# The Measuring Technique of Compact Fluorescent Lamps

YE GUANRONG, HOU MINXIAN, ZHAO TIANDONG
Institute of optical radiation technique
Zhejiang University, P.R.China

**ABSTRACT**

Recently, many countries in the world have paid attention to the "Green Light". As an energy-saving light source, the compact fluorescent lamps are applied more and more widely. The research organizations and factories want to know the properties of the developed lamps, therefore, they need spectrophotometer (spectral colorimeter) to measure the compact fluorescent lamps (CFLs). According the international standard, the instruments should be strictly administered by the state metrological department to get the right test results. The measuring technique of compact fluorescent lamps is described in this article.

**THE OPTICAL STRUCTURE OF THE DESIGNED INSTRUMENT**

The photometric and colorimetric testing results for the CFLs include following parameters: Color coordinate x,y, color temperature Tc, luminous flux and efficiency etc. In order to obtain this technical data it is necessary to use spectral photometric testing method. The instruments employ a dispersion device, such as grating, prism. Double monochromator are used in high quality spectrophotometer to reduce its stray light and to enhance the measuring accuracy as showing in Fig.1.

The light from light source through the slit 1 of the first monochromator incidences into monochromator and dispersed by the grating G1, then through second slit 2 dispersed by the grating G2. Monochromatic light with very low stray light can be obtained from slit 3. The second monochromator is used as a filter to filter the stray light outside the setting spectrum. Therefore the stray light is very low about 10-8. Such instruments can be applied as standard testing equipment.

Generally, in order to reduce the cost of the manufacture, a single monochromator can be used for routine measurement of the electric light source as showing in Fig.2. Because of only using one single monochromator, the additive stray light on the spectrum from slit 2 is much more than that by using double monochromators. The stray light is about $10^{-4}$.

The stray light has the critical influence for the spectral measurement of the electric light source in short spectral region. This is due to use a standard illuminate A to calibrate the spectrophotometer (spectral colorimeter), its spectral power distribution is showing in Fig.3.

The relative spectral power distribution of the standard illuminate A in 380-450nm spectral region is very low, therefore, the influence of the stray light in this region is bigger than that in long wavelength region. The designer should make efforts to reduce this influence and thereby increases the measuring accuracy.

Two methods can be used to decrease the stray light:

1. To set narrow-band filters to select the desired wavelength.
2. According to technical specifications of the monochromator the optical aperture of the monochromator should be just filled with the light from light source to be measured, otherwise the light outside the aperture incidences into the dark case of the monochromator, it increases the stray light.

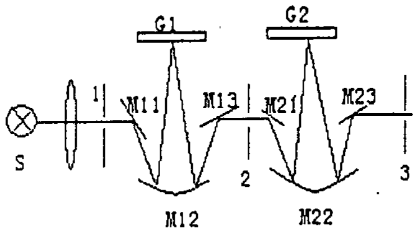


Fig.1. Double monochromator.

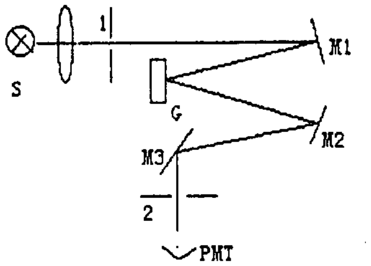


Fig.2. Single monochromator.

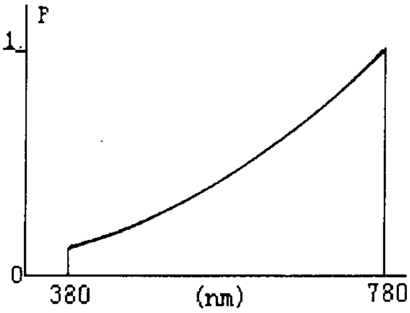


Fig.3. Spectral power distribution of standard illuminate A.

### THE REQUIREMENTS OF THE WAVELENGTH AND CHROMATICITY ACCURACY FOR THE SPECTROPHOTOMETER USED IN THE MEASUREMENT OF THE ELECTRIC LIGHT SOURCES

The accuracy of the spectrophotometer is considered as follows:

1. The uncertainty of the wavelength,
2. The repeatability of the wavelength,
3. The photometric linearity,
4. The uncertainty of the chromaticity,
5. The stray light.

1). The uncertainty of the wavelength

For the measuring the electric light sources the wavelength error of the instrument about ±nm causes the error of the color temperature of CFLs at 6400k about ±100k, and the error of the chromaticity x,y about ±0.0015-0.002. Therefore the wavelength uncertainty of the instrument should be within ±0.4nm or better than ±0.2nm.

The measurement of the wavelength uncertainty:

Place a low-pressure mercury lamp in the integrating sphere, The instrument with wavelength width 0.1nm scans the spectra. The trait spectrum 404.66nm, 435.88nm and 546.07nm of the low-pressure mercury lamp can be recorded. repeat 5 times, The uncertainty Uλ of the wavelength can be obtained:

$$U_\lambda = \max \frac{1}{5}\sum_{i=1}^{5}\left|\lambda_i - \lambda_o\right|$$

(1)

in which $\lambda_i$ correspond to the measuring data of the spectrum, $\lambda_0$ correspond to the trait spectra of the low pressure mercury lamp.

2) Repeatability δ λ:

$$\delta_\lambda = \max\left|\lambda_0 - \tfrac{1}{5}\sum_{i=1}^{5}\lambda_i\right|$$

(2)

3) The chromaticity uncertainty for the influence of the color temperature

Table (1) shows the influence of chromaticity error on the color temperature for three CFLs at 6500k, 5000k and 2700k.

According to Table 1, the chromaticity accuracy of the spectrophotometer using in measurement of the electric light source should be very high. The error consists of the wavelength uncertainty, repeatability. Stray light and photometric accuracy etc. The chromaticity error ±0.002 causes the deviation of the color temperature about ±100k. Therefore the uncertainty of chromaticity of the spectrophotometer should not exceed 0.002.

### MEASUREMENT ERRORS IN PHOTOMETER

The photometer, which measures luminous flux quickly and conveniently, can be used widely. But the producing deficiency can bring many errors in the measurement. Fig.4 shows the principle of measuring luminous flux.

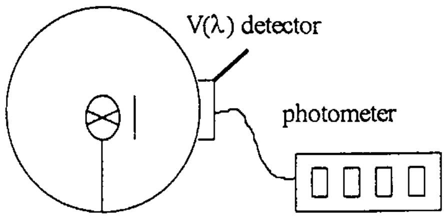


Fig.4. The principle of measuring luminous flux.

In the measurement of luminous flux, these are many kinds of errors caused by the producing. Two important errors are :

1. *The coating character of the integrating spheres.*

Besides the foreign body error and the baffle error in the

Table 1. The influence of the chromaticity for the color temperature.

| Color temp. (k) | Standard x: y: | Error x: -0.001 y: +0.001 | Error x: +0.001 y: -0.001 | Error x: -0.002 y: -0.002 | Error x:+0.002 y:+0.002 |
|---|---|---|---|---|---|
| 6500 | 0.313 0.337 | +58k | -38k | +99k | -116k |
| 5000 | 0.346 0.359 | +43k | -31k | +76k | -63k |
| 2700 | 0.463 0.420 | +7k | -6k | +13k | -12k |

integrating sphere, the spectral selection of the coating will cause the measure errors in the measurement of CFLs of the different color temperature.

According to the theory of integrating sphere, illumination Ec of the V(() detector on the sphere wall can be given by

$$E_c = \frac{\Phi_C}{4\pi R^2}\cdot\frac{\rho}{1-\rho} = \frac{\Phi_C}{4\pi R^2}\cdot f$$

**(3)**

Where **Φc** correspond to the luminous flux of lamp source, R correspond to the radius of the integrating sphere and ρ correspond to the spectral reflectance of the coating in the sphere.

$$\rho=0.95: \quad f = \frac{\rho}{1-\rho} = 19$$

$$\rho=0.8: \quad f = \frac{\rho}{1-\rho} = 4$$

If the spectral character of ρ is not neutral, ρ becomes ρ(λ). In the measurement of the lamp sources with different color temperature, the larger f is, the more effect on the chromaticity x,y and color temperature of the CFLs is caused by non-neutral of ρ(λ). The efforts should be made to develop the coating as neutral as possible. To reduce the effect of the non-neutral ρ(λ) if it decrease the response of integrating sphere unremarkably, putting ρ=0.8 by means of using dark material will reduce the measurement errors caused by ρ(λ).

*2. The impropriety matching of the* V(λ) *detector.*

According to the demand of the CIE standard, the V(λ) detector must be used in the instrument of measuring the luminous flux. The V(λ) detector should be matched to class A or better according to the international standard.

In the measurement of the CFLs with different color temperature, if the photometer was calibrated by the luminous flux standard lamp, the measuring errors can be obtained by Eq.4. The compensation factor K can be defined:

$$K = \frac{\int_{380}^{780} P_C(\lambda)V(\lambda)d\lambda}{\int_{380}^{780} P_A(\lambda)V(\lambda)d\lambda} \bullet \frac{\int_0^{\infty} P_A(\lambda)S(\lambda)d\lambda}{\int_0^{\infty} P_C(\lambda)S(\lambda)d\lambda}$$

**(4)**

In which $P_C(\lambda)$ correspond to the spectral distribution of the CFLs. Which can be obtained by the spectrophotometer. $P_A(\lambda)$ correspond to the spectral distribution of standard lamp. S(λ) correspond to the spectral response of the detector.

## THE MEASUREMENT OF OPTICAL PARAMETERS OF THE CFLS

Because of the matching errors of the V(λ) detector in the luminous flux measurement using photometer, there are different compensation factor K for the CFLs with different color temperature. To eliminate this errors, the spectrophotometric method can be used in the luminous flux measurement.

Fig.5 is the CAS-III Color Analysis System which can be used in the luminous flux measurement of CFLs and also can measure the parameters of the light sources and phosphor, such as, color coordinate x,y, spectral power distribution, color temperature, color rendering index and luminous flux etc.

The light from test lamp or the phosphor is received by optical fiber (8) and reference detector (9). The Ref. detector gets the electronic signal through the computer to compensate the drift of the test lamp. The optical signal, which is passing through the optical fiber, optics, monochromator and converted by the photomultiplier into electronic signal. If the spectral power distribution of the test lamp as $P_C(\lambda)$, the transmittance of the monochromator, optics, optical fiber as τ(λ). The sensitivity of the photomultiplier is s(λ). the electronic signal from the photomultiplier can be written:

$$I_{ph}(\lambda) = K * P_c(\lambda) * \tau(\lambda) * s(\lambda) = K \ (\lambda) * P_c(\lambda)$$

**(5)**

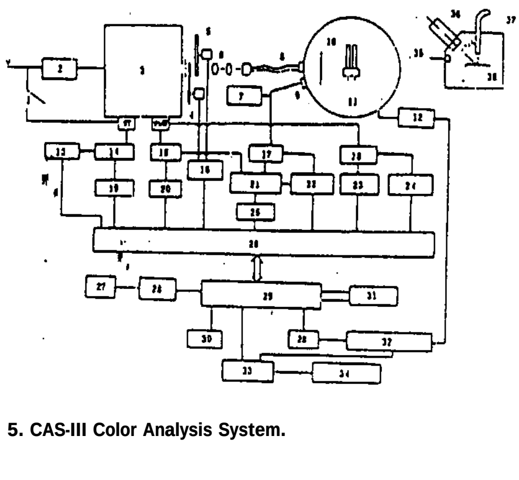

**Fig. 5. CAS-III Color Analysis System.**

K'(λ) is called instrument factor. Because the spectral properties of the components used in the spectrophotometer (CAS-III), for example photomultiplier, optics, fiber, monochomator are dependent on the wavelength, so that the instrument factor K' is not constant against the wavelength. In order to calibrate the instrument a standard illuminate can be used , for example standard illuminate A. Its spectral power distribution $P_s(\lambda)$ is known. If we measure the standard illuminate A, then the electronic signal $I_{phs}(\lambda)$ can be written.

$$I_{phs}(\lambda) = K'(\lambda) * P_s(\lambda)$$
$$K'(\lambda) = I_{phs}(\lambda)/P_s(\lambda)$$

**(6)**

The spectral power distribution $P_c(\lambda)$ is given as follows:

$$P_c(\lambda) = I_{ph}(\lambda) * P_s(\lambda)/I_{phs}(\lambda)$$

**(7)**

The data of the spectral power distribution of standard illuminate A is stored in computer already. So if we measure the electronic signal $I_{ph}(\lambda)$ of the test lamp, its spectral power distribution $P_c(\lambda)$ can be obtained. Fig.6 is a measuring result of a C FL.

In order to calculate the tristimulus values and chromaticity coordinates of a radiator. The first thing is to know its spectral power distribution $P_c(\lambda)$, then, according to CIE color system, CIE X,Y,Z tristimulus and the chromaticity x,y are given by:

$$X = K\int_{380}^{780} P_c(\lambda)\bar{x}(\lambda)d\lambda \qquad x = \frac{X}{X+Y+Z}$$
$$Y = K\int_{380}^{780} P_c(\lambda)\bar{y}(\lambda)d\lambda \qquad y = \frac{Y}{X+Y+Z}$$
$$Z = K\int_{380}^{780} P_c(\lambda)\bar{z}(\lambda)d\lambda \qquad z = \frac{Z}{X+Y+Z}$$

**(8)**

Using a luminous flux standard lamp, the luminous flux of test lamp can be measured. Turn on the standard lamp with knowing luminous flux Φs. By scanning the wavelength, the equation can be written as follows:

$$\phi_s \infty \int_{380}^{780} P_s(\lambda)V(\lambda)d\lambda$$
$$\phi_s = k\int_{380}^{780} P_s(\lambda)V(\lambda)d\lambda$$
$$k = \int_{380}^{780} P_s(\lambda)V(\lambda)d\lambda \,/\, \phi_s$$

**(9)**

In which, Φs correspond to the luminous flux of the standard lamp. $P_s(\lambda)$ can be measured by the CAS-III and the date of V(λ) have been stored in the computer. So K can be calculated with eq 10. When the C FL is measured, the luminous flux $_c$ can be given by

$$\phi_c = k\int_{380}^{780} P_c(\lambda)V(\lambda)d\lambda$$

**(10)**

$P_c(\lambda)$ can be obtain with CAS-III.

$$\phi_c = \frac{\int_{380}^{780} P_c(\lambda)V(\lambda)d\lambda}{\int_{380}^{780} P_s(\lambda)V(\lambda)d\lambda}\phi_s$$

**(11)**

Therefore the errors of the unneutral coating and inperfact matching of V(λ) can be avoided. ●


**REFERENCES**

[1] Wu Jizhong¡¢Ye Guanrong, *Optical Radiation Measurement*, MechanicalIndustry Press, 1992.

[2] CIE Pub.63 *The Spectroradiometric Measurement of LightSources* (1984).

[3] CIE Pub.84 *The Measurement of Luminous Flux* (1989).