UNDERSTANDING COLD CATHODE FLUORESCENT LAMPS (CCFL'S)

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ABSTRACT

An examination of the Cold Cathode Fluorescent Lamp (CCFL) utilized extensively as the light source for LCD displays such as used in laptop computers and other portable devices is reviewed. Discussion includes electrical dynamics in relation to physical dimensions and temperature of the lamps. A general overview of the efficiency of the lamp and inverter system is given. Depletion of mercury from the discharge column influencing light output is attributed to DC operation and temperature. Included is an overview of low-pressure CCFL mercury lamp construction and physics. Normal failure mode is attributed to phosphor degradation.

Introduction

Portable devices predominately use a liquid crystal display (LCD) to convey information to the user. It is important to efficiently backlight the LCD, for which cold cathode fluorescent lamps (CCFLs) have come to be used very extensively. CCFL's efficiently convert electrical energy into visible white light providing a backlight, with the capability of a full spectrum of color filtered out and displayed. In addition to back lighting, CCFL's provide visible and ultraviolet energy for scanning and detection applications in portable devices.

Lamp size (diameter and length) substantially influences electrical dynamics. An overview of the lamp's physics and construction in relation to gas discharge and phosphor stimulation helps in an understanding of the lamp's ignition and the ionized gas arc.

A royer oscillator typically drives CCFL's with a sinusoidal waveform with a nominal frequency of 20-100 kHz.Direct current (D.C.) operation of the lamp improves efficiency and reduces RFI causing harmonics but induces a rapid deterioration of the lamp's performance.

Operating a CCFL over time results in degradation of light output. Lamp phosphor degradation produces the corresponding reduction in output. Typical CCFL life ratings in lamp manufactures catalogs are stated as 20,000 hours to 50% of the lamps initial output at a drive current of 5mArms. Various lamp sizes are often capable of performance well beyond this generalized specification. A matched inverter to the lamp provides a low crest factor sinusoidal waveform with minimal D.C. content preventing mercury vapor migration provides best lamp life.

Electrical dynamics

Cold cathode Fluorescent lamps are relatively efficient in comparison to other light sources such as incandescent lamps. The CCFL converts about 20% of the applied electrical energy into usable photopic light in the 380-780nm range. The factors, which influence efficiency, include the lamp's physical size, driving wave shape, temperature, and the definition of the "desired" usable light or energy for a particular application. In the next paragraph an examination of the lamps conversion of electrical input to light output is given.

Comparisons made for three lamps of varied diameters all 100mm in length indicate differences in the electrical characteristics and light output. As the lamp diameter is decreased the cross section of the conductive path of ionized gasses is also decreased hence an increase in the lamps impedance and operating voltage. The lamps evaluated in Table #1 below are operate at 5mArms with minimal aging, <10 hours at a nominal ambient temperature of 25° C. The smallest diameter lamp has the highest wattage with the highest surface intensities arise from greater energy loading on the phosphor from the mercury vapor arc. Table #2 includes data for output flux percentages in relation to surface intensity and wattage. As the diameter of the test CCFL's are increased the efficiency of the electrical energy to light conversion decreases.

Table #1

DIA.	Vrms	WATTS	Cd/m2 %
3.0	263	100	100
4.1	230	87	50
6.5	214	81	25

Table #2

DIA.	WATTS. %	Cd/m2. %	FLUX. %
3.0	100	100	100
4.1	87	50	84
6.5	81	25	59

The smallest diameter lamp having the highest wattage is also the lamp with the smallest mass. The optimal
mercury vapor pressure for the typical CCFL occurs in the typical CCFL occurs in the 45-65° C range producing the best efficiency for the lamps. With the lamps operated at 25° C the small mass of the 3.0mm CCFL is closer to the optimal operating temperature by its inherent higher wattage as can be seen in Table #3. As the ambient temperature in which the lamp operates increases, the lamps may pass through the optimal operating temperature zone producing a less efficient electical-to-light conversion. Driving the lamp at a higher current level also may raise the lamp temperature. After the lamps have stabilized in a 25° C ambient environment, the temperature is measured at the center of the lamp length.

Table #3

DIA.	WATTS	MASS G	TEMP °C
3.0	1.32	1.40	46.3
4.1	1.15	1.70	40.7
6.5	1.07	4.30	36.9

Temperature has an extreme effect upon the mercury vapor pressure of the lamp. The optimal operating temperature is the point at which the ionized mercury vapor is most efficient at producing ultraviolet energy to stimulate the lamp's phosphor.

The mercury arc of the lamp at optimal vapor pressure has about 60% efficiency in converting the 20-100 kHz-input energy into 253.7nm ultraviolet energy.

Operating the lamp on direct current can enhance the efficiency of the mercury discharge but a rapid decrease in the lamp output will result. Direct current operation of a mercury discharge lamp causes a migration of the mercury vapor toward the cathode end of the lamp. Mercury is migrated via cataphoretic pumping effect in the discharge column. A CCFL operated on direct current will exhibit a pink emission from the lamps penning gases toward the anode end with the mercury in the discharge column depleted.

Table #4 indicates the percent of light output in relation to lamp temperature for a typical CCFL. The 3.0mm lamp is in the range of optimal temperature for the highest light output. Increased lamp drive current will achieve more light output, and a greater heating of the lamp will occur. Increasing the lamp's temperature beyond 65°C will decrease the efficiency of the lamp. With operation of a CCFL at temperatures approaching zero centigrade the mercury discharge will be very weak. With weak phosphor stimulation, the lamp will have a pink color emission from the ionized penning gases. With a weak stimulation of the lamp's phosphor at low temperature, the discharge of the penning gases becomes visible through the lamp's phosphor.

Table #4

°C	25	35	45	55	65	75
%	50	73	92	100	98	87

A CCFL and inverter system is a cascaded transducer converting electrical energy into light energy. A series of frequency conversions accomplishes the transformation of electrical energy into light energy. In reference to Table #5 and #6 below, the basic steps in the frequency conversion process are given with the typical efficiency percents for the stages of conversion. In the development of portable devices, it is often desired to design the inverter as efficient as possible for conversion of battery life, Inverter designs with efficiency as high as 92% are claimed for Royer oscillator based systems.

Table #5

INVERTER	
DC	INPUT
20-100kHz	85%
HEAT	15%

Table #6

CCFL	
20-100kHz	INPUT
253.7nm	60%
380-780nm	20%
HEAT	80%

Lamp construction and physics

The CCFL is a low-pressure discharge lamp. Construction of the lamp uses a glass tube coated on the inside with an inorganic phosphor. The sealed lamp's envelope contains a mixture of mercury and a fill or "penning" gas at a typical pressure of 2-6 torr. Introduces electrical energy into the lamp is via the "cold cathodes" or electrodes. The ultraviolet discharge produced by the electrical energy ionization of the mercury vapor stimulates the phosphor, which increases the 253.7nm wavelength of the ultraviolet energy into the visible spectrum.

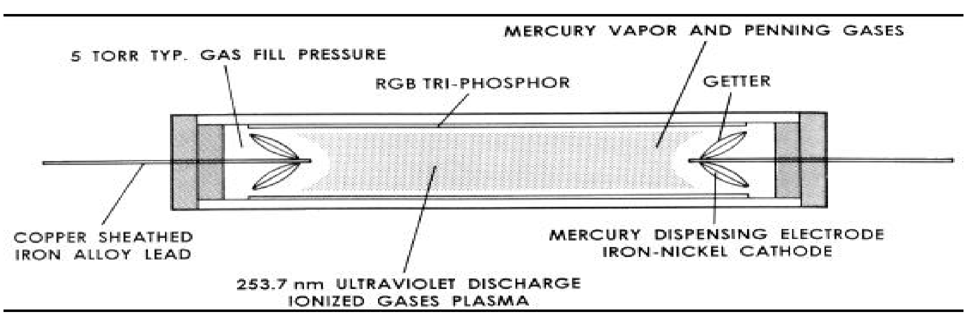
The low-pressure type of discharge lamp functions by the applications of an electrical field, which accelerates electrons between the two electrodes. The collision of electrons with the mercury atoms excites the atoms above the stable ground state. Ultraviolet energy release occurs as excited mercury atoms return to the stable ground state. Adding a fill gas enhances ionization of the mercury vapor at a lower voltage potential. Before ionization, the mercury vapor pressure is very low with few atoms available for collision. With a fill gas such as argon, electrons collide with the large number of argon atoms, the excited argon atoms and electrons then collide with the available mercury atoms, enhancing ionization.

The cold cathode electrodes of the lamp are comprised of a nickel-plated iron structure, which contains pockets retaining the mercury during lamp manufacturing. The cathode structure retains the mercury until releasing by heating the structures using RF energy after the lamp envelope is sealed. Depending on the size and type of cathodes, the typical CCFL will contain from 2-10mg of mercury.

The cathode structure also contains a gettering material on its surface to remove damaging residual gases. The getter material used is comprised of an alloy of 84% Zr and 16% Al. With a lamp operated from alternating current, the cathodes actually alternate their function as anode and cathode.

The phosphor coating on the inside of the glass envelope is a tri-phosphor RGB (Red-Green-Blue) type. It is composed of individual red, green, and blue emitting phosphors. Varying the phosphor ratios will change the characteristics of the white light emitted. Operating a CCFL over an extended period will decrease the light output. Ion bombardment from the discharge column may be the attributing factor in depreciation of the phosphor. Ion bombardment of the phosphor over a period of time can cause the inner surface of a phosphor coating to become non-luminescent. Ion bombardment over time can cause some phosphors to have a greater tendency to absorb mercury.

The largest diameter lamps operated at the same drive levels, as small diameter lamps tend to have less output degradation over time. The energy loading of the phosphor is less for lamps with a larger phosphor area. Operating a CCFL within the design drive levels will have a normal slow degradation in output. The normal failure mode of the lamp will be that of reduced output from phosphor degradation.



Conclusion

The designers of portable devices will want to examine the difference that lamp size induces on electrical characteristics. Functional temperature range in relation to lamp operation needs consideration in the design stage. An understanding of an inverter/lamp system as a cascaded frequency converter aids in the understanding of its function. Familiarity with the construction and basic physics of a CCFL can help in the determining suitable applications and design limitations.

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