chromaticity co-ordinates	x = 0 393 y = 0 395			
Life (nominal objective)	1500 hrs			
Operating position	Horizontal ± 90°			

Control Gear

One choke G53307T PF correction capacitors and 20 kV minimum output* starter unit

Recommended type, see circuit diagram

Power factor correction capacitors are optional The use of 175 μF capacitors reduces the line current from 15 amps to approx 5 amp

*As measured by a sphere gap to BS358 Spikes approximately double this value may be recorded on an oscilloscope

)eration and Maintenance

tallation

ndard G38 lampholders should not be used with this ıp and circuit as they will not necessarily carry the high se voltages required for hot restart A lamp holder with l insulated sockets is necessary

table lampholders Ref GL1198

ırt well insulated leads between starter and lamp are ential to prevent actual arcing and to minimise pulse ses by 'brushing' The following minimum clearance and epage distances between the hot lead and any adjacent tal, whether earthed or not, are recommended

arance distance (1) Between smooth surfaces 15 mm
(2) Between sharp projections 30 mm
epage distances i e bridged by an insulating surface nm.

dichroic mirror will transmit radiated heat through the ector directly on to the fitting, which should be designed hat the following operating temperatures are not eeded

ıp ferrule measured at a point 4 mm from the glass — °C max
ıp pin/lampholder contact — 180°C max
ss envelope — 350°C max

ctrical Characteristics 220/240V 50Hz

ply voltage	220	240
ply frequency (Hz)	50	50
ply current (A)	5 6	5 0
al circuit watts (W)	1120	1140
ply power factor (lagging)	0 91	0 94
ıp voltage (V)	77	77
ıp current (A)	14 7	14 7
ıp wattage (W)	1000	1000
imum starting current (A)		
ne current (175 µF PFC)	5	3 5
mp current no PFC	16	16
d harmonic content		
ine current should be 21% for 240V)	18	18
ommended fuse rating	20A	20A

er Factor Correction

acitors are connected between phase and neutral for e phase operation The recommended value of power or correction is 175 µF which results in a supply power or of 0 94 (lagging) in the 240V circuit and 0 91 in the V circuit

details of Three Phase Operation and supply voltages r than 220/240V AC 50Hz see Thorn Lighting Data t Ref 49/T available on request

ty

re Use

ays isolate the equipment from the electricity supply re inserting or replacing a lamp.

k that the replacement lamp is the correct type for the cation, wattage and cap for use in the circuit and with rol gear

re that the lamp is correctly located in the lampholder he glass outer is not scratched during insertion.

During Use

If the outer envelope is broken the lamp must not be operated

Where mercury discharge and metal halide lamps are used for prolonged periods in close proximity to eyes and skin there may be a slight possibility of a low level UV radiation hazard Suitable protection should be employed

Certain metal halide lamps have operating restrictions, details of which are specified with the lamps

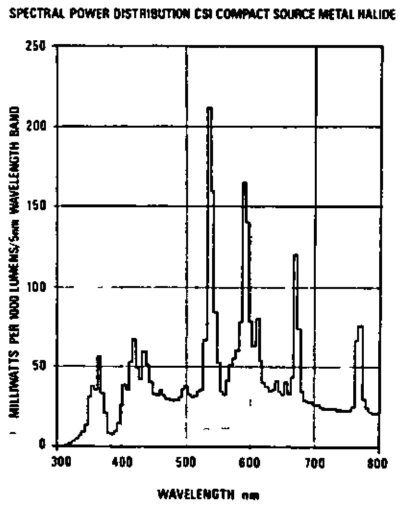
Disposal

These lamps should be broken in a container Precautions must be taken against flying glass or other fragments The operation should be carried out outdoors (or in a well ventilated area) With high pressure mercury lamps it is not necessary to break up the inner arc tube Where applicable, the debris of large quantities of lamps must be disposed of in accordance with the rules of the Local Authority

Warning

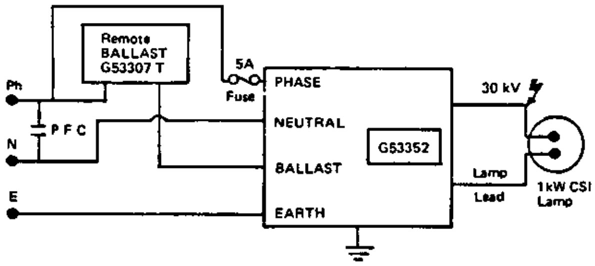
The unit generates high voltage pulses for lamp starting Suitable safety precautions should be taken during installation and operation of the unit

The control unit and associated lamp house must be earthed The H V cable should be protected from accidental damage The supply must be disconnected before servicing For outdoor use the lamp must be protected from rain



Circuit Diagram

1kW Hot Re-start Circuit (for 220/240V 50 Hz supplies)



Schematic wiring diagram for Hot Re-strike with G53352 ignitor

The G53352 consists of a 50/60Hz transformer (T2) high voltage capacitor (C9), spark gap (SG1), output transformer (T3) and control circuitry

Thorn Lighting reserve the right to alter the specification without prior notice or public announcement.

THORN EMI

Issue date. August 1983
Replaces September 1982

4:99.9

CSI

Compact Source Mercury Iodide Projector Lamp 1kW

Available from —
THORN EMI Lamps and Components Limited

Miles Road Mitcham Surrey CR4 3YX
Telephone 01-640 1221 Telex 25534 Sandby Mitcham

Identification

Specification Ref 99—0221

Applications

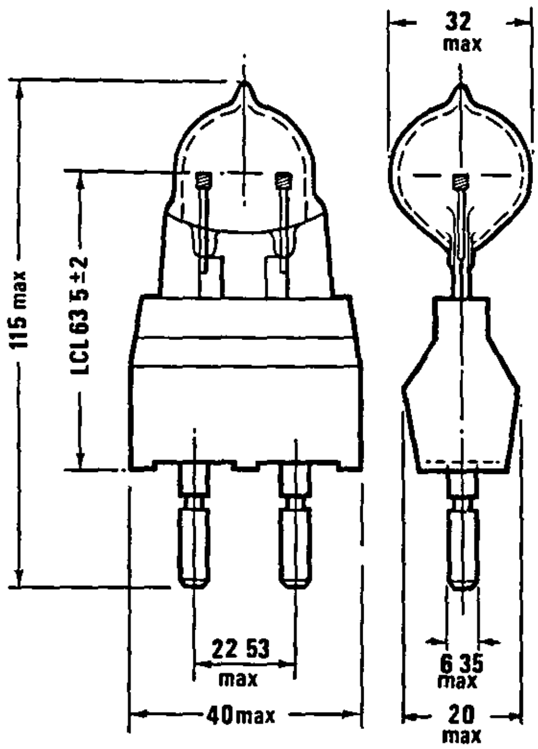
The high efficacy, robustness and small size of this lamp makes it eminently suitable for projector purposes such as for follow spotlights For photographic use it is suitable for use with daylight colour film stock

Description

The 1000W Compact Source Iodide Lamp gives white light of good colour rendering at an efficacy of 90 L/W for 500 hours life The arc size is approximately 15 mm x 5 mm and the brightness is about 8000 candelas per square cm

The high efficacy is obtained by the use of an arc discharge The iodide technique has been used to introduce additional elements into the arc and to keep the bulb wall clean throughout life

The lamp is somewhat unconventional in appearance It is extremely robust The small total physical size and the ability to operate it in any position ensures that the lamp can be readily fitted into existing equipment, and simplifies the design of new equipment The single ended construction and the degree of prefocusing provided means that lamp replacement is straightforward



All dimensions in mm

Performance

Electrical Characteristics

Supply volts	240
Arc watts	1000
Arc volts	70/85
Arc current	15 amps
Run-up time	30 secs
Re-start time	2/5 mins

Dimensions

Arc length	14–15 mm
Overall length	85 mm max excluding pins
Light centre length	63 5 ± 2 mm
Diameter	32 mm max
Cap	Medium Bipost-G22

Luminous Characteristics

Initial efficacy	90 L/W
Lumen maintenance	85%
Colour rendering index	RA 85
Chromaticity co-ordinates	x = 0 385
	y = 0 395
Life (nominal objective)	500 hours
Operating position	Universal

;ontrol Gear

;ontrol gear and box G 53255

)peration and Maintenance

;afety

;efore Use

\lways ısolate the equıpment from the electrıcıty supply
efore ınsertıng or replacıng a lamp

;heck that the replacement lamp ıs the correct type for the
pplıcatıon, wattage and cap for use in the cırcuıt and wıth
ontrol gear

:nsure that the lamp ıs correctly located ın the lampholder
nd the Quartz envelope ıs not scratched durıng ınsertıon

)urıng Use

Vhere mercury dıscharge and metal halıde lamps are used
or prolonged perıods ın close proxımıty to eyes and skın
here may be a slıght possıbılıty of a low level UV radıatıon
ıazard Suıtable protectıon should be employed

;ertaın metal halıde lamps have operatıng restrıctıons, detaıls
f which are specıfıed wıth the lamps

ıgh pressure mercury dıscharge lamps wıth quartz envelopes
vıthout glass outer bulbs emıt short wave ultra violet
adıatıon which ıs readıly transmıtted through quartz Thıs
adıatıon ıs harmful to eyes and skın, operators must be
hıelded from dırect or reflected short wave ultra vıolet
adıatıon.

)ısposal

hese lamps should be broken ın a contaıner Precautıons
ıust be taken agaınst flyıng glass or other fragments The
peratıon should be carrıed out outdoors (or ın a well
entılated area) With hıgh pressure mercury lamps ıt is not
ıecessary to break up the ınner arc tube Where applıcable,
he debrıs of large quantıtıes of lamps must be dısposed of
ı accordance wıth the rules of the Local Authorıty.

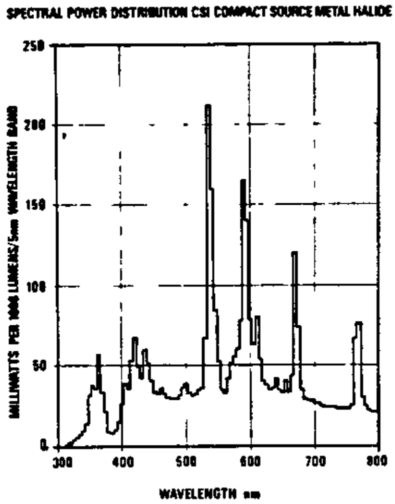
Varnıng

he unıt generates hıgh voltage pulses for lamp start'ng
uıtable safety precautıons should be taken durıng ınstallatıon
nd operatıon of the unıt

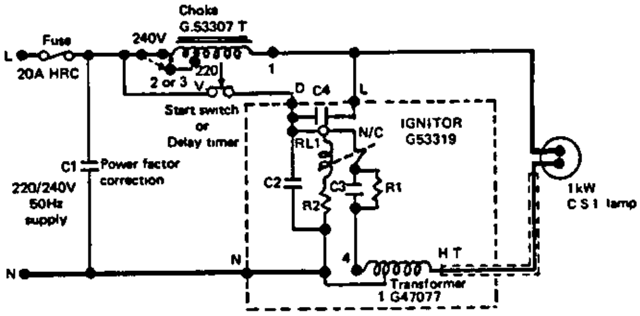
he control unıt and assocıated lamp house must be earthed
he H V cable should be protected from accıdental damage
he supply must be dısconnected before servıcıng. For
utdoor use the lamp must be protected from raın

loodlıghtıng Fıttıng

uıtable fıttıngs ref OQ 1000 serıes avaılable for use wıth
hese lamps, gıvıng a varıety of lıght dıstrıbutıons, and
ıcorporatıng the starter unıt G53319 wıthın the fıttıng
ıousıng



1kW CSI Circuit Diagram Using Choke G53307-T and Ignitor G53319



C1 – 175 μF 250V A.C.
C2/C3 – 0.22 μF 1000V
C4 – 0.005 μF 250V A.C.

R1 – 4.7kΩ10W
R2 – 4.7kΩ1W
RL1 – Magnetic Devices 325/TS 14084

THORN LIGHTING

Issue date October 1981 **4:9.9.3** PROVISIONAL

CID compact iodide daylight lamp
200W metal halide discharge lamp
Specification Ref: 99–0211

Identification

Applications

For use in film and television lighting For colour film stock balanced for light of 5500K and for all colour or monochrome television productions

Particularly suitable for portable reporter lighting Battery or mains operating

Description

Thorn Lighting scientists have developed a new single-ended discharge lamp to meet demand from the TV and film industry for a portable, 200W hot restrike lamp of 'daylight' colour

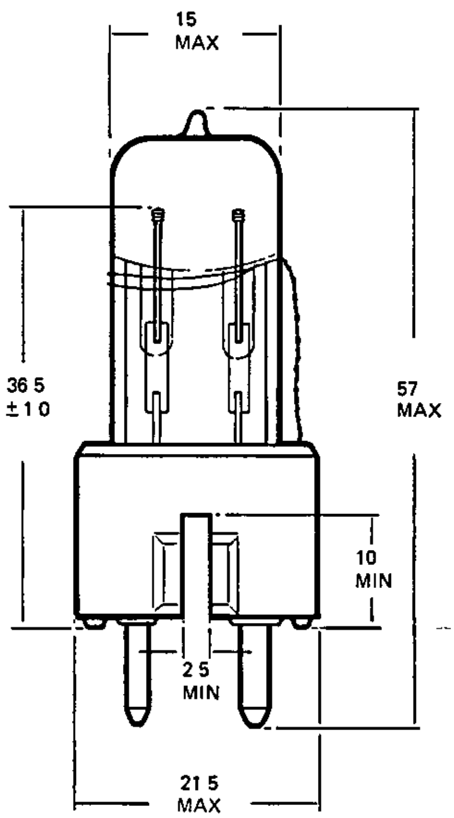
The Compact Iodide Daylight (CID) lamp is one of the most important developments in the lighting industry for many years, offering for the first time an extremely robust single-ended lamp which gives correct colour rendering on film stock balanced for 5500°K

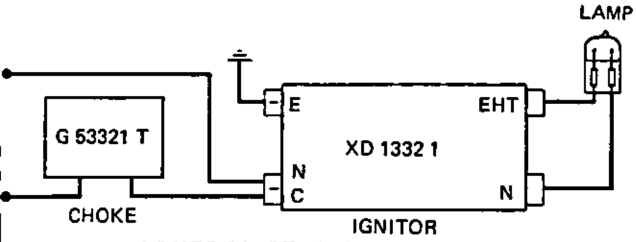
The CID lamp is able to meet the very stringent demands of film lighting cameramen and TV lighting directors because of these combined advantages –

1 Correlated colour temperature of 5,500°K ± 400
2 Ra colour rendering index of 85
3 DIN standard 5035 classification class 1
4 Unique single-ended construction
5 Maintenance of colour throughout life
6 Reduced flicker

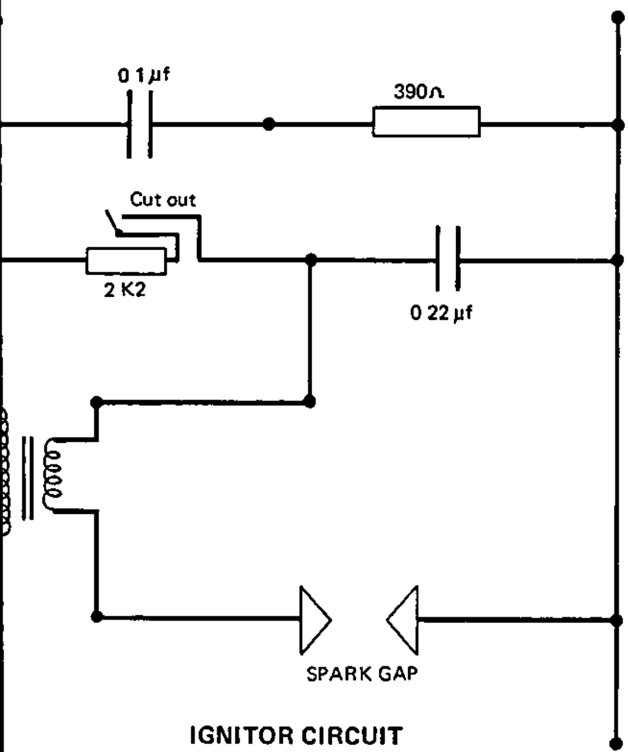
Performance

Electrical characteristics	
Supply volts	220/240
Arc watts	200
Arc volts	70
Arc current (amps)	3 3
Starting voltage (Pulse)	10kV min
Control gear	
Series choke	G 53321 T
Ignitor	X D 1332 1
Circuit	See Over
Luminous characteristics	
Initial efficacy	70 L/W
Colour	Daylight
Run up time	1 minute
Restart time	Instantaneous
Life	
Nominal objective	100 hours
Dimensions (mm)	
Arc length	5
Dia (max)	15
L C L	36 5 ± 1
Overall length (max)	57
Cap	GY9 5 with centre slot (See drawing)

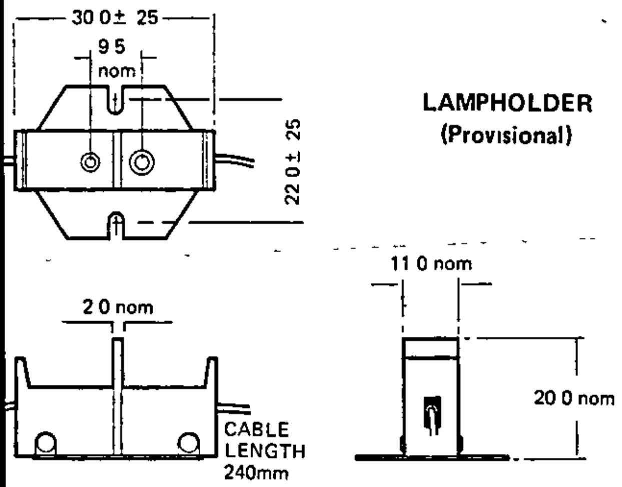




CONTROL GEAR CIRCUIT
FOR MAINS OPERATION



IGNITOR CIRCUIT



LAMPHOLDER
(Provisional)

ARNING

e unit generates high voltage pulses for lamp starting
propriate safety precautions should be taken when
vicing or operating the unit

lighting units should be provided with a front safety glass
ich will give protection from harmful ultra-violet radiation
d non-quiescent lamp failure

te: The lamp may also be operated from suitable electronic
lasts to give flicker free light output These ballasts can be
signed for 120/240 volt, 50/60 Hz mains or for low voltage
C supplies

rther Information

orn Lighting reserve the right to alter the specification without prior
ice or public announcement

PROVISIONAL

THORN LIGHTING

Issue date September 1982 **4:99.**

CID 500W Compact Source Discharge Lamp Hot Restrike

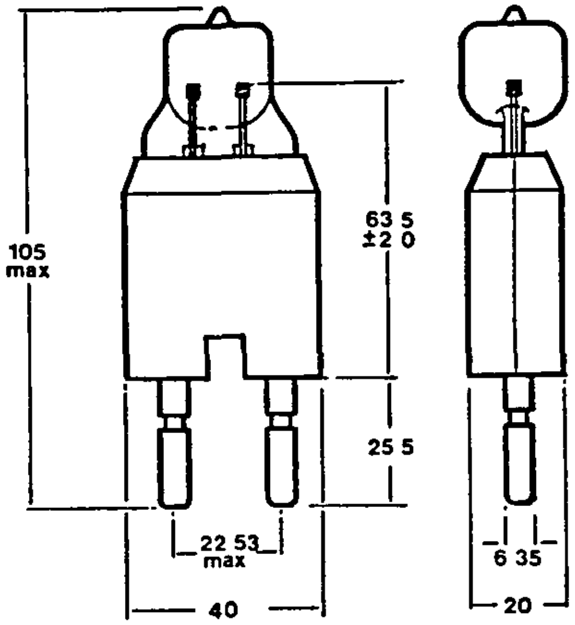
Specification No.: 99–0415

Identification

Applications

For use with colour film balanced for light of 5500°K and all monochrome film stock Suitable for monochrome or colour television productions

Designed for use in Fresnal lens luminaires and ellipsoidal spotlights Also for theatre and allied applications where suitable lighting fittings can make good use of the high intensity, compact light source.



Performance

Electrical Characteristics

Supply Voltage	220/240 AC
Arc Voltage	80
Nominal Arc Current	7 amp
Run-up Time	1 minute
Re-start Time	Instantaneous

Luminous Characteristics

Arc Length	9 ±1 0
Lumen Output	35,000
Lumen Maintenance	90%
Correlated Colour Temperature	5,500 ± 400°K
General Colour Rendering Index Ra	85
Rated Life	500 hrs
Base	G22 Bipost
Operating Position	Any
Chromaticity co-ordinates	x' 0 333 y' 0 341

Operation and Maintenance

Safety

Before Use

Always isolate the equipment from the electricity supply before inserting or replacing a lamp

Check that the replacement lamp is the correct type for the application, wattage and cap for use in the circuit and with control gear

Ensure that the lamp is correctly located in the lampholder and the quartz envelope is not scratched during insertion

WARNING

The unit generates high voltage pulses for lamp starting Appropriate safety precautions should be taken when servicing or operating the unit

All lighting units should be provided with a front safety glass which will give protection from harmful ultra-violet radiation and non-quiescent lamp failure

Note: The lamp may also be operated from suitable electronic ballasts to give flicker free light output These ballasts can be designed for 120/240 volt, 50/60 Hz mains or for low voltage D C supplies

Further Information

THORN LIGHTING

Issue date April 1982 **4:99.6**

PROVISIONAL

CID 1000W Compact Source Discharge Lamp Hot Restrike

Specification No.: 99–0422

Identification

Applications

For use with colour film balanced for light of 5500°K and all monochrome film stock Suitable for monochrome or colour television productions

Designed for use in Fresnal lens luminaires and ellipsoidal spotlights Also for theatre and allied applications where suitable lighting fittings can make good use of the high intensity, compact light source

Performance

Electrical Characteristics

Supply Voltage	220/240 AC
Arc Voltage	70–85
Nominal Arc Current	15 amp
Run-up Time	1 minute
Re-start Time	Instantaneous

Luminous Characteristics

Arc Length	14 ± 1 0
Lumen Output	70,000
Lumen Maintenance	90%
Correlated Colour Temperature	5,500 ± 400°K
General Colour Rendering Index Ra	85
Rated Life	500 hrs
Base	G38 Bipost
Operating Position	Any

Operation and Maintenance

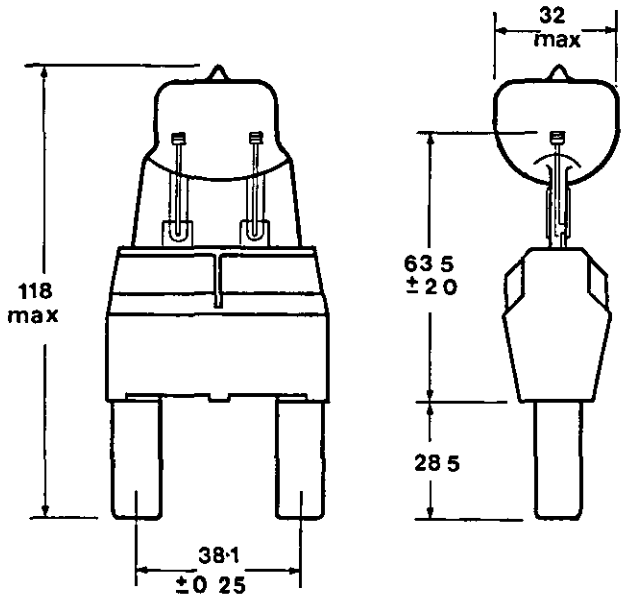
Safety

Before Use

Always isolate the equipment from the electricity supply before inserting or replacing a lamp

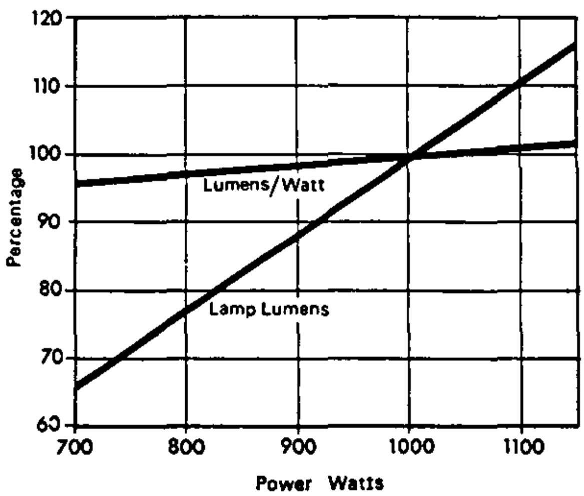
Check that the replacement lamp is the correct type for the application, wattage and cap for use in the circuit and with control gear

Ensure that the lamp is correctly located in the lampholder and the quartz envelope is not scratched during insertion

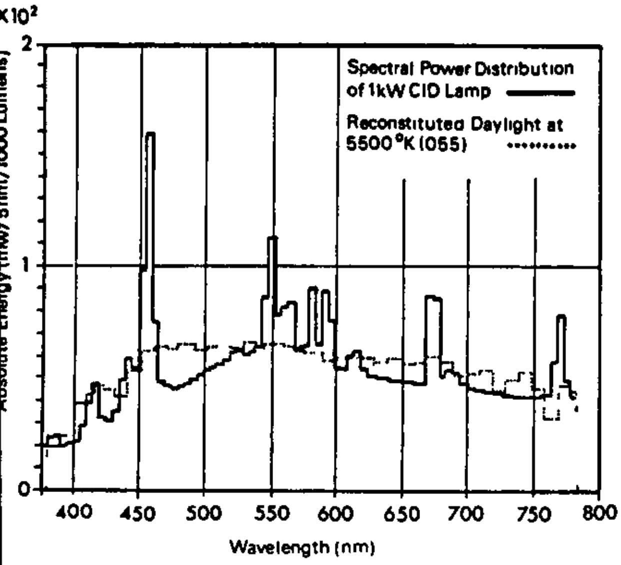


All dimensions in mm

DEPENDENCE OF OPTICAL CHARACTERISTICS OF LAMP ON POWER DISSIPATED



TYPICAL SPECTRAL POWER HISTOGRAM



ing Use

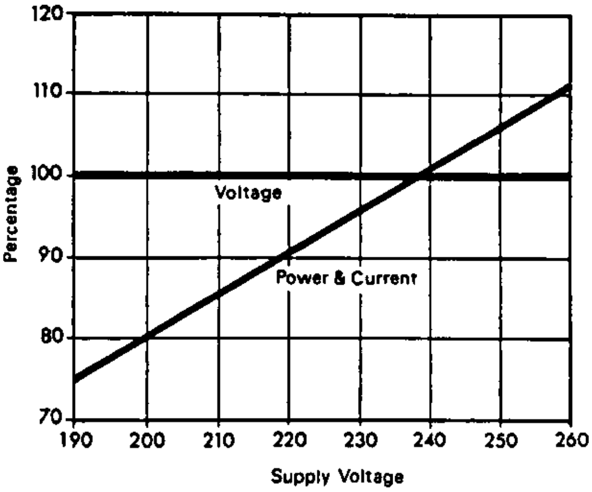
h pressure mercury discharge lamps with quartz envelopes hout glass outer bulbs emit short wave ultra violet ation which is readily transmitted through quartz This ation is harmful to eyes and skin, operators must be lded from direct or reflected short wave ultra violet ation

tain metal halide lamps have operating restrictions, details vhich are specified with the lamps

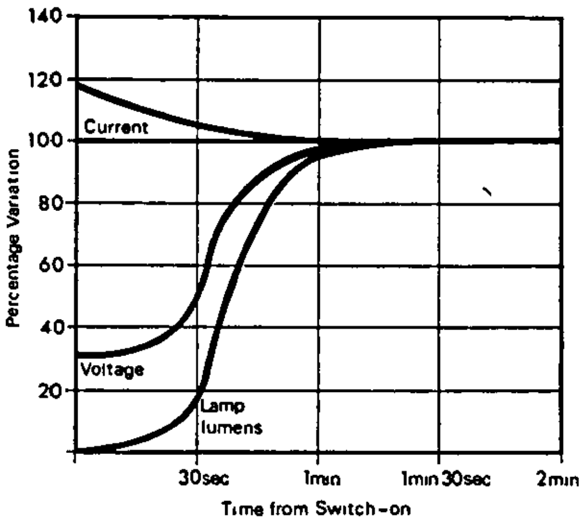
posal

se lamps should be broken in a container Precautions t be taken against flying glass or other fragments The ration should be carried out outdoors (or in a well tilated area) Where applicable, the debris of large ntities of lamps must be disposed of in accordance with rules of the Local Authority

DEPENDENCE OF ELECTRICAL CHARACTERISTICS OF LAMP SUPPLY VOLTAGE



TRANSIENT CHARACTERISTICS OF LAMP FROM SWITCH-ON



Thorn Lighting reserve the right to alter the specification without prior notice or public announcement

THORN LIGHTING

Issue date September 1981

4:9.9.1

CID Compact Iodide Daylight Lamp
1kW Metal Halide Discharge Lamp
Specification Ref. 99 - 1225

Identification

Applications

For use in film and television lighting Suitable for colour film stock balanced for light of 5500K and for all colour or monochrome television productions.

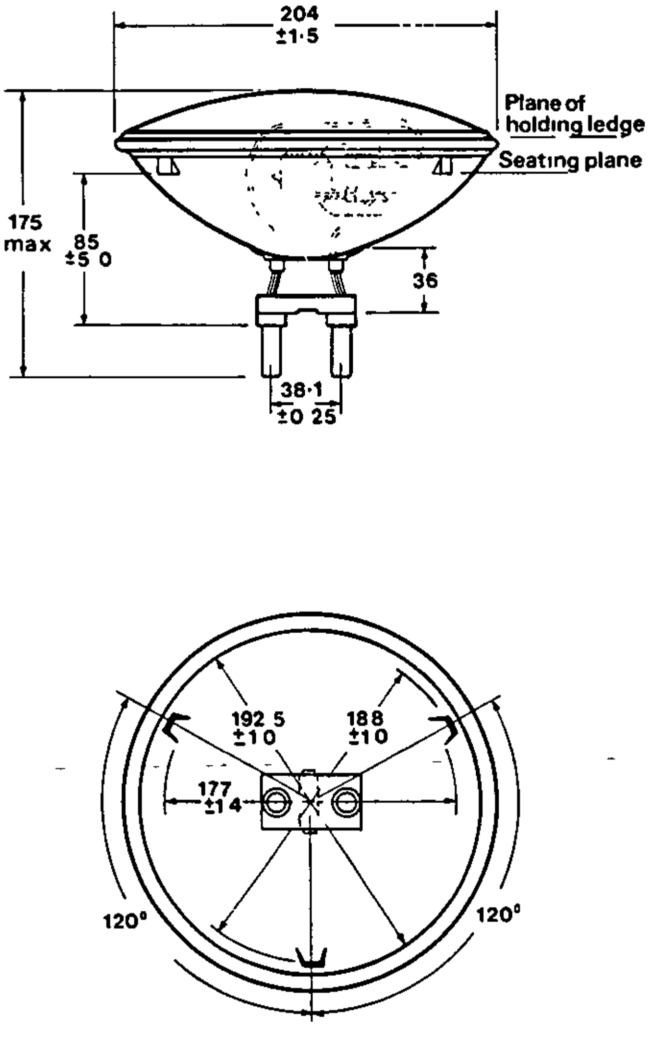
The CID lamp is also widely used for theatre lighting and allied applications where suitable lighting fittings can make good use of this robust, lightweight, compact high intensity light source

Description

This 1kW CID lamp consists of a high pressure metal halide discharge lamp enclosed within an 8 inch sealed beam glass envelope

The arc tube is of quartz and the discharge is between tungsten electrodes in an atmosphere of mercury vapour with additional metallic iodides These additions ensure a light of 5500 ± 400K and the lamp operates at very high efficacy

The extremely accurate positioning of the arc tube within the outer envelope gives a beam candle power in excess of ¾ million candelas with a total spread of 20° (to ¹⁄₁₀ peak)



All dimensions in mm

Performance

Electrical Characteristics

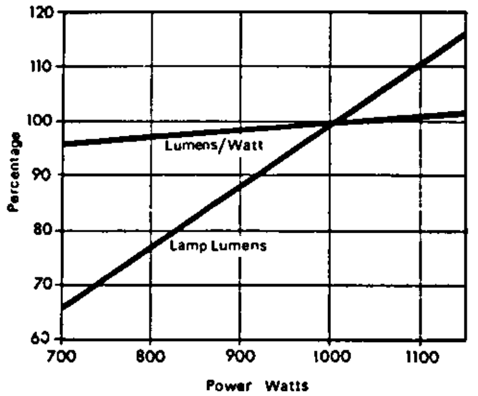
Supply Voltage	220/240 AC*
Base	G38 Bipost
Arc Voltage	70–85
Nominal Arc Current	15 amp
Run-up time	1 minute
Operating Position	Any

Luminous Characteristics

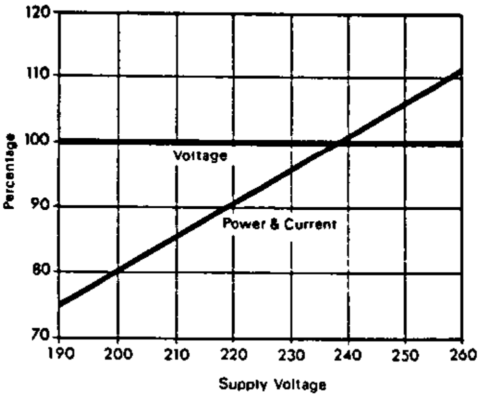
Peak Initial Beam Candlepower	850,000 cds
Beam Width (½ peak) included angle	8°
Field angle (¹⁄₁₀ peak) included angle	20°
Correlated Colour Temperature	5500 ± 400K
Colour Rendering Index Ra	85
Chromaticity co-ordinates	x' 0 333 y' 0 341

*Details upon application for control gear for operating on supply voltage between 100V and 240V AC 50Hz or 60 Hz

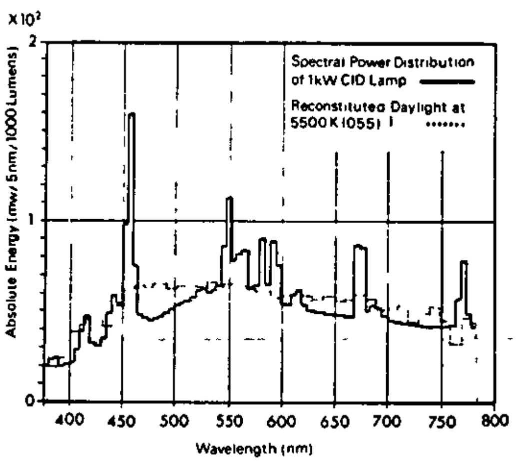
DEPENDENCE OF OPTICAL CHARACTERISTICS OF LAMP ON POWER DISSIPATED



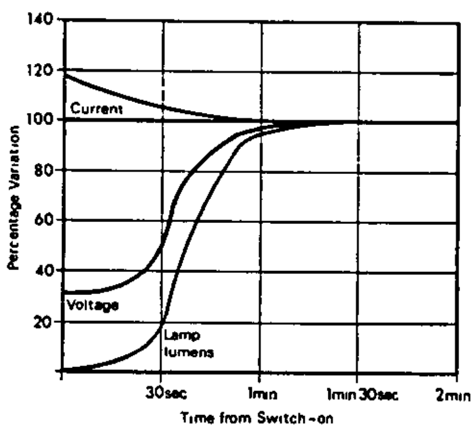
DEPENDENCE OF ELECTRICAL CHARACTERISTICS OF LAMP SUPPLY VOLTAGE



TYPICAL SPECTRAL POWER HISTOGRAM



TRANSIENT CHARACTERISTICS OF LAMP FROM SWITCH-ON



Operation and Maintenance

Safety

Before Use

Always isolate the equipment from the electricity supply before inserting or replacing a lamp

Check that the replacement lamp is the correct type for the application, wattage and cap for use in the circuit and with control gear

Ensure that the lamp is correctly located in the lampholder and the glass outer is not scratched during insertion

During Use

If the outer envelope is broken the lamp must not be operated

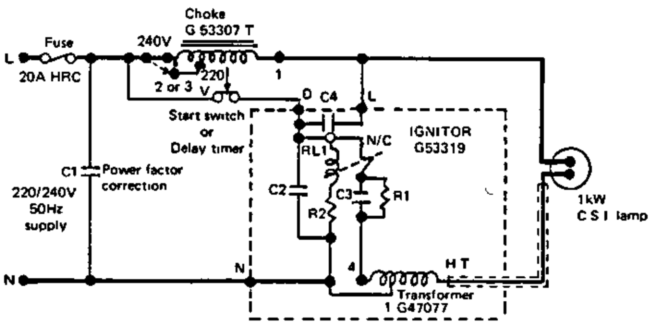
Where mercury discharge and metal halide lamps are used for prolonged periods in close proximity to eyes and skin there may be a slight possibility of a low level UV radiation hazard Suitable protection should be employed

Certain metal halide lamps have operating restrictions, details of which are specified with the lamps

Disposal

These lamps should be broken in a container Precautions must be taken against flying glass or other fragments The operation should be carried out outdoors (or in a well ventilated area) With high pressure mercury lamps it is not necessary to break up the inner arc tube Where applicable, the debris of large quantities of lamps must be disposed of in accordance with the rules of the Local Authority

1kW CSI Circuit Diagram Using Choke G53307-T and Ignitor G53319



C1 – 175 µF 250V A C	R1 – 4 7kΩ10W
C2/C3 – 0 22 µF 1000V	R2 – 4 7kΩ1W
C4 – 0.005 µF 250V A.C.	RL1 – Magnetic Devices 325/TS 14084

Warning

The unit generates high voltage pulses for lamp starting Suitable safety precautions should be taken during installation and operation of the unit

The control unit and associated lamp house must be earthed The H V cable should be protected from accidental damage The supply must be disconnected before servicing For outdoor use the lamp must be protected from rain

Floodlighting Fitting (see data sheet T30)

Suitable fittings ref OM 1000 series available for use with these lamps, giving a variety of light distributions, and incorporating the starter unit OMX within the fitting housing

Further Information

Thorn Lighting reserve the right to alter the specification without prior notice or public announcement.

THORN LIGHTING

Issue date September 1981 **4:9.9.2**

CID Compact Iodide Daylight Lamp
1kW Hot Restrike Metal Halide Discharge Lamp
Specification Ref. 99 - 1425

Identification

Applications

For use in film and television lighting Suitable for colour film stock balanced for light of 5500K and for all colour or monochrome television productions

The CID lamp is also widely used for theatre lighting and allied applications where suitable lighting fittings can make good use of this robust, lightweight, compact high intensity light source

Description

This 1kW CID lamp consists of a high pressure metal halide discharge lamp enclosed within an 8 inch sealed beam glass envelope with a dichroic coated reflector

The arc tube is of quartz and the discharge is between tungsten electrodes in an atmosphere of mercury vapour with additional metallic iodides These additions ensure a light of 5500 ± 400K and the lamp operates at very high efficacy

The extremely accurate positioning of the arc tube within the outer envelope gives a beam candle power in excess of ¾ million candelas with a total spread of 20° (to ¹⁄₁₀ peak)

Performance

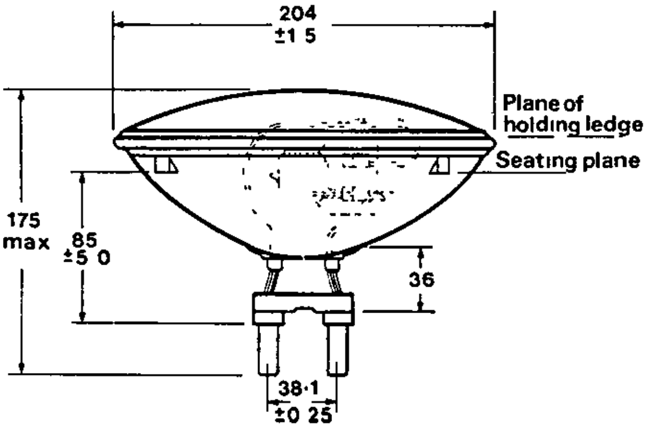
Electrical Characteristics

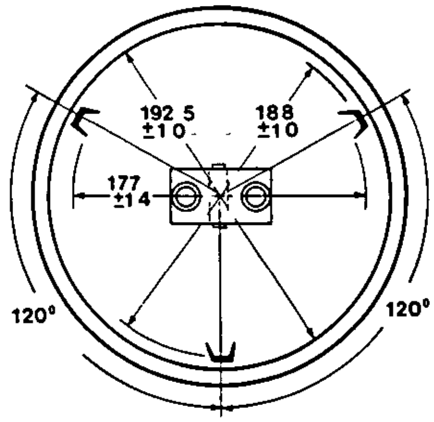
Supply Voltage	220/240 AC*
Base	G38 Bipost
Arc Voltage	70–85
Nominal Arc Current	15 amp
Run-up time	1 minute
Restrike time	Instantaneous
Operating Position	Any
Average Rated Life	1000 hrs

Luminous Characteristics

Peak Initial Beam Candlepower	850,000 cds
Beam Width (½ peak) included angle	8°
Field angle (¹⁄₁₀ peak) included angle	20°
Correlated Colour Temperature	5500 ± 400K
Colour Rendering Index Ra	85
Chromaticity co-ordinates	x' 0 333 y' 0 341
Reflector	Dichroic coated

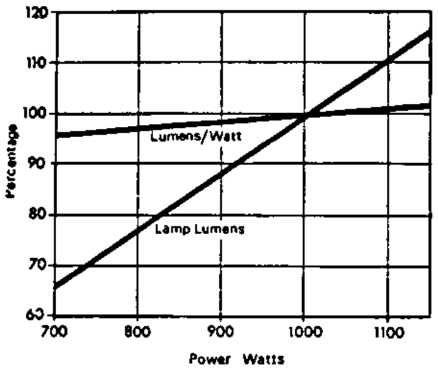
*Details upon application for control gear for operating on supply voltage between 100V and 240V AC 50Hz or 60 Hz



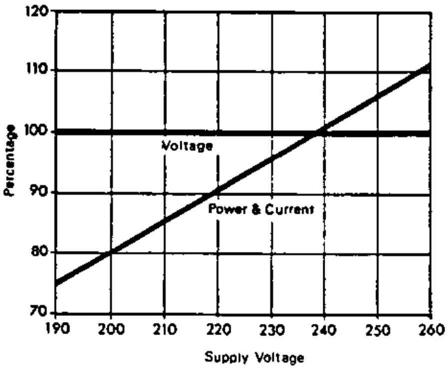


All dimensions in mm

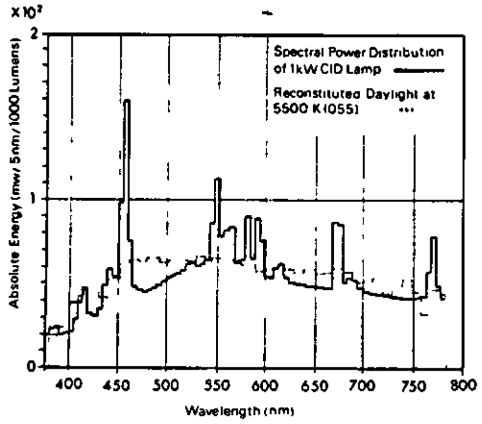
DEPENDENCE OF OPTICAL CHARACTERISTICS OF LAMP ON POWER DISSIPATED



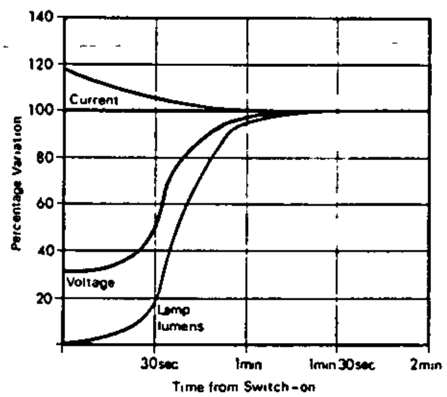
DEPENDENCE OF ELECTRICAL CHARACTERISTICS OF LAMP SUPPLY VOLTAGE



TYPICAL SPECTRAL POWER HISTOGRAM



TRANSIENT CHARACTERISTICS OF LAMP FROM SWITCH-ON



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During Use

If the outer envelope is broken the lamp must not be operated

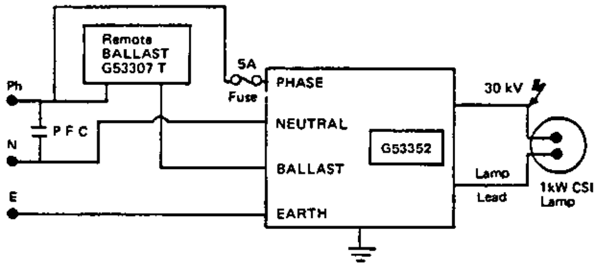
Where mercury discharge and metal halide lamps are used for prolonged periods in close proximity to eyes and skin there may be a slight possibility of a low level UV radiation hazard Suitable protection should be employed

Certain metal halide lamps have operating restrictions, details of which are specified with the lamps

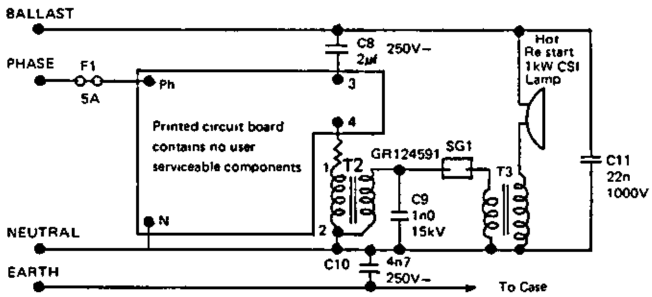
Disposal

These lamps should be broken in a container Precautions must be taken against flying glass or other fragments The operation should be carried out outdoors (or in a well ventilated area) With high pressure mercury lamps it is not necessary to break up the inner arc tube Where applicable, the debris of large quantities of lamps must be disposed of in accordance with the rules of the Local Authority

1kW Hot Re-start Circuit (for 220/240V 50Hz supplies)



Schematic wiring diagram for Hot Re-strike with G53352 ignitor



The G 53352 consists of a 50/60Hz transformer (T2) high voltage capacitor (C9), spark gap (SG1), output transformer (T3) and control circuitry

Electrical Characteristics 220/240V 50Hz

Supply Voltage	220	240
Supply Frequency (Hz)	50	50
Supply Current (A)	5 6	5 0
Total Circuit Watts (W)	1120	1140
Supply Power Factor (Lagging)	0 91	0 94
Lamp Voltage (V)	77	77
Lamp Current (A)	14 7	14 7
Lamp Wattage (W)	1000	1000
Maximum starting current (A)		
1) line current (175 µF PFC)	5	3 5
2) lamp current no PFC	16	16
% 3rd Harmonic content in line current	18	18
Recommended fuse rating	20A	20A

Power Factor Correction

Capacitors are connected between phase and neutral for single phase operation The recommended value of power factor correction is 175µ F which results in a supply power factor of 0 94 (lagging) in the 240V circuit and 0 91 in the 220V circuit

For details of Three Phase Operation and supply voltages other than 220/240V AC 50Hz see Thorn Lighting Data sheet ref T49/T available on request

Further Information

Thorn Lighting reserve the right to alter the specification without prior notice or public announcement.

THORN LIGHTING

Issue date: October 1981 **4:9.9.4**

CID Compact Iodide Daylight Lamp

2.5kW Hot Restrike Metal Halide Discharge Lamp

Specification Ref. 99 - 0431

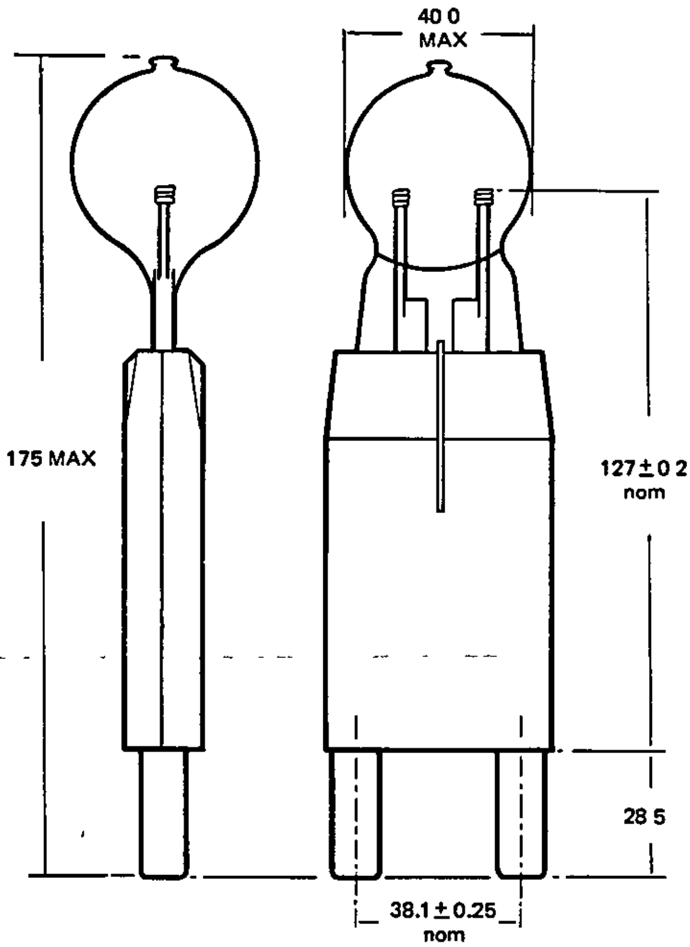
Identification

Applications

For use with colour film stock balanced for daylight of 5500K and for all colour or monochrome television productions The CID lamp is designed for use in fresnel lens luminaries and for theatre lighting and allied applications where suitable lighting fittings can make good use of this high intensity compact light source

Description

The 2 5kW CID lamp gives light of 5500±400K at an efficacy of 80 L/W The CID lamp is a metal halide discharge arc lamp with a quartz envelope and is of extremely robust construction in single ended form of compact dimensions The international standard G38 base ensures that the lamp can be readily fitted into many existing luminaires and simplifies the design of new equipment



Performance

Electrical Characteristics

Supply Voltage	220/240 AC*
Base	G38 Bipost
Arc Voltage	100 nom.
Nominal Arc Current	30 amp
Run-up time	1 minute
Restrike time	Instantaneous
Ignitor	IREM AD 3050

Luminous Characteristics

Arc Length	18 nom
Lumen Output	200,000
Lumen Maintenance	90%
Correlated Colour Temperature	5500±400K
General Colour Rendering Index Ra	85
Chromaticity co-ordinates	x'0.333 y'0 341
Operating Position	Any
Average Rated Life	350 hrs

*Details upon application for control gear for operation on supply voltages between 100V and 240V AC 50Hz or 60Hz

Operation and Maintenance

Safety

Before Use

Always isolate the equipment from the electricity supply before inserting or replacing a lamp

Check that the replacement lamp is the correct type for the application, wattage and cap for use in the circuit and with control gear

Ensure that the lamp is correctly located in the lampholder and the quartz envelope is not scratched during insertion

During Use

Where mercury discharge and metal halide lamps are used for prolonged periods in close proximity to eyes and skin there may be a slight possibility of a low level of UV radiation hazard. Suitable protection should be employed

Certain metal halide lamps have operating restrictions, details of which are specified with the lamps

High pressure mercury discharge lamps with quartz envelopes without glass outer bulbs emit short wave ultra violet radiation which is readily transmitted through quartz This radiation is harmful to eyes and skin, operators must be shielded from direct or reflected short wave ultra violet radiation

Disposal

These lamps should be broken in a container Precautions must be taken against flying glass or other fragments The operation should be carried out outdoors (or in a well ventilated area) With high pressure mercury lamps, it is not necessary to break up the inner arc tube Where applicable, the debris of large quantities of lamps must be disposed of in accordance with the rules of the Local Authority

urther Information

horn Lighting reserve the right to alter the specification without rior notice or public announcement

APPENDIX 2

DETAILS OF TRIALS INVOLVING USE OF TWO COLOUR RATIO PYROMETER AS MEASUREMENT INSTRUMENT

APPENDIX 2

TRIALS CARRIED OUT USING RATIO PYROMETER

This instrument was selected for evaluation as a possible measuring tool as it has the advantage over the majority of other temperature measuring techniques of not requiring an emissivity correction to be made in order to obtain a value for true surface temperature of the target material.

This depends though on the emissivity remaining constant for the wavelength bands observed by the instrument. Although the value of emissivity for tungsten does vary with wavelength the criteria is satisfied in this instance as the wavelength regions are sufficiently close together to make any difference negligible. The wavelength bands compared in the instrument are two narrow bands centred on 550 and 650 nanometers.

The instrument works by focussing radiant energy from the hot target at a target image plane, the rays then pass through a beam splitting mirror which sends a fraction of the radiation back to the view finding eyepiece which focusses on the field of view iris and on the target image. The greater fraction of radiation passes through the beam splitting mirror and into an integrating sphere.

The integrating sphere has two photomultipliers attached to it, one having a green filter (550nm) and the second, a red filter (650nm). The ratio of the signals from these two detectors is determined by the electronics of the instrument and is proportional to the temperature of the target surface.

The instrument has an internal calibration standard in the form of a tungsten lamp and the meter should be checked before making any measurements.

The readout is in degrees centigrade via a digital L.E D display or a pen-recorder output terminal. The particular instrument used was non-standard and had an extra iris inserted in the target image plane which could be used to limit the size of the target area. The layout of the detector head and control unit are shown in Figure A1. The procedure for operation was that after setting the calibration the target was viewed via the eyepiece and the target brought into focus by adjustment of the focussing ring on the object lens system. The iris could then be closed down to define the target area which, when fully closed, gave a target circle of approximately 2mm diameter. If the low intensity light is alight on the control panel the radiation level is insufficient to give a reading and the instrument has to be repositioned with a reduced target-detector distance. This procedure was adopted in an attempt to make some temperature measurements on the coils of some 2.5kW CID lamps with the following results:-

Initial measurements were made viewing centrally the coil of a 2.5kW CID lamp @ 260v Input ($\simeq$ 2800W)
@ 240v Input ($\simeq$ 2500W)
@ 210v Input ($\simeq$ 2050W)
@ 180v Input ($\simeq$ 1700W)

and the temperatures monitored by means of a pen-recorder. Typical traces are shown in Figure A2 . The traces show the considerable instability of the readings giving a total spread of as much as 310^{o}C. If the lamp power is reduced still further to 1500W after approximately 10 minutes a significant change occurs as is seen by the bottom trace shown in Figure A2.

This stabilising of the trace is accompanied by an equally noticeable change in the behaviour of the gases in the arc tube. With the lamp operating at the higher wattages, clouds of gas can be clearly seen swirling in the arc tube. At 1500W when the stable temperature trace is obtained, no such gaseous movement can be seen and the gas cloud within the lamp looks to be stationary.

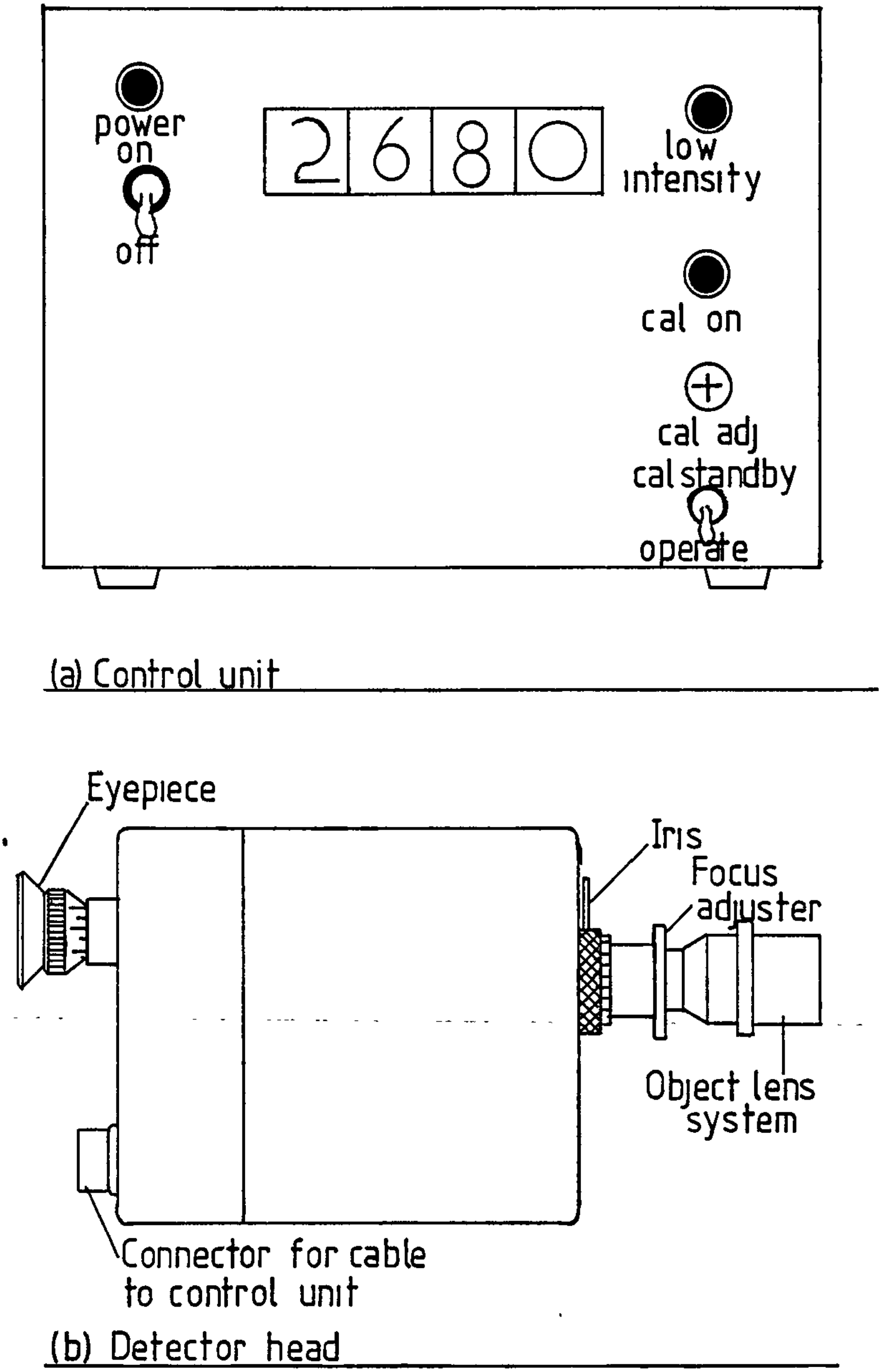


Figure A1. Two colour pyrometer

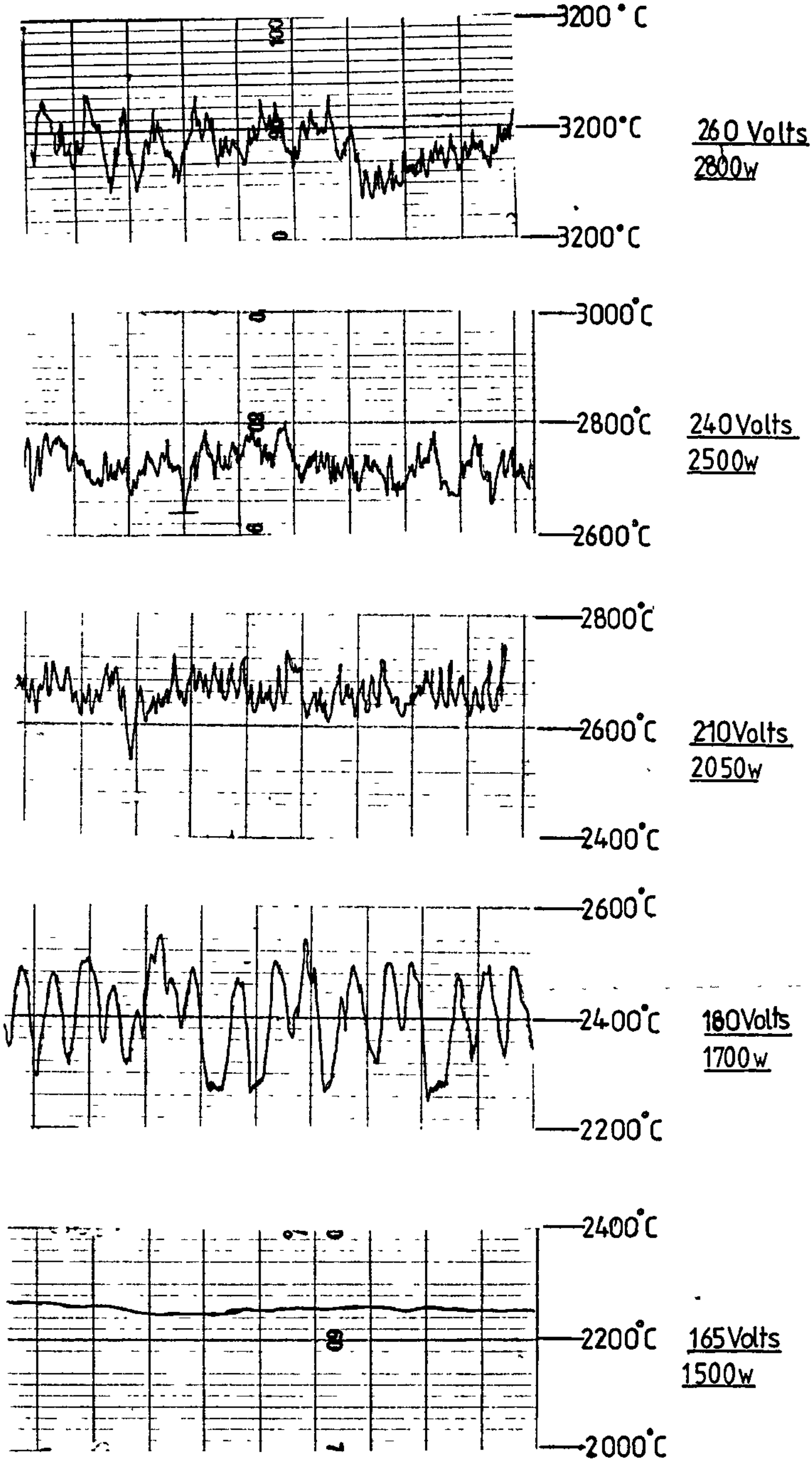


Figure A2. Temperature traces for 2·5Kw CID Measured at various input voltages using ratio pyrometer.

The most likely explanation for this phenomena is that the moving gas cloud contains a high concentration of mercury which has a resonance line at 550 nm, within one of the bands at which the instrument measures, and the reading is being affected by emission, or absorption, of radiation by the mercury in this region thus causing the fluctuation as the amount of mercury in the pyrometers optical path can be changed by the convection currents in the lamp. If this is the case it does not therefore follow that the stable temperature reading is correct as the interference may still be occuring but at a constant level. In order to obtain a value for the temperature without incurring this error one possible solution would be to change the 550nM band to one which is in a region not affected by emission or absorption in the gas cloud. This would involve a major modification to the instrument which could not be carried out as it is also in use for other work which would be adversely affected by a major modification to the instrument. A further alternative is to extrapolate a cooling curve for the electrode back to time zero after switch off and assuming any arc radiation would decay instantaneously at switch off. This method is not feasible for two major reasons:- Firstly, the decay in electrode radiation rapidly takes the level below the low intensity level for the instrument and although the arc decays very rapidly the wall temperature is such that clouds of mercury and metal halide vapours will still remain in the optical path of the instrument for several seconds until the walls cool sufficiently to allow them to condense and they can still absorb the radiation from the electrode.

The only way to overcome the problem of absorption/ emission at a wavelength utilised by the instrument would be the construction of a ratio pyrometer using wavelengths in an area not affected by the arc or vapour clouds in the lamp. The building of such a pyrometer was not considered practical for this investigation and ratio pyrometry was not pursued further.

This oscillation of output was also encountered in the limited trials carried out using a pyrometer employing a silicon detector, the response of which extends across the areas of strong emission and absorption of the mercury and consequently suffer a similar drawback.

APPENDIX 3

DETAILS OF ALL MEASURED AND CALCULATED TEMPERATURE PROFILES

	2.5kW run at 2.5kW				@2.0kW				@1.5kW			
X	T.Meas	T.Calc	ΔT	%	T.Meas.	T.Calc	ΔT	%	T.Meas.	T.Calc	ΔT	%
0	3268	3268	0	0	3076	3076	0	0	2903	2903	0	0
.05	3169	3196	27	0.8	2963	3014	51	1.7	2815	2850	35	1.2
.15	3097	3064	-33	-1.1	2924	2900	-24	-0.8	2753	2751	-2	-0.1
.25	3030	2945	-95	-2.8	2826	2797	-29	-1.0	2665	2661	-4	-0.1
.35	2908	2838	-70	-2.4	2722	2703	-19	-0.7	2592	2578	-14	-0.5
.4	2791	2769	-22	-0.8	2614	2642	28	1.1	2483	2524	41	1.6
.5	2679	2644	-35	-1.3	2549	2532	-17	-0.7	2421	2426	5	.1
.6	2602	2534	-68	-2.6	2477	2433	-44	-1.8	2357	2337	-20	-0.8
.7	2520	2435	-85	-3.4	2409	2343	-66	-2.7	2290	2256	-34	-1.5
.8	2455	2345	-110	-4.5	2340	2261	-79	-3.4	2218	2182	-36	-1.6
.9	2372	2263	-109	-4.6	2261	2187	-74	-3.3	2146	2114	-32	-1.5
1.0	2296	2188	-108	-4.7	2193	2119	-74	-3.4	2082	2051	-31	-1.5
1.1	2226	2120	-106	-4.8	2128	2055	-73	-3.9	2009	1993	-16	-0.8
1.2	2170	2057	-113	-5.2	2061	1997	-64	-3.1	1963	1939	-24	-1.2
1.3	2119	1998	-121	-5.7	2030	1943	-87	-4.3	1918	1889	-29	-1.5
1.4	2084	1944	-140	-6.7	1986	1892	-94	-4.7	1893	1842	-49	-2.7
1.5	2048	1893	-155	-7.6	1952	1845	-107	-5.5	1864	1798	-66	-3.5
1.6	2006	1846	-160	-8.0	1922	1801	-121	-6.3	1842	1756	-86	-4.7
1.7	1959	1802	-157	-8.0	1880	1759	-121	-6.4	1830	1717	-113	-6.2

TABLE 11

A comparison of predicted and measured temperatures (K) for the 2.5kW CID electrodes operat on A C at various wattages.

	No. 1				No. 2			
X	T.Meas.	T Calc.	ΔT	%	T.Meas.	T.Calc.	ΔT	%
0	3735	3735	0	0	3343	3343	0	0
.05	3654	3597	-57	-1.6	3292	3255	-37	-1.1
.15	3575	3356	-219	-6.1	3239	3097	-142	-4.4
.25	3414	3153	-261	-7.6	3179	2957	-222	-7.0
.35	3258	2980	-278	-8.5	3080	2833	-247	-8.0
.4	3197	2902	-295	-9.2	3035	2776	-259	-8.5
.5	3048	2761	-287	-9.4	2923	2670	-253	-8.7
.6	2914	2637	-277	-9.5	2859	2574	-285	-10.0
.7	2801	2526	-275	-9.8	2770	2486	-284	-10.3
.8	2657	2427	-230	-8.7	2699	2406	-293	-10.9
.9	2570	2337	-233	-9.1	2601	2332	-268	-10.3
1.0	2462	2255	-207	-8.4	2503	2264	-239	-9.5
1.1	2377	2181	-196	-8.3	2438	2201	-237	-9.7
1.2	2301	2112	-189	-8.2	2347	2142	-205	-8.7
1.3	2222	2049	-173	-8.0	2272	2088	-186	-8.1
1.4	2159	1991	-168	-7.8	2201	2036	-165	-7.5
1.5	2109	1937	-172	-8.2	2157	1988	-169	-7.8
1.6	2091	1886	-205	-9.8	2118	1943	-175	-8.3
1.7	2038	1839	-199	-9.8	2074	1900	-174	-8.4

TABLE 12

A comparison of predicted and measured temperatures (K) for the electrodes of lamps No. 1 and 2 operating at 2.5kW on A.C.

X	1kW CSI				1kW CID			
	T Meas	T.Calc	ΔT	%	T.Meas.	T.Calc	ΔT	%
0	2929	2929	0	0	3034	3034	0	0
.05	2833	2868	35	1.2	2921	2967	46	1.6
.15	2747	2755	8	0.3	2787	2844	57	2.0
.25	2643	2653	10	0.4	2715	2734	19	0.7
.3	2542	2593	51	2.0	2584	2669	85	3.3
.4	2437	2482	45	1.8	2472	2551	79	3.2
.5	2305	2383	78	3.4	2374	2466	72	3.0
.6	2211	2294	83	3.7	2267	2352	85	3.7
.7	2139	2213	74	3.4	2155	2266	111	5.1
.8	2073	2139	66	3.2	2064	2188	124	6.0
.9	2033	2071	38	1.9	2054	2117	63	3.1

TABLE 13

A comparison of measured and predicted temperature profiles (K) for the electrodes of 1kW CSI/CID lamps operated on A.C. at rated wattage.

LAMP No.339

X	@ 2.4kW				@ 1.95kW				@ 1.4kW			
	T Meas.	T Calc.	ΔT	%	T Meas.	T Calc.	ΔT	%	T.Meas.	T.Calc.	ΔT	%
0	3550	3550	0	0	3529	3529	0	0	3273	3273	0	0
.05	3544	3461	-83	-2.3	3429	3441	12	0.4	3178	3201	23	0.7
.15	3475	3299	-176	-5.1	3395	3281	-114	-3.4	3165	3068	-97	-3.1
.25	3549	3155	-394	-11.1	3332	3140	-192	-5.8	3086	2948	137	-4.5
.35	3352	3027	-325	-9.7	3142	3013	-129	-4.1	2909	2840	-69	-2.4
.4	3199	2948	-251	-7.8	2940	2935	-5	-0.2	2739	2773	34	1.2
.5	3055	2805	-250	-8.2	2828	2793	-34	-1.2	2593	2651	58	2.2
.6	2892	2679	-213	-7.4	2698	2669	-29	-1.1	2526	2541	15	0.6
.7	2767	2566	-200	-7.2	2558	2557	-1	0	2439	2443	4	0.2
.8	2635	2466	-169	-6.4	2452	2457	6	0.2	2342	2354	12	0.5
.9	2534	2375	-160	-6.3	2360	2367	7	0.3	2253	2273	20	0.9
1.0	2435	2292	-143	-5.9	2269	2285	16	0.7	2165	2199	34	1.6
1.1	2354	2216	-138	-5.9	2226	2210	-16	-0.7	2090	2131	41	2.0
1.2	2257	2147	-110	-4.9	2128	2141	13	0.6	1994	2068	74	3.7
1.3	2207	2083	-124	-5.6	2058	2077	20	0.9	1934	2010	76	3.9
1.4	2139	2023	-115	-5.4	2020	2018	-2	-0.1	1894	1956	62	3.3
1.5	2080	1968	-112	-5.4	1968	1964	-4	-0.2	1903	1905	2	0.1
1.6	2005	1917	-88	-4.4	1891	1913	21	1.1	1875	1858	-17	-0.9

TABLE 14

A comparison of measured and predicted temperature profiles (K) of the anode of 2.5kW CID lamp 339 run at various wattages on D.C.

LAMP No. 339

X	@ 2.4kW				@ 1.95kW				@ 1.4kW			
	T Meas.	T Calc.	ΔT	%	T Meas.	T Calc.	ΔT	%	T.Meas.	T.Calc.	ΔT	%
0	2709	2709		0	2662	2662	0	0	2525	2525	0	0
.05	2665	2664	-1	0	2550	2619	69	2.7	2407	2487	80	3.3
.15	2606	2581	-26	-1.0	2531	2539	9	.3	2393	2417	24	1.0
.25	2583	2504	-80	-3.1	2458	2465	8	.3	2372	2352	-20	-0.8
.35	2516	2432	-84	-3.3	2432	2397	-36	-1.5	2342	2291	-51	-2.2
.4	2461	2385	-76	-3.1	2369	2351	-18	-0.8	2263	2251	-12	-0.5
.5	2399	2297	-102	-4.2	2317	2266	-51	-2.2	2234	2175	-59	-2.6
.6	2368	2218	-151	-6.4	2271	2189	-81	-3.6	2182	2106	-77	-3.5
.7	2319	2144	-175	-7.5	2209	2119	-91	-4.1	2123	2042	-82	-3.9
.8	2283	2077	-205	-9.0	2171	2054	-117	-5.4	2072	1982	-89	-4.3
.9	2211	2016	-195	-8.8	2122	1994	-129	-6.1	2027	1928	-100	-4.9
1.0	2168	1959	-210	-9.7	2087	1938	-149	-7.1	1981	1877	-104	-5.3
1.1	2123	1905	-218	-10.3	2044	1886	-157	-7.7	1926	1829	-97	-5.0
1.2	2108	1856	-252	-12.0	2026	1838	-188	-9.3	1914	1784	-130	-6.8
1.3	2087	1809	-278	-13.3	2024	1793	-231	-11.4	1900	1742	-158	-8.3
1.4	2068	1766	-302	-14.6	2005	1750	-255	-12.7	1884	1703	-181	-9.6
1.5	2027	1725	-302	-14.9	1990	1711	-280	-14.0	1878	1666	-213	-11.3
1.6	2066	1687	379	-18.4	1990	1673	-317	-15.9	1839	1631	[illegible]	-11.[illegible]

TABLE 15

A comparison of measured and predicted temperature profiles (K) for the cathode of 2.5kW CID Lamp 339 run at various wattages on D C

X	LAMP No.2				LAMP No.6			
	T Meas.	T Calc.	ΔT	%	T.Meas.	T Calc.	ΔT	%
0	3657	3657	0	0	3709	3709	0	0
.05	3589	3547	-42	-1.2	3707	3595	-112	-3.0
.15	3521	3352	-169	-4.8	3578	3393	-185	-5.2
.25	3433	3182	-251	-7.3	3456	3218	-238	-6.9
.35	3273	3033	-240	-7.3	3313	3065	-248	-7.5
.4	3256	2965	-291	-8.9	3225	2995	-230	-7.1
.5	3124	2841	-283	-9.1	3081	2867	-213	-6.9
.6	3034	2729	-305	-10.1	2942	2753	-189	-6.4
.7	2937	2628	-309	-10.5	2805	2649	-155	-5.5
.8	2809	2536	-273	-9.7	2698	2556	-142	-5.3
.9	2680	2452	-228	-8.5	2589	2470	-119	-4.6
1.0	2550	2375	-175	-6.8	2499	2392	-107	-4.3
1.1	2448	2304	-144	-5.9	2424	2320	-104	-4.3
1.2	2373	2239	-134	-5.7	2320	2253	-67	-2.9
1.3	2310	2178	-132	-5.7	2272	2191	-81	-3.6
1.4	2241	2121	-121	-5.4	2213	2133	-80	-3.6
1.5	2172	2068	-104	-4.8	2154	2079	-75	-3.5
1.6	2112	2018	-94	-4.5	2074	2029	-45	-2.2
1.7	2083	1971	-112	-5.4	2049	1981	-68	-3.3

TABLE 16

A comparison of measured and predicted temperature profiles (K) for the anodes of lamps No. 2 and 6 operated at 2.5kW on D.C.

X	LAMP No. 2				LAMP No. 6			
	T Meas.	T Calc.	ΔT	%	T.Meas.	T.Calc.	ΔT	%
0	3067	3067	0	0	3182	3182	0	0
.05	2990	2997	7	0.2	3160	3088	-72	-2.3
.15	2901	2867	-34	-1.1	3103	2919	-184	-5.9
.25	2823	2752	-71	-2.5	3013	2773	-240	-8.0
.35	2745	2648	-97	-3.6	2909	2645	-264	-9.1
.4	2696	2599	-97	-3.6	2867	2586	-281	-9.8
.5	2662	2509	-153	-5.7	2792	2478	-314	-11.3
.6	2604	2427	-177	-6.8	2712	2382	-330	-12.2
.7	2553	2351	-202	-7.9	2636	2294	-342	-13.0
.8	2497	2281	-216	-8.7	2557	2215	-342	-13.4
.9	2448	2216	-232	-9.5	2483	2142	-341	-13.7
1.0	2381	2156	-225	-9.4	2441	2075	-366	-15.0
1.1	2333	2100	-233	-10.0	2387	2013	-374	-15.7
1.2	2266	2048	-218	-9.6	2321	1956	-364	-15.7
1.3	2180	1999	-181	-8.3	2280	1903	-377	-16.5
1.4	2108	1953	-155	-7.4	2214	1854	-360	-16.3
1.5	2081	1909	-172	-8.3	2154	1808	-346	-16.1
1.6	2057	1868	-188	-9.2	2109	1764	-345	-16.4
1.7	1990	1830	-160	-8.1	2058	1724	-334	-16.2

TABLE 17

A comparison of measured and predicted temperature profiles (K) for the cathodes of lamps No. 2 and 6 operated at 2.5kW on D.C.

APPENDIX 4

TEST SET CALIBRATION CERTIFICATE

THORN LIGHTING

Calibration Certificate

Standards Laboratory
Gt Cambridge Road
Enfield Middlesex

S.E.D. 490/2
Sheet 1 of 1

Instrument A C TEST SET **Serial No** 731785

Manufacturer Sullivan Instruments **Reference** INB/9

This is to certify that the above instrument has been fully tested and calibrated to manufacturer's specifications and that the accuracies of the standards used are traceable to NPL or have been derived by the ratio of self calibration techniques.

Voltage Range

500V		250V		125V		50V		25V		10V	
INST	STD	INST.	STD	INST	STD	INST	STD	INST.	STD	INST	STD.
500.0	500.0	250.0	250.3	125.0	125.1	50.0	50.06	25.0	25.03	10.0	10.04
400.0		200.0		100.0		40.0		20.0		8.0	8.04
300.0		150.0		75.0		30.0		15.0		6.0	6.02
200.0		100.0		50.0		20.0		10.0		4.0	4.00
100.0		50.0		25.0		10.0		5.0		2.0	1.97

Current Range

25A		10A		5A		2·5A		1A		0·5	
INST	STD.	INST.	STD.	INST.	STD	INST	STD	INST	STD	INST.	STD.
25.0	25.03	10.0	10.01	5.0	4.99	2.5	2.501	1.0	.999	.5	.500
20.0		8.0		4.0		2.0		.8	.799	.4	
15.0		6.0		3.0		1.5		.6	.599	.3	
10.0		4.0		2.0		1.0		.4	.399	.2	
5.0		2.0		1.0		.5		.2	.199	.1	

Watts

INSTRUMENT	250.0	200.0	150.0	100.0	50.0	125.0	100.0	75.0	50.0	25.0
TRUE	249.7	200.0	149.2	99.5	49.3	124.4	99.6	74.3	49.6	24.6

This instrument DOES/~~DOES NOT~~ conform to appropriate sections of B.S.89(1970)

Signed K [signature]

Date 12 August 1981