

HIGH EFFICIENCY LIGHTING

By: S. Marais, Cosine Developments

Due to the complex dynamics of electrode thermal delay and relaxation times of the plasma and electron gas, the lamp performance varies considerably with supply frequency. At low frequencies, as in mains operation, the lamp periodically extinguishes and then re-ignites at every current zero. This re-ignition voltage requirement is far lower than that of a cold lamp, because the plasma remains for up to 10 ms^[6] after the lamp has extinguished and the electrodes are already at operating temperature. As the lamp re-ignites the process of cumulative ionisation follows the lamp current fluctuations resulting in a non-linear voltage-current characteristic. The periodic re-ignition reduces efficiency and the waveform consequent distortion is a source of electromagnetic interference. As the supply frequency increases the ionisation state can no longer follow the rapid changes in lamp current and the plasma density becomes constant, resulting in a constant effective resistance throughout the cycle^[1]. A further advantage is that no periodic re-ignition is required. As the frequency increases the electrode falls also decrease resulting in increases in efficiency^[1,7,8]. The use of direct current has a similar effect on efficiency as high supply frequency because the plasma density remains constant.

The mechanism responsible for plasma relaxation is ambipolar diffusion. This is the process whereby electrons and ions travel to the wall of the tube, where they recombine. Polman *et al*^[7] cites representative values for ambipolar diffusion (T_a) of 1 ms and electron temperature relaxation time (T_e) of 5 μ s. As the plasma relaxation time is less than 10 ms, at mains frequencies both the plasma density and the electron temperature are modulated by the instantaneous current variations^[6]. There are, however, frequencies where the current variations are followed by the electron temperature (T_e) but not by the whole plasma^[6,7].

Polman *et al*^[7] conducted an experiment by modulating a dc discharge. When the modulation period was greater than both plasma and electron temperature relaxation times, the result was a slowly varying dc discharge with hardly any variation in electron temperature. This is because only slight changes in electron temperature cause current variations due to the exponential relationship between electron temperature and the ionisation rate. When the modulation period ($2\pi/\omega$) was much less than both periods then the discharge was too slow to follow the variation, and the electron temperature adjusted to a level corresponding to the average current. When the modulation period was in the region $T_a \leq 2\pi/\omega \leq T_e$ the modulated discharge current caused a modulation in electron temperature with no modulation in plasma concentration, as expected. However, as the modulation coefficient was increased above 0.5 the concentration of excited atoms increased, contrary to expectations. The result was that there were relatively more electrons of high energy than there would be in a dc discharge with the same average electron energy. This clearly caused an increase in populations of electrons at high energy levels, resulting in an increase in 436 nm emission. As this emission is visible, blueish light, no phosphor conversion is necessary and so efficiency is improved. These effects occur when a rapid increase in field strength caused a rapid rise in electron temperature, as in pulsed discharges.

The highest efficiencies are achieved at frequencies of 100 kHz^[7,17], although an upper

frequency limit of 50 kHz is recommended due to increasing electromagnetic interference generated by the lamp^[2]. Capacitive coupling between the lamp and luminaire requires consideration at high frequencies. Although capacitive coupling assists lamp ignition, efficiency is adversely affected during an arc discharge. Hammer^[21] cautions that the capacitive coupling could result in substantial current flowing if the separation distance is less than 3 mm. His data, using 2.5 m long T12 lamps, revealed that 12 mm was adequate for reliable starting at 25 kHz. His measurements also revealed that a 30% increase in lumen efficiency over mains operation is achievable at 25 kHz. Hammer also observed that there were no significant shift in chromacity co-ordinates when the lamps were dimmed with high frequency operation.

Elenbaas^[1] captured oscillograms of lamp voltage at various frequencies. The waveforms are nearly sinusoidal at 8 kHz. He states that "... for lamps of 1 or 1.5 inch diameter, the form of both current and voltage is nearly sinusoidal at 400 Hz and higher". This observation will impact on the model selected for the 9 W compact fluorescent lamp.

