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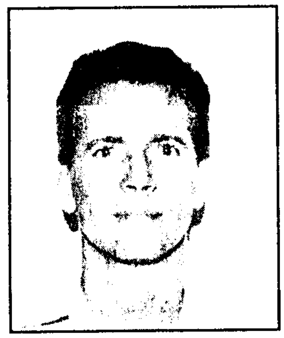
SUMMARY

Battery operated fluorescent lamp ballasts are used in both portable and emergency lighting applications. However, a lack of relevant published data on fluorescent lamps often results in the development of sub optimum circuitry. This paper describes the load presented by a 9 W compact fluorescent lamp with a built in starter (PL-S9W[PhilipsTM]). The lamp ignition and arc discharge characteristics are established. The electrode thermal delay, onset of transverse discharge and temperature characteristics are also presented. The glow starters are characterised in terms of minimum power requirement and dynamic resistance. Six lamps from three different manufacturers were used in the tests in order to illustrate performance variations.



S V Marais

Compact fluorescent lamps - an electronic ballast's perspective

by S V Marais, University of Natal, Durban (Electronic Engineering Department)

Fluorescent lamp performance specifications relevant to high frequency or dc operation are usually scarce or non-existent. This hampers the ballast designer and is the primary reason for the large performance variations in both commercial and industrial battery powered ballasts. It is preferable to use compact fluorescent lamps with built in starters (Philips[TM] PL-S prefix) for emergency lighting applications, to simplify the changeover wiring and because they are generally cheaper than the electronic versions (PL-E prefix). The use of PL-S type lamps, however, complicates ignition due to the load presented by the starter components. This paper provides performance characteristics of PL-S 9 W lamps and their starter components.

A total of six 9 W compact fluorescent lamps from three different manufacturers were tested. The manufacturers were Philips, Osram and "No Name Brand". The latter were chosen in order to investigate whether any other characteristics would be distinguishable from reputable products besides lumen maintenance and/or colour rendering. The lamps were first aged for 100 hours to obtain more representative results[1]. All tests were conducted with the lamps in a horizontal position. The total light output was measured by situating the lamp in an integrating sphere with an aperture to accommodate a cosine corrected illuminance meter. The absolute measurements of illuminance given here are thus of little value, but the relative results are of interest. Lamp tests were conducted without the starter components connected.

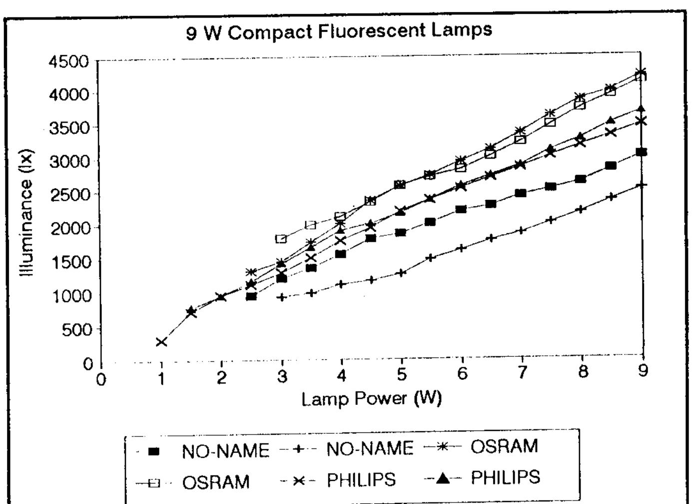


Fig 1: Comparison of luminous efficacy using dc lamp current.

DC Arc Discharge Performance

The dc performance of the lamp is similar to the performance at high frequency as there is no periodic arc extinction[2,3,4]. The aim was to determine the lamp negative resistance and to reveal performance variations between lamps. The output from a variable mains supply was full wave rectified and smoothed. The dc supply was then connected to the lamp via a ballast resistor.

✦*Test Results*

Fig 1 shows a large variation in light output between the lamps at rated power. The 'No Name Brand' lamps provided the lowest luminous efficacy. The point at which the lamps extinguished is indicated by the lowest registered power. Although operation at low powers was possible (one of the Philips lamps operated down to 14% of rated light output), reliable operation with all lamps was only possible above 3 W. The elongation of the cathode fall at low powers was clearly visible, it being necessary to maintain electron emission from the electrodes.

For this reason operation at reduced powers must be accompanied by increased heater current, otherwise excessive ion bombardment will occur resulting in reduced lamp life. This could be significantly improved by providing additional electrode heating.

Fig 2 shows the plasma resistance variation with discharge power. These values of plasma resistance are also valid for high frequency operation[4]. This graph is useful for circuit synthesis as the intended lamp power is usually an initial consideration during circuit design. Note the close correlation between the lamps, especially at high powers. This indicates that the prime concern of lamp manufacturers is electrical rather than luminous compatibility.

Electrodes

The thermal properties of the electrodes were investigated in order to optimise starting conditions. During the heating phase (starter switch closed) it is reasonable to assume that the output of the electronic ballast will be current limited regardless of the topology chosen. For this

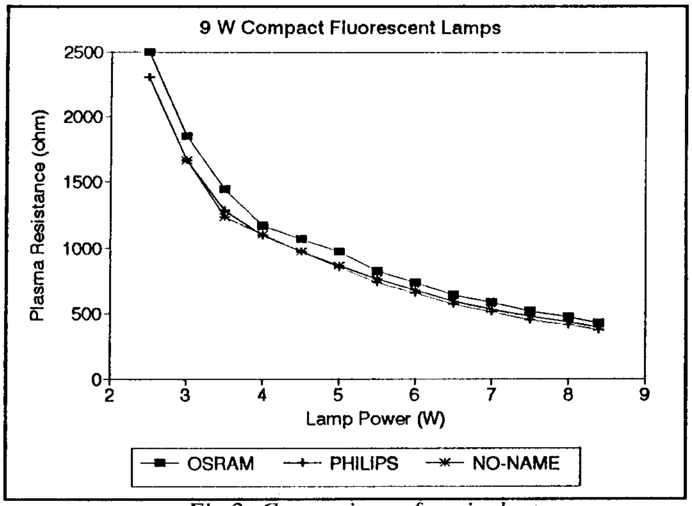


Fig 2: Comparison of equivalent plasma resistance

reason the test was conducted by driving the electrodes via a constant current source. The compliance of the current source was high in order to prevent the current varying during electrode resistance changes.

Test Results

The electrode temperatures shown in Fig 3 assume uniform heating[5]. The filament temperature was calculated by measuring the resistance of the filament at room temperature and taking the temperature co-efficient for tungsten as 0.0058 K^{-1}[6]. The threshold for the formation of a transverse discharge never occurred on any electrode below 170 mA. This discharge is clearly visible as a bright glow surrounding the electrode. The electrode temperature began to flatten above 200 mA, indicating decreasing gains in electrode temperature above this point. Note that as the heater current

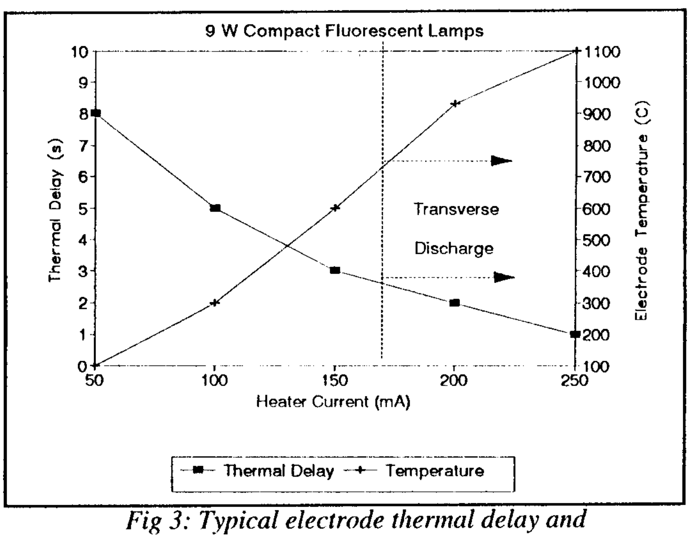


Fig 3: Typical electrode thermal delay and temperture versus various heater current.

decreased, so the time to reach the corresponding temperature increased.

Lamp Starting

Lamp ignition is dependant upon many factors besides starting voltage amplitude.

These include[2,3,4]

- Lamp temperature
- Humidity (lamp resistance)
- Electrode temperature
- Presence of a transverse discharge (supply of charge carriers)
- Starting voltage dv/dt.

Due to all of the above factors, it is not possible to define a minimum starting scenario for all ballast designs. Rather, this investigation attempts to describe basic phenomena and trends.

Various dc voltages were applied across the lamps. The heater current was then initiated and the ignition voltage noted. It was important to consider that heater current raised the temperature of the lamp and hence the gas pressure. This meant that the ignition voltage had to be applied before initiating heater current, and that after every test the lamp had to be allowed to cool for approximately 5 minutes. A constant current source supplied current to the cathode.

✦*Test Results*

Fig 4 plots the extremes of required lamp ignition voltage against increasing heater current. Due to the many parameters affecting ignition, the results were not always repeatable and hence there was little value in plotting individual lamp data. However, as the heater current increased, so the lamp ignition voltage became more predictable. The formation of a transverse discharge reduced the starting voltage requirement for individual lamps by more than 200 V. The ignition voltage requirement for any lamp rarely decreased below 250 V for any value of heater current.

The results indicate that it is desirable to provide rated heater current in order to both reduce the starting voltage requirement and provide reliable starting. The results also indicate that a transverse discharge assists starting.

The Glow Starters

All glow starters tested were of similar internal construction in that the contacts consisted of a metal pin and a single bimetal element. A variable dc voltage was applied across each starter. Current and visual effects were noted. The polarity of the applied voltage was reversed and the tests were repeated. The tests were conducted without the suppression capacitor connected.

✦ *Glow Discharge Threshold*

At a certain voltage, a glow discharge formed around the cathode. This glow discharge threshold varied between starters from 100 V to 120 V when the metal pin was cathode. The threshold voltage when the bimetal element was cathode was on average 6 V higher. This voltage difference was due to the dissimilar work functions of the two electrodes.

✦ *Minimum Power*

The power required to close the switch varied considerably depending on whether the metal pin was the cathode or whether the bimetal element was the cathode. When the bimetal element was the cathode, the starters required 300 to 400 mW to close within five seconds. When the metal pin was the cathode, the starters required 1400 mW to 2200 mW to close within the same period.

Heat is generated in the cathode fall of the glow discharge, and hence using the bimetal element as the cathode results in rapid heat transfer and prompt switch closure. Using the bimetal element as the anode results in inefficient heat transfer and hence delayed switch closure. Thus the glow starter requires more energy to close if the metal pin is the cathode.

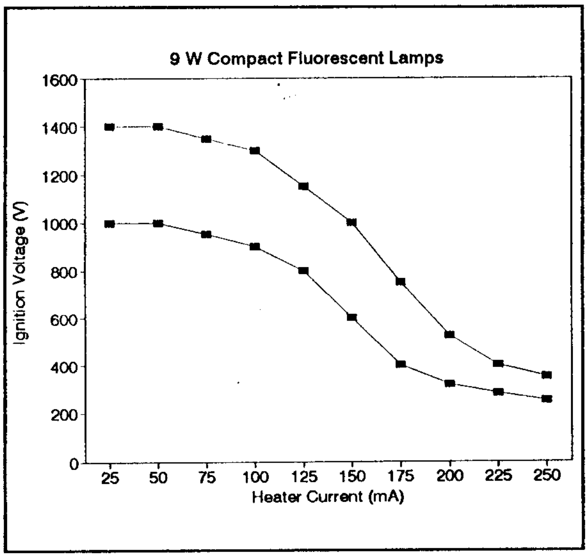


Fig 4: Extremes of required dc ignition voltage versus heater current

At a discharge power of 1 W the starters required from 1 s to 2 s to close when the bimetal element was the cathode. However, the starters required from 12 s to 15 s to close when dissipating the same power but with the metal pin as the cathode.

This phenomenon is responsible for polarity sensitive ignition performance of converter (dc) type ballasts.

✦ *Dynamic Resistance*

Once a glow discharge has been established, further increases in supply voltage result in an increase in current and luminous intensity of the glow. Hence the V/I characteristic is positive and exhibits a certain dynamic resistance.

As glow starters operate in the positive region of the discharge V/I characteristic curve, a model comprising two back to back zener diodes in series with a resistor adequately simulates the load presented at dc and low frequencies. The zener voltages equate to the glow threshold voltage and the series resistance equates to the dynamic resistance of the starter (in this case approximately 1000 µ).

Although there was some decrease in dynamic resistance with increasing current, this variation was swamped by sample spread. Further, while the dynamic resistance was asymmetrical due to dissimilar work functions of the electrodes, this variation was also exceeded by sample spread. The dynamic resistance of the four starters varied from 800 µ to 2000 µ. There was correlation between manufacturer and dynamic resistance. The Osram starters were 800 µ and 1000 µ whilst those from Philips and "No Name Brand" lamps were all approximately 2000 µ.

✦ *Switch Closure Tmes*

The period that the glow starter contacts remain closed is also dependant upon polarity. The glow discharge heat is generated in the cathode fall, so if the bimetal element is the cathode then heat is readily transferred and switch closure is affected before the temperature of the gas in the starter increases significantly. The period that the switch remains closed is therefore only dependant upon the thermal inertia of the bimetal element. If the metal pin is the cathode, then heat transfer to the bimetal element occurs via the gas. The glass envelope temperature also increases appreciably. The period that the switch remains closed is now roughly dependant upon the energy dissipated prior to switch closure. Tests revealed that the switch contacts remained closed roughly twice as long when the metal pin was cathode.

The Suppression Capacitor

The purpose of the suppression capacitor is to limit the bandwidth of voltage transients and to increase the time that the switch contacts remain closed[1]. The measured values of the suppression capacitors varied from 2,8 nF to 3,4 nF.

As the bimetal element touches the metal pin, the glow discharge extinguishes and bimetal heating ceases. The energy stored in the suppression capacitor is dissipated at the point of contact. The period the switch remains closed is now determined by the thermal time constant of the bimetal element and by the strength of the weld formed between the contacts[4]. The suppression capacitor value has therefore been chosen to both limit the voltage transients and to store energy to form the weld.

Conclusions

The operating lamp power of PL-S type lamps must be controlled between tight limits. Any increase above the rated lamp power will result in reduced lamp life and luminous efficiency[2]. The lower lamp power is limited by the glow threshold of the glow starter (100 V), disregarding lamp life considerations. Assuming that the lamp current is a pure sinusoid, the maximum lamp rms voltage would be limited to 70 V, which corresponds to a lamp power of 4,2 W, based on a sample of only six lamps. It is therefore not feasible to dim PL-S type lamps using a high frequency supply. Designers of battery powered inverters must also ensure that this minimum power is provided at low supply voltages otherwise intermittent starter operation may occur.

The use of dc permits reduced lamp operating powers, but the design must include resistance between the dc smoothing capacitor and the lamp, otherwise glow starter failure due to high inrush currents could result. The designers of dc type ballasts should also ensure that starting is reliable for both lamp polarities.

About the Author

Stirling Marais has been involved in the development of emergency lighting systems and was intrigued by the complex dynamics of fluorescent lamps. He is presently studying for an MSc Eng. degree through the University of Natal, Durban. The title of his thesis is: Fluorescent Lamp Characterisation and the Design of an Optimal Battery Powered Ballast. The thesis is almost complete and will be submitted during this academic year.

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