Journal scientific and applied research, vol. 5, 2014
Association Scientific and Applied Research
International Journal

Original Contribution

ISSN 1314-6289

OPTICAL SCHEME FOR SPECTROPHOTOMETER

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Abstract: *The work is about the design and development of compact optical system for spectrophotometer. The equation of plain diffraction grating allows the design of a compact appliance with optimal combination of the separate optical elements and their parameters.*

There are certain constructions of spectral appliances, which are developed by leading companies. The path of the rays is used, it is reflected by mirrors many times and the result is a compact construction. There are company catalogues for the choice of separate optical elements when developing appliances, but they do not describe the elements in detail. These facts do not allow scientific research and experimental construction on a high scientific and technical level with own recourses and materials.

Key words: *compact, design, optical, scheme*

I. INTRODUCTION

The aim is to make correlations for the choice of the optical components of spectrophotometer when the light intensity, range of scanning, resolution and condition for compact construction are known[2,3,4]. The concrete aim is to situate the optical components and to define the correlation of their parameters.

A compact optical scheme of a spectrophotometer is represented, which allows rational usage of the capacity, small dimensions, high resolution, high light intensity and small field of vision within the boundary of a given spectral range. In order to achieve the best utilization of the light intensity and resolution of the spectrophotometer with a spatial source, the calculations are based on the angular dimensions of the studied radiation source, the collimator lens, the reflecting components, and the diffraction grating parameters with rendering an account of the entrance and exit sight hole.

Correlations are found about the assembly of optical elements of the spectral appliance and about the study of the spatial and spectral characteristics of the atmospheric layers. They can be successfully applied when designing and construction of spectral appliances which work in laboratories and outside, as well as on the board of cosmic flying machines. The basic stages in the development of appliances for spectral analysis are systematized, which gives many solutions when different initial conditions and restrictions are assigned.

II. COMPACT OPTICAL SCHEME OF A SPECTRAL APPLIANCE

Generally, the spectral appliance consists of an optical receiving system, a diffraction grating, a gathering optical system and a photo receiver. Besides this, it consists also of a mechanical scanning system, short- and high- voltage leading blocks, an electronic part, etc. The aim is to define the optical components and to find correlations between their parameters. The scheme has to ensure the rational usage of the volume, small dimensions and high resolution, big light power and small field of vision within the boundaries of a defined radiation range. There exist some versions of functional scheme. Without mentioning the advantages and disadvantages of the different versions, the base scheme on fig. 1 will be used to find the correlations.

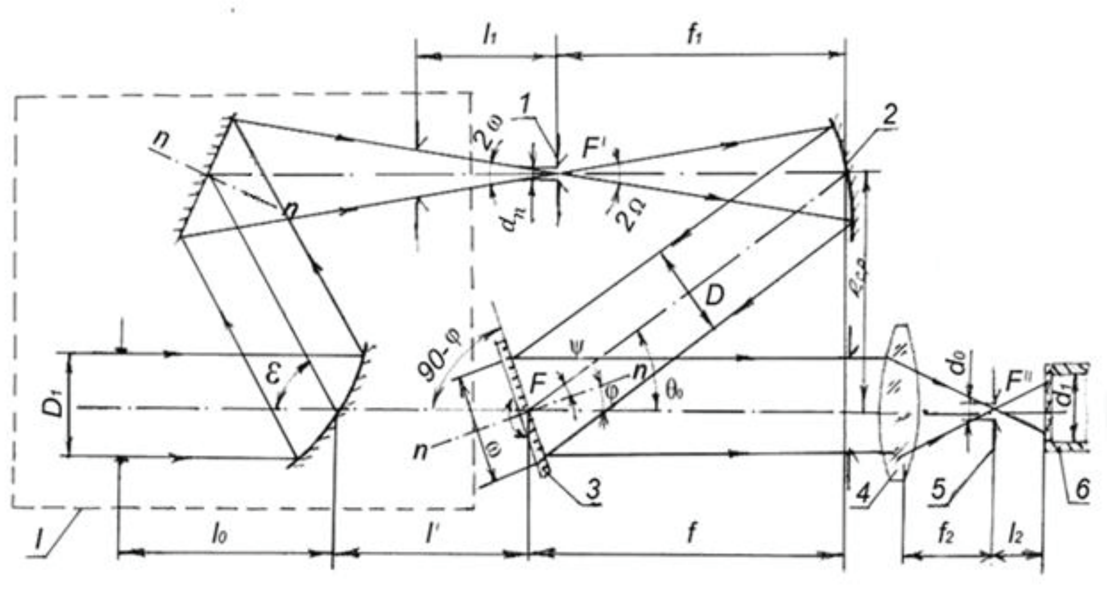

Fig. 1. Optical scheme of spectrometer I – light – receiving system, 1 – entrance hole, 2 – spheric mirror of the collimator, 3 – diffraction grating, 4 – objective lens, 2 – exit hole, 6 – receiving and registering system

As it is shown on fig. 1, the compactness of the spectrometer optical scheme is achieved by squeezing the optical axes of the light-receiving system and receiving and registering system and an additional parallel way of the rays. The parallel is situated in the middle of a spherical mirror *2*, i.e. at a distance R_{cp} from the appliance geometric axe. The following symbols are introduced: D_1 – appliance entrance hole; d_H – dimension of the entrance hole; f_1 – focal distance of the collimator; *D* – appliance working hole; *W* – width of the diffraction grating effective area with parameter d ($W=Nd$, *N* – total number of the hatches); f_2 – focal distance of the spherical mirror; f_2 – focal distance of the objective *4;* d_0 – dimensions of the exit hole; d_1 – effective area of the receiving and registering system. Additional dimensions are: f_0, l_0, l, l_1, l_2 and l' according to fig. 1.

The equal angular dimensions and the basic mirror elements are used to ensure the best usage of the light power and resolution of the appliance with spatial source and maximum transparency of the optical components. The solution of the problem begins with the calculation of the collimator objective. When the angle of the appliance field of vision is defined – 2w, f and Rcp are defined the parameters of the spherical mirror 2, which sends a parallel shaft of rays to the diffraction grating according to fig. 1.

(1) $$tg\Omega = \frac{D}{2\cos Q_0}\frac{1}{f_1},$$

where $tg\Omega = R_{cp}/f$, R_{cp} and f are preliminary defined quantities, then

(2) $$f_1 = \frac{D}{2tg\Omega\cos Q_0},$$

where $2\Omega = 2w$

The light receiving system ensures angle of filed vision *2w* and according to fig. 1 and entrance hole D_1, we receive:

(3) $$tgw = \frac{D_1}{2}\sin 45^\circ\frac{1}{L},$$

and then:

$$L = \frac{D_1}{2}\frac{\sin 45^\circ}{tgw}.$$

A diaphragm with dimensions $a_x a$ is situated at distance l_1 from the focus *F'* which ensure the square form of the field of vision from the optical conditions for it at distance l_1 from *F',* the result is:

(4) $$a = (L - l_1)tgw.$$

The focal distance $f_0 = f_1$ from the condition $2w = 2\Omega$ where it is divided into two sections: l and $f_0 = l$, according to fig. 1. Their definition can be given by the solution of a system of equations:

(5) $$\left|\begin{array}{l} l(1+\cos\varepsilon) = f_0 - l' \\ l\sin\varepsilon = R_{cp}, \end{array}\right.$$

For that reason after the change of $\sin\varepsilon$ with $\sqrt{1-\cos^2\varepsilon}$ and transition towards l, we have:

(6) $$\frac{1+\cos\varepsilon}{1-\cos\varepsilon}=\left(\frac{f_0-l'}{R_{cp}}\right)^2,$$

from where:

(7) $$\cos\varepsilon=\frac{A^2-1}{A^2+1},$$

at $A=(f_0-l')/R_{cp}$.

Then we get the dimension *l* from one of the equations of the system (5):

(8) $$l=R_{cp}/\sin\varepsilon.$$

The parameters of the diffraction grating and the objective in front of the receiving and registering system are calculated according to fig. 1 and the equations for diffraction of the light flux. According to the basic equation for level diffraction gratings [1]:

(9) $$d\cos\beta(\sin\psi+\sin\varphi)=q\lambda,$$

where d=1.10^{+6}/p [nm] – parameter of the diffraction grating;

$\beta=0^\circ$ – angle of incidence of the rays towards the main plane of the diffraction grating;

ψ – angle of incidence of the rays towards the normal diffraction grating;

φ – angle of diffraction of the diffraction grating rays;

$q=0,1,2,\ldots 1d/\lambda$ – range of the specter, when q=0, zero “white” maximum;

$\lambda-[nm]$ – length of the radiation.

After a substitution, the basic equation turns into

(10) $$\sin\psi+\sin\varphi=\lambda p10^{-6}.$$

The equation is not suitable to solve in the above mentioned form. Let it be written in the following way:

(11) $$2\sin\frac{\varphi+\psi}{2}d\cos\frac{\varphi-\psi}{2}=\lambda p10^{-6},$$

$(\varphi - \psi) = Q$ about a concrete appliance. When we have $(\varphi + \psi) = w$, the equation becomes suitable for calculation in the following way:

(12)
$$2\sin w = \frac{\lambda p 10^{-6}}{2socQ_0 / 2}.$$

When the range of the registered radiation is defined by $\lambda_{\min}..\lambda_{\max}$ and after we substitute in (12), we get $w_{\max}$ and $w_{\min}$. According to them and the formulas

(13)
$$2\varphi = w + Q_0;\ 2\psi = w - Q_0,$$

the range of the diffraction grating rotation and the angle of its normal towards the appliance optical axe are defined.

The parameters of the exit holes and the objective lens 4 are given by the formulas [1]

(14)
$$d_0 = \frac{2 f_2 1{,}22\lambda}{w\sin(90-\varphi)},$$

(15)
$$d_0 \le 2\Delta r,$$

where $\Delta r = f\Delta\frac{\pi}{180}$ when $\Delta = \frac{dQ}{d\lambda} \approx \frac{\Delta Q}{\Delta\lambda}$, angle dispersion which is approximately close to the variation range of the reflection angle ΔQ for $\Delta\lambda = \lambda_{\max} - \lambda_{\min}$ in degrees.

Depending on the type of the receiving and registering system and its parameters, the situation is also defined by the correlation

(16)
$$\frac{w\sin(90-\varphi)}{f_2 l_2} = \frac{d_1}{l_2}.$$

For the entrance hole, the dimension is given by the formula [1]

(17)
$$d_H = f_1\frac{\lambda}{D},$$

where $\lambda = \frac{\lambda_{\min} + \lambda_{\max}}{2}$ or $\lambda = \frac{\lambda_{\max}}{2}$.

The appliance resolution $\lambda / \delta\lambda$ is

(18)
$$\frac{\lambda}{\delta\lambda} = \frac{q(\sin\varphi + \sin\psi)}{\lambda} \approx \frac{2w}{\lambda},$$

and it depends on the effective area of the diffraction grating which is chosen according to the working hole of the appliance D.

III. CONCLUSION

Correlations are found for the optical elements of the spectral appliance for the research of the spatial characteristics of the atmosphere layers. They can be used for the design and construction of special appliances which work on the ground, as well as in Space. The basic stages in the construction of appliance for spectral analysis are systematized, which gives opportunities for multiple salvations at defined initial conditions and restrictions. They are used in the construction of the appliance "Laboratory spectrometer".

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