International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-5 Issue-5, October 2015

Computation Specifics for a Family of Monochromators with a Plane Diffraction Grid

Adrian Titi Pascu, Daniel Băcescu

Abstract—The use of a family of monochromators offers the possibility of obtaining high performance measurements for multiple parameters. The Czerny – Turner version is the one studied in this paper. The choice is justified by the fact that this schematic allows the obtaining of very low levels of dispersed light. In addition, the technological execution of a mirror of the type employed by the Ebert schematic is difficult to construct and expensive. The spectral interval proposed for the study is 280 nm – 750 nm

Keywords—. Czerny – Turner monochromator, diffraction grid, mirror, spectrometer

I. Introduction

The monochromators are used in the construction of spectrometer devices and some optical stands.

Their operation involves the receiving of light from other devices or processes and the emission of light for new wavelengths.

The optical diagram of the monochromator includes: Input slit, collimator objective, dispersion system, focusing objective, output slit.

There are various constructive versions of monochromators:

a. With interference filter (fig. 1)

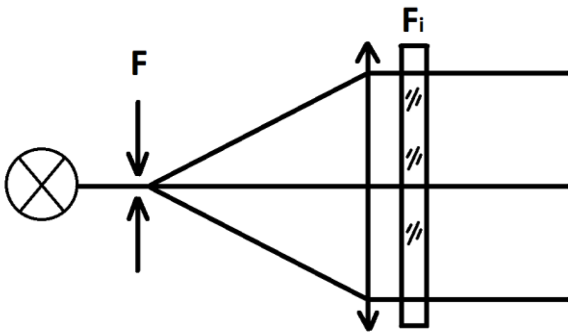

Fig. 1 Monochromators with interference filter

F - slit;

Fi - Interference filter calculated for the desired wavelength.

b. With dispersion prism (fig. 2)

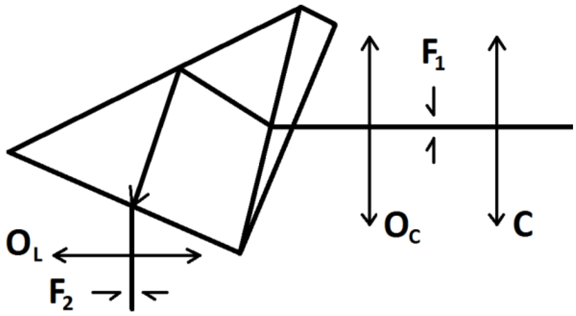

Fig. 2 Monochromators with dispersion prism

O_L - objective diopter;

O_C – collimator objective;

F_1, F_2 – slits;

C – capacitor.

c. With holographic diffraction grid

d. With reflecting diffraction grid: plane or concave.

There are two versions of design for the monochromator with diffraction grid:

-Ebert - that employs a single concave - spherical mirror with a double purpose; first to receive the complete light from the input slit, reflecting it telecentrically toward the grid, and then to receive the light diffracted by the grid, refocusing it toward the output slit of the monochromator.

-Czerny - Turner, which employs two mirror. The first one collimates the light receive from the source through the input slit, projecting it telecentrically toward the diffraction grid; the second mirror receives the light diffracted by the grid, and focuses it in the output slit of the monochromator.

The Czerny – Turner version is the one studied in this paper. The choice is justified by the fact that this schematic allows the obtaining of very low levels of dispersed light. In addition, the technological execution of a mirror of the type employed by the Ebert schematic is difficult to construct and expensive. The use of a family of monochromators offers the possibility of obtaining high performance measurements for multiple parameters. For example, it is well known that in order to obtain a higher decrease of the distance between two spectral peaks detected by the analyzer. The increase of the focal distance leads to an increase of the optical path of teh light and a reduction of the light beam in the output slit. If we require a strong light beam, we reduce the focal of the system, detrimental to the resolution, and, using the paraboloid mirrors in place of the concave - spherical ones, we reduce the sphere and astigmatism aberrations. In addition, the dimensions will decrease considerably, at small focals.

Manuscript published on 30 October 2015.
*Correspondence Author(s)
Ass.Prof..Phd.eng.Adrian Titi Pascu, Department of Mechatronics and precision mechanics, University "Politehnica" Bucharest, Romania.
Prof. Phd.eng.Daniel Băcescu, Department of Mechatronics and precision mechanics, University "Politehnica" Bucharest, Romania.

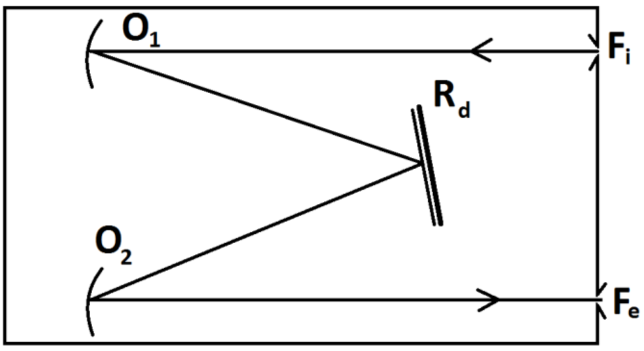

Fig. 3. Czerny – Turner schematic for the monochromator with diffraction grid.

F_i - Input slit.
O_L – collimator mirror 1;
R_d - diffraction grid.
O_2 – collimator mirror 2;
F_e - output slit.

Domains of application:

-Spectroscopy: - direct observation of the spectra through the field glass.

-Spectrography: - recording the spectra images with the aid of the photographic plate or film.

-Spectrometry: - the spectra are developed over time, recording the intensities.

- Extinction measurement for spectrophotometers. Allow the high precision determination of the concentration of various substances.

II. CALCULATION OF THE CZERNY – TURNER MONOCHROMATOR WITH DIFFRACTION GRID

The spectral interval proposed for the study is 280 nm – 750 nm.

The spectral interval includes both the visible part and a part of the ultraviolet domain.

II. 1. Dimensioning of the lighting system

To achieve this interval of wavelengths we will employ two light sources:

-Deuterium lamp (D_2E) that emits continuously in the UV domain, but discreetly in the visible domain.

-Halogen lamp (HgE) that emits continuously in the UV domain.

Deuterium lamp characteristics:

- Priming voltage 350 V.
- Operating voltage 70 - 100 V.
- Discharge current 0.3 A.
- Filament temperature 3500 K.
- Source dimensions 2 mm x 2 mm.

Manufacturing company: NARVA (Germany)

Halogen lamp:

- Operating voltage 6.27 V.
- Current 1.44 A.
- Filament temperature 3335 K.
- Source dimensions 2 mm x 1 mm.

Manufacturing company: WELCH ALLYN (SUA)

The image of the source in the light slit has the dimensions: 14 mm x 2 mm

Transversal dimension $\beta = \dfrac{Y'}{Y} = 7$

Both the halogen lamp and the deuterium one are placed at a distance of S_1 = 25 mm from the cylindrical mirror 1, measured on the optical axis.

The deuterium lamp has a vertical position, and the halogen one a horizontal one, when assembled.

$\alpha = 40^{O}$ – rotation angle of the cylindrical mirror 1 to receive the light beam and transmit it toward the cylindrical mirror 2.(fig.4 a,b,c)

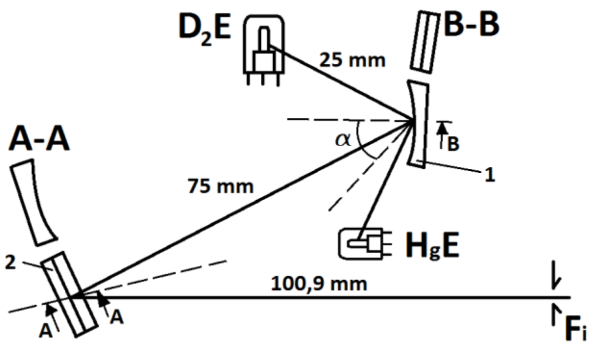

Fig. 4a. Schematic calculation of the lighting system

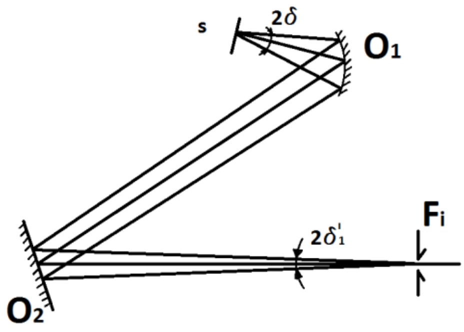

Fig. 4b. Schematic calculation of the lighting system (PLANE I)

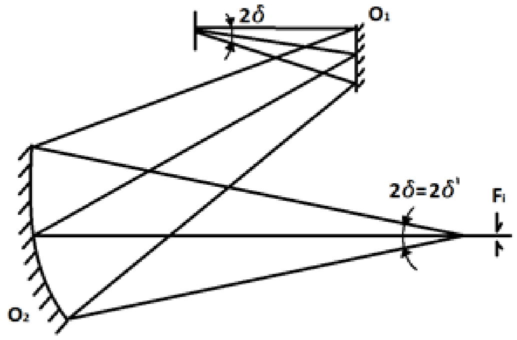

Fig. 4c. Schematic calculation of the lighting system(PLANE II)

$$\beta'_1 = \frac{S_2}{S_1} = 7{,}07 \quad \Rightarrow \quad s_2 = 176{,}75 \text{ mm}$$

s_1 = 25 mm

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

$$\beta_2' = \frac{s_4}{s_3} = 1 \Rightarrow s_3 = s_4 = \frac{s_1 + s_2}{2} = 100{,}9\ \mathrm{m}$$

- O_1 has the useful dimension in the plane I:

$X_1 = 2 \cdot 25 \cdot tg30^0 = 28{,}86\ \mathrm{mm}$

$X_1 = 30$ mm

- O_1 has the useful dimension in the planeII:

$Y_1 = 2 \cdot 25 \cdot tg30^0 = 28{,}86\ \mathrm{mm}$

$Y_1 = 30$ mm

- O_2 has the useful dimension in the plane I:

$X_2 = 2 \cdot 100{,}9 \cdot tg4{,}67^0$

$X_2 = 18$ mm

- O_2 has the useful dimension in the planeII:

$Y_2 = 2 \cdot 100{,}9 \cdot tg30^0$

$Y_2 = 118$ mm

For the mirror of 30 mm x 30 mm, $f_1 = 6.77$ mm

$R_1 = 20$ mm

For the mirror of 18 mm x 118 mm, $f_2 = 25.97$ mm

$R_2 = 80$ mm

II.2 Plane mirrors dimensioning

Czerny –Turner mirrors assembly are presenting in the figure 5.

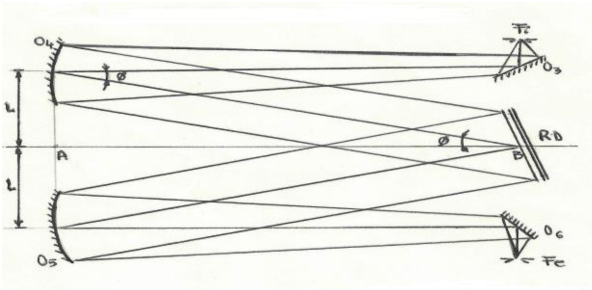

Fig.5 Czerny –Turner mirrors assembly

O_4, O_5 are concave mirrors
O_3, O_6 are plane mirrors
R_d-refraction grinding
F_i-entrance slit
F_e-exit slit
Dimensioning of plane mirrors are presenting in figure 6.

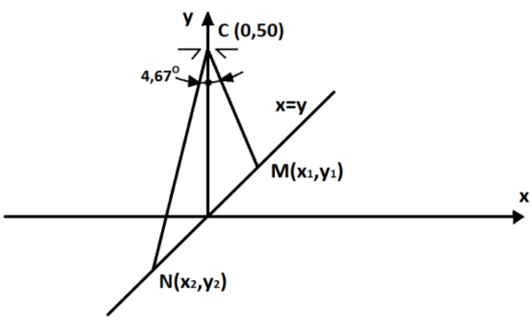

Fig. 6 Dimensioning of plane mirrors

To find the useful dimensions of the mirror, we will determine the coordinates of teh points M and N. The mirror is placed at 50 mm from the slit.

$$\begin{cases} x_{1,2} = y_{1,2} \\ y_{1,2} - 50 = [tg(90^0 \pm 4{,}67^0)](x_{1,2} - 0) \end{cases} \Rightarrow \begin{matrix} M(3{,}77; 3{,}77) \\ N(-4{,}55; -4{,}55) \end{matrix}$$

MN = 11.62 mm

The plane mirror will have the dimensions 12 mm x 12 mm.

II.3 Dimensional calculation of the diffraction grid

Dimensional calculation of the diffraction grid is based on its maximum inclining.

The extreme positions of this inclining are atfigure 7 and table 1

$\lambda_1 = 280\ \mathrm{mm}$

$\lambda_2 = 750\ \mathrm{mm}$

$$\Theta = \frac{\arcsin m\lambda}{2 \cdot d_{1,2} \cdot \cos\phi}$$

Θ = inclining degree of the grid

ϕ = device constant - 10°

$d_{1,2}$ = grid constant – $d_1 = 833$; $d_2 = 1667$

λ = wavelength

M = order number of the diffraction

Table 1. The extreme positions of this inclining of the diffraction grind

	Θ	
	$d_1 = 833$	$d_2 = 1667$
λ = 280 mm	9.82^O	4.89^O
λ = 750 mm	27.2^O	13.2^O

D_r = gauge dimension of the grid;
D_{ogl} = gauge dimension of the concave mirror

$$D_r = 1{,}14 \cdot D_{ogl}$$

In accordance with the tendency of the last years toward the miniaturization of devices, we introduced in the monochromator two plane mirrors that direct the light beam to and from the device slits.

These mirrors have the axes in the same plane as the grid axis

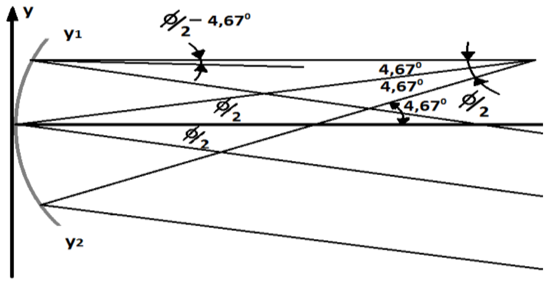

Fig.7 Calculation of the diffraction grid

Is imposed:

$\phi = 10^O$ and f = focal distance

AB = distance between the center of the diffraction grid and the straight line uniting the centers of the concave mirrors

AB = f – 50 mm

1. Calculation of the monochromatic with:

- $f^1 = 1000$ mm

$L = AB \cdot tg\,\phi = 167.5$mm

$X_0 = f \cdot \cos\frac{\phi}{2}$

$Y_0 = f \cdot \sin\frac{\phi}{2}$

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Knowing that R = 2000 mm result X_0 = 997.67 mm, Y_0 = 67.93 mm and Y_1 = 80.97 mm; Y_2 = - 82.05 mm.

We will dimension the spherical mirror as 165 mm x 165 mm.

Optical path through the monochromator D:

$$D = 2 \cdot f + 2 \cdot \frac{f - 50}{\cos\phi}$$

D = 3929.3 mm

Aperture number K:

$$K = \frac{f}{D_{pi}}$$

K = 6.06

The grid will have: 188.1 mm x 188.1 mm

2. Calculation of the monochromator with:
   f = 500 mm.

L = 79.35 mm.

R = 1000 mm; X_0 = 498.5 mm; Y_0 = 39.05 mm.

We solve the system A and obtain:

Y_1 = 42.86 mm; Y_2 = -43.01 mm;

We will dimension the concave - spherical mirror as: 87 mm x 87 mm.

Optical path D:

D = 1913.88 mm.

Aperture number K:

K = 5.75

The grid will have: 99.18 mm x 99.18 mm.

3. Calculation of the monochromator with:

f = 250 mm.

L = 35.26 mm.

AB = 200 mm.

For this focal we will replace the concave - spherical mirrors with the paraboloid ones to reduce the aberrations.

The system is:

$$B \begin{cases} Y^2 = 2 \cdot p \cdot x \\ Y - Y_0 = \left[tg\left(\frac{\phi}{2} \pm 4,67^0\right)\right](X - X_0) \end{cases}$$

$$p = 2 \cdot f = 500 \text{ mm}$$

X_0 = 249.51 mm

Y_0 = 15.53 mm

We solve the system and obtain:

Y_1 = -20.7 mm; Y_2 = 20.37 mm;

The gauge dimension will be: 41.4 mm x 41.4 mm.

Optical path D:

D = 906.17 mm.

Aperture number K:

K = 6.03.

The grid will have: 47.2 mm x 47.2 mm.

4. Calculation of the monochromator with:

f = 125 mm.

L = 13.22 mm.

AB = 75 mm.

p = 250 mm.

X_0 = 124.39 mm.

Y_0 = 12.3 mm.

Table 3

We solve the system B, and obtain:

Y_1 = -9.57 mm; Y_2 = 10.12 mm;

The gauge dimensions of the paraboloid mirror are: 20.25 mm x 20.25 mm.

Optical path D:

D = 402.31 mm.

Aperture number K: K = 6.17

The grid will have the dimensions: 23.09 mm x 23.09 mm.

III. SELECTION OF THE DIFFRACTION GRID

In this paper we propose the study of a spectral interval between: 280 nm and 750 nm.

With a single diffraction grid we cannot cover the whole domain between 280 nm and 750 nm.

We will employ two grids:

a) The first with the reference wavelength of 300 nm, which covers the spectral interval 180 nm - 550 nm.
   - Grid constant d = 833.

b) The second grid with the reference wavelength of 500 nm, which covers the spectral interval 350 nm and 1000 nm.
   - Grid constant d = 1667.

Equation of the diffraction grid: m = d (sin i + sin r)

λ = wavelength

d = grid constant

i = incidence angle

r = diffraction angle

i = $\Theta + \phi$

r = $\Theta - \phi$

Θ =rotation angle measured from the zero order position.

$m = 2 \cdot d \cdot \sin\Theta \cdot \cos\Theta$, from here results Θ

- Angular dispersion:

$$\frac{d_r}{d} = \frac{m}{d \cdot \cos r}$$

- Reciprocal linear dispersion:

$$\frac{d}{d_x} = \frac{d \cdot \cos r}{f \cdot m}$$

Resume of monochromators angular dispersion and reciprocal linear dispersion are present in tabelul 2

f[mm]	1000		500		250		125	
λ [mm]	300	500	300	500	300	500	300	500
$\frac{d_r}{d_x}$	1.2	1.6	1.2	0.6	1.2	0.6	1.2	0.6
$\frac{d_\lambda}{d_x}$	0.83	1.6	1.6	.3	3.3	6.6	6.6	13.3

Tabel 2

Parameters of the monochromator

W = slit width

λ_1 = 300 mm

λ_2 = 500 mm

-Light losses through the monochromator (20%)

-Transmission factor = 0.8

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

IV. METHODS FOR CHECKING THE WIDTH OF THE SPECTRAL BAND

f [mm]	K	Resolution: $R = w \cdot \frac{d_\lambda}{d_x}$ [nm]									
		w = 0.1 mm		w = 0.15		w = 0.25		w = 0.5		w = 1	
		λ_1	λ_2	λ_1	λ_2	λ_1	λ_2	λ_1	λ_2	λ_1	λ_2
1000	6.06	0.083	0.16	0.124	0.249	0.2	0.4	0.4	0.8	0.8	1.6
500	5.75	0.16	0.33	0.24	0.48	0.4	0.8	0.8	1.6	1.6	3.2
250	6.03	0.33	0.66	0.5	1	0.825	1.65	1.65	3.3	3.3	6.6
125	6.17	0.66	1.33	1	2	1.65	3.3	3.3	6.6	6.6	12.3

- The device is programmed to measure the internal spectral transmission factor for a set wavelength and for a given mechanical width of the slit (used for the theoretical calculation).

- The emergent beam is transmitted from the spectrophotometer on the input slit of a monochromator coupled with a recorder.

- The spectrum is traced obtaining an image similar to the one from the image below. The spectral wavelength is determined from the obtained spectrum.

- The determined value is compared to the prior one from the theoretical calculation.

REFERENCES

1. Dumitrescu N, Optică tehnică, Curs I.P.B,1980
2. Curatu *E*, Calitatea sistemelor optice. Funcția de transfer optic, Ed. Academiei Române,1992
3. Dumitrescu N., Ionescu S., Opticã instrumentală, Ed. Politehnica, Bucureşti, 1991.
4. D.Băcescu, Optică Aplicată. Analiza şi sinteza componentelor, Ed. Medro 2004.
5. Dodoc, P. - Calculul şi construcţia aparatelor optice, E.D.P., 1983
6. Dodoc, P. - Teoria şi construcţia aparatelor optice, Ed. Tehnică, 1989
7. Dodoc, P. - Teoria şi construcţia sistemelor optice,

AUTHOR PROFILE

Ass. Prof. Phd. Eng. Adrian Titi Pascu, Mechanical engineer in the optical field, optometrist, assistant professor at department of mechatronics and precision mechanics at the Polytechnics University of Bucharest Romania, President of Optometric Association of Romania.and member of EAOO.The main research are focusing on the human cornea,contact lenses,ophthalmic lenses and spectrofometry.

Prof. Phd. Eng. Daniel Băcescu, Mechanical engineer in the optical field, professor at department of mechatronics and precision mechanics at the Polytechnics University of Bucharest Romania. The main research are focusing on human eye, design of the optical component, holography .