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Selection and results of the aberration computation and peculiarities of polarizing effect compensation in double UV monochromators for satellite-borne UV ozonometers

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Results of calculations are presented for optical-mechanical peculiarities of the double diffraction monochromator arrangement with dispersion subtraction based on spherical diffraction gratings for remote probing of the Earth's ozonosphere from space platforms within the 255.5–339.8 nm spectrum range with the aim to obtain global mapping for vertical concentration profiles and total ozone content. Special requirements to the equipment installed at space platforms were also taken into account. The double diffraction monochromator, as well as a prismatic one, has its own polarizing impact on the measured radiation. Negligence or non-consideration of monochromator polarizing influence on spectrometric measurements could cause an error up to 70 %. Experimental results show that the spectral sensitivity dependence on the measured radiation polarization is defined by the system of dispersion elements and the input aperture value. A source of completely depolarized radiation was used for the measurements. To decrease the polarization effect of UV spectrometer, special depolarizers and polarizing effect compensators had been developed. Measurement results obtained with and without such devices have been compared to determine their work efficiency. Measurements were performed for all wavelengths of the spectrometer operating spectral range.

Представлены результаты вычислений оптико-механических характеристик схемы двойного дифракционного монохроматора с вычитанием дисперсии на базе сферических дифракционных решеток для дистанционного зондирования озоносферы Земли с космических платформ в спектральном диапазоне 255.5–339.8 nm для глобального картографирования вертикальных профилей концентрации и общего содержания озона. При этом учитывались специальные требования для оборудования, устанавливаемого на космических платформах. Двойной дифракционный монохроматор, как и призменный монохроматор, имеет собственное поляризующее воздействие на измеряемое излучение. Пренебрежение поляризационным влиянием монохроматора на спектрометрические измерения может привести к ошибке до 70 %. Экспериментальные результаты показывают, что зависимость спектральной чувствительности на поляризацию измеряемого излучения определяется системой дисперсионных элементов и значением входной апертуры. Для измерения был использован источник полностью деполяризованного излучения. Для уменьшения эффекта поляризации УФ-спектрометра разработаны специальные деполяризаторы и компенсаторы эффекта поляризации. Проведено сравнение результатов измерения с использованием и без использования таких приборов для определения их рабочей эффективности. Измерение было выполнено для всех длин волн рабочего спектрального диапазона спектрометра.

Development of automatic space spectral ozonometers is associated with specific strict physical and technical requirements to space installations. Thus, during their development, it is important to avoid complicated electro-mechanical units for control of optic elements. A peculiar feature of the double monochromator scheme, which we have chosen under such approach, was the absence of discrete linear movements of optic components and the possibility to equalize signal amplitudes at its output. During UV spectrum scanning, flow change in the operational range increases up to 4–5 orders. So the optical scheme was evaluated in a way that transmission coefficient of monochromator within the short-wave spectral range, where ozone absorption is the highest, would be maximum. Orientation plane and degree of polarization of backscattered solar radiation in the Earth atmosphere are significantly influencing the results of space spectral ozonometric measurements [1]. The intrinsic spectral polarization sensitivity of spectral ozonometer depends mainly on the input aperture width and type of dispersion elements [2] and is determined as:

$$k(\lambda) = \frac{1}{2}\left[k_{\parallel}(\lambda) + k_{\perp}(\lambda)\right], \tag{1}$$

where $k_{\parallel}$ and $k_{\perp}$ are the spectrometer polarization sensitivities to plane-polarized radiation at the polarization plane orientation parallel or perpendicular to the input aperture plane S_{in}.

The total polarization capacity of spectrometer is described by equation:

$$\Delta I_p = \frac{I_{out}^{\max} - I_{out}^{\min}}{I_{out}^{\max}}. \tag{2}$$

In order to decrease or completely eliminate polarization effect of spectrometer, depolarizers or special compensators of polarizing action are required.

At the diffraction grating curvature radius R, a condition for focusing spectral line image relative to input aperture is the following [3, 4]:

$$\frac{\cos^2\phi}{d} + \frac{\cos^2\varphi}{d'} = \frac{\cos\phi + \cos\varphi}{R}, \tag{3}$$

where ϕ is the incidence angle of beam to the grating; φ diffraction angle; d, the distance between input aperture S_{in} and diffraction grating; d', the distance from diffraction grating to output aperture S_{out}. While locating input aperture in the grating curvature center ($d = R$) and provided the condition of normal beam incidence to diffraction grating is fulfilled ($\phi = 0$), the following focusing condition for concave diffraction grating: $f = R\cos\varphi$ will be valid.

For a circle of radius equal to the curvature radius R of diffraction grating, chord length coming at an angle β from diffraction grating center equals $2R\cos\varphi$. If a second concave diffraction grating is located on the same circle so that it is irradiated by beam diffracted at the first grating, then this radiation will be focused at the circle center.

To guarantee identical distribution conditions for radiation of different wavelengths, there can be designed two options of double monochromator schemes with dispersion subtraction. The first option provides for the use of second grating having considerably greater dimension than the first one; while the second variant provides scanning of spectrum by way of mechanical optical superposition of the first diffraction grating image on the working surface of the second grating. A simplified variant of the first scheme can be created for limited portion of spectrum, using identical first and second diffraction grating, when incomplete illumination of working surface of the second diffraction grating will be compensated by greater intensity of measured radiation in spectral regions where the working surface of the grating is not fully irradiated. This schematic variant for double monochromator with subtraction of dispersion (Fig. 1) is preferable and optimum for installation in UV ozonometers [5].

To form photometrical channel with 380 nm central wavelength for control of

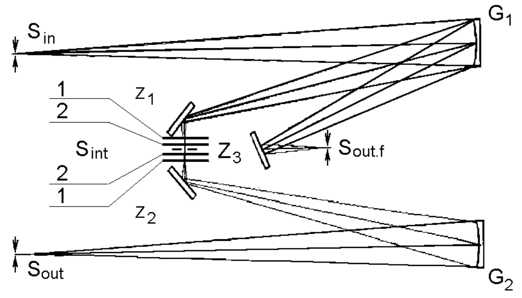

Fig. 1. Optical schematics of spectrometer: S_{in}, S_{out} — input and output apertures, S_{int} intermediate aperture, G_1, G_2 — diffraction gratings, Z_1, Z_2, Z_3 — mirrors to turn beams; $S_{out.f}$ — output aperture of cloud layer photometer. *1* — phase-shifting plates, *2* — rotators.

cloudy cover and laying surface [6], the second order derivative of spectrum from grating G_1 is used.

In the spectrometer optical scheme, linear shifting of optic elements is absent. In focal plane of the first diffraction grating G_1 of the spectrometer channel, a mask of intermediate apertures is located, each aperture corresponding to one working wavelength. The spectrum is scanned by one-by-one opening of one of the intermediate mask apertures. Scanner is a device with disc in which radial cuts-apertures are made corresponding to the mask intermediate apertures. The apertures are evenly located on disc — each in its sector so that while disc is rotated by 30 degrees, there is opened only one of the intermediate apertures. Dimensions of the intermediate mask apertures are determined based on two conditions: 1) no screening of radiation passing through the intermediate aperture should be on the aperture edges; 2) radiation going through the intermediate aperture should not be dissipated and get to the neighboring intermediate mask apertures.

The scanner disc is controlled by step-generator in accordance to interrogating program for spectral channels of UV spectrometer. In case step-by-step engine fails, if stop error is within ±5 degrees, fixation device located in the scanning device body brings the disc to evolution position. There are additional holes on the disc to code spectral channel number.

Diffraction gratings have the energy concentration maximum at 250 nm. If S_{in} is located at the normal to the diffraction grating surface at the distance equal to the grating curvature radius, then spectrum is focused at the circle of Roland. Width of radiation spectral interval after S_{out} is defined by S_{int} dimension. The transmission band necessary for UV ozonometry at output aperture of monochromator, i.e. separation spectral capability, is 1 nm which corresponds to $S_{int} = 0.15$ mm. Distances L between intermediate apertures for ozonometric wavelengths which are calculated from S_{int} for minimum wavelength are presented in Table 1.

Reflecting layers back on flat mirrors are applied at the outside for preventing the influence of manufacturing errors; for example, edges influencing monochromatizing quality. Special precise mirrors are made having thickness $d = r/5$ to $d = r/7$, where r is the biggest dimension, or mirror diameter.

Table 1

λ, nm	L, mm	δ, %
255.5	0.00	100.0
273.6	2.75	86.2
283.0	4.18	79.1
287.6	4.88	74.7
292.2	5.58	72.0
297.5	6.39	68.0
301.9	7.06	64.6
305.8	7.65	61.6
312.5	8.68	56.5
317.5	9.44	52.7
331.2	11.54	42.2
339.8	12.85	35.6

While cutting spherical grating, the angle between the forming chisel surface and the preform, called the glistening angle, gradually changes along its width. As a result, effectiveness of the grating at the given wavelength on the edges of its work surface can vary by a few orders [7].

Intensity distribution in grating spectrum is determined by the formula:

$$I = \Phi(u)\Psi(\nu), \tag{4}$$

where $\Phi(u) = \dfrac{\sin^2 u}{u^2}$ describes intensity distribution in diffraction image from one mirror plane of hatch, $\Psi(\nu) = \dfrac{\sin^2 m\nu}{\sin^2\nu}$ — describes interference result for beams diffracted from all mirror planes of hatches, where m is the total number on hatches in the grating, $u = \dfrac{\pi\Delta'}{\lambda}$, $\nu = \dfrac{\pi\Delta}{\lambda}$, Δ' is the difference of distance which arises at diffraction at ϕ' angle for two beams falling on the edges of one and the same plane. With width b, Δ is the difference in distance for two beams falling on the points of near-by planes so that the distance between them equals to grating step.

$$\Delta' = b(\sin i + \sin i'), \tag{5}$$

$$\Delta = e(\sin\phi + \sin\phi'), \tag{6}$$

where ϕ is the beam incidence angle to the grating, ϕ' is diffraction angle, i — angle between the normal to the hatch plane of grating and incident beam, $i = \phi - \gamma$, i' is an angle between the normal to the hatch plane of grating and diffracted beam, $i' = \phi' - \gamma$, where γ is a glistening angle of the grating ($\gamma > 0$ clockwise). Function $\Psi(\nu)$ is periodic and has its period π. For given λ it gets maximum at $\nu = k\pi$, i.e. provided:

$$\sin\phi + \sin\phi' = \frac{k\lambda}{e}. \tag{7}$$

Between two neighbor maxima defined by condition (5), there are $m - 1$ minima and $m - 2$ secondary maxima of very low intensity compared to the main maxima, since almost all the energy is being distributed within the main maxima. While the wavelength λ is changed, characteristics of the $\Psi(\nu)$ function are sustained whereas only distance between neighbor maxima is changing in proportion to λ. Relative intensity of the chief maxima of different orders and their dependence on λ is generally defined by function $\Phi(u)$. This function is slowly changing with λ. Designating $\beta = (\phi + \phi')/2$ and $\theta = \phi - \phi'$, we obtain:

$$\Delta' = 2b\sin(\beta - \gamma)\cos\frac{\theta}{2}, \tag{8}$$

$$\Delta = 2e\sin\beta\cos\frac{\theta}{2}. \tag{9}$$

Considering the (5–7) formula, formula (8) may be transformed to:

$$\Delta' = k\lambda\frac{b\sin(\beta - \gamma)}{e\sin\beta}. \tag{10}$$

Then:

$$u = k\pi\frac{b\sin(\beta - \gamma)}{e\sin\beta}. \tag{11}$$

In case of rectangular profiles of hatches, i.e. at $b = e\sin(\gamma)$:

$$u = k\pi\frac{\sin\gamma b\sin(\beta - \gamma)}{\sin\beta}. \tag{12}$$

Glister angle is related to wavelength λ_{max} (at maximum radiation concentration in the spectrum) based on correlation:

$$\sin\gamma = \frac{k\lambda_{\max}}{2e\cos\frac{\theta}{2}}. \tag{13}$$

For spherical diffraction grating, angle β is unchanged, whereas only angle γ is changing. Instead of angle γ, Bruns [8] introduces angle p which is the angular distance from the point on grating or its continuation to the normal to grating coinciding with the normal to the hatch, and then $p = \gamma$. If angle α is to be introduced, so that it is counted from the grating center, then $\alpha = \gamma - \gamma_0$; it follows:

$$u = k\pi\frac{\cos(\alpha + \gamma_0)\sin(\beta - \gamma_0 - \alpha)}{\sin\beta}. \tag{14}$$

Function $\Psi(\nu)$ for spherical grating takes maximum values at $\nu = k\pi$ and has the shape:

$$\Psi_{\max} = \frac{\sin^2 mk\pi}{\sin^2 k\pi}. \tag{15}$$

This is uncertainty of type 0/0, while opening it gives $\Psi_{\max} = m^2$ where m is a hatch number in the grating or in its illuminated portion during non-complete lighting of the grating working surface.

Efficiency of two concave diffraction gratings for double monochromator is defined by multiplication of $\Phi(u_1)$ and $\Phi(u_2)$:

$$u_1 = k\pi\frac{\cos(\alpha + \gamma_{01})\sin(\frac{\phi'}{2} - \gamma_{01} - \alpha)}{\sin\frac{\phi'}{2}}. \tag{16}$$

Since in our scheme of double monochromator with subtraction of dissipated radiation which after being diffracted at the first grating, enters non-corresponding portion of the second grating, besides of shift of the image of the first grating on the second one for wavelengths different from the initial one and for which the scheme has been calculated, by the angle $\delta = 2(\phi_i' - \phi_1)$, then:

$$u_2 = k\pi\frac{\cos(\gamma_{02} - \alpha + \delta)\sin(\frac{\phi'}{2} - \gamma_{02} + \alpha - \delta)}{\sin\frac{\phi'}{2}}. \tag{17}$$

The efficiency δ for double monochromator with subtraction of dispersion for 250 nm wavelength on spherical diffraction gratings having their efficiency maximum at the same wavelength, was evaluated based on methodology from [8].

To eliminate side radiation at the monochromator input, blending device was employed with a set of diaphragms for geometrical limitation of radiation flow and cutting-off any occasional side blicks.

To calibrate the facility twice, after direct solar radiation during each orbiting, a dissipating Lambertian plate made of milk glass MS20 was periodically introduced into spectrometer's vision field.

For plane polarized light with polarization azimuth ν, Jones vector is the following [9]:

$$\mathbf{E}_{in} = \begin{vmatrix} E_x \\ E_y \end{vmatrix} = E_0 \begin{vmatrix} \sin\nu \\ \cos\nu \end{vmatrix}, \tag{18}$$

where E_x and E_y are the amplitudes of simple linear harmonic oscillations of electric field components along x and y axes. And if phase-shifting plates and rotators are installed in a symmetric double monochromator in symmetry to its S_{int} (Fig. 1), then Jones vector for radiation at S_{out} will be:

$$\mathbf{E}_{out} = \begin{vmatrix} E_x' \\ E_y' \end{vmatrix} = \tag{19}$$

$$= \begin{vmatrix} ae^{i\Delta} & 0 \\ 0 & b \end{vmatrix} * \begin{vmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{vmatrix} * \begin{vmatrix} ae^{i\Delta} & 0 \\ 0 & b \end{vmatrix} * \begin{vmatrix} E_x \\ E_y \end{vmatrix},$$

where $\begin{vmatrix} E_x \\ E_y \end{vmatrix}$ is "light" vector at the input; Δ — phase shift between E_x and E_y, that is evoked in the system of main planes of single monochromator (one of which coincides with dispersion plane); φ is the total rotation of polarization plane ensured by rotators; a, b — polarizing ability coefficients of monochromator.

Since radiation intensity at S_{in}:

$$I_{in} = E_x E_x^* + E_y E_y^*, \tag{20}$$

then by multiplying matrices (19), we shall obtain for intensity I_{out} at the output S_{in}:

$$I_{out} = I_{in}[(a^4\sin^2\nu + b^4\cos^2\nu)\cos^2\phi + a^2b^2\sin^2\phi +$$
$$+ 2ab(a^2 - b^2)\sin\nu\cos\nu\sin\phi\cos\phi\cos\Delta]. \tag{21}$$

Provided $\phi = 0$, that is, without rotator:

$$I_{out} = I_{in}(a^4\sin^2\nu + b^4\cos^2\nu). \tag{22}$$

For $a \geq b$, there are two extremes: $I_{out}^{\max}$ (at $\nu = 0°$), and $I_{out}^{\min}$ (at $\nu = 90°$). Polarization azimuth at which I_{out} reaches extremal value, is found based on condition:

$$\frac{dI_{out}}{d\nu} = I_{in}[(a^4 - b^4)\cos^2\phi\sin2\nu + \tag{23}$$
$$+ 2ab(a^2 - b^2)\sin\phi\cos\phi\cos\Delta\cos2\nu].$$

By differentiating (23), we obtain:

$$\mathrm{tg}2\nu = \frac{2ab\,\mathrm{tg}\phi\cos\Delta}{a^2 + b^2}. \tag{24}$$

Equation (24) has two solutions:

$$\nu_1 = -\mathrm{arctg}\frac{ab\,\mathrm{tg}\varphi\cos\Delta}{a^2 + b^2)}; \tag{25}$$

$$\nu_2 = \nu_1 + \frac{\pi}{2}.$$

When ν_1 corresponds to the minimum, then:

$$I_{out}^{\max} = I_{in}[(a^4\cos^2\nu_1 + b^4\sin^2\nu_1)\cos^2\phi + \tag{26}$$
$$+ 2a^2b^2\sin^2\phi + (a^4 - b^4)\mathrm{tg}2\nu_1\sin\nu_1\cos\nu_1\cos^2\phi],$$

$$I_{out}^{\min} = I_{in}[(a^4\sin^2\nu_1 + b^4\cos^2\nu_1)\cos^2\phi + \tag{27}$$
$$+ 2a^2b^2\sin^2\phi - (a^4 - b^4)\mathrm{tg}2\nu_1\sin\nu_1\cos\nu_1\cos^2\phi].$$

Then:

$$\Delta I_p = \frac{I_{out}^{\max} - I_{out}^{\min}}{I_{out}^{\max}} = \frac{a^4 - b^4}{\cos2\nu_1}\cos^2\phi\frac{I_{in}}{I_{out}^{\max}} = \tag{28}$$
$$= \frac{2(a^4 - b^4)}{a^4 - b^4 + [a^4 + b^4 + 2a^2b^2\mathrm{tg}^2\phi]\cos2\nu_1}.$$

If $\phi = 90°$, then according to (21) $I_{out} = a^2b^2I_{in}$. That is, if at S_{int} of symmetric double monochromator, the polarization azimuth is rotated by 90°, then spectrometer becomes non-sensitive to polarization of measured radiation, so the output signal would be proportional to the input one. However, rotation of polarization plane by active crystals depends on the wavelength, so rotation by 90° would be strictly realized only for one wavelength. In order to decrease the steepness of polarizing action dependence upon ϕ for double monochromator, two 1/4th-wave phase-shifting plates set symmetrically relative to S_{int} are used (Fig. 2). Next, using (11) and (12), we obtain:

$$\Delta I = (a^4 - b^4)\cos2\nu_1\cos^2\phi(1 + \mathrm{tg}^22\nu_1), \tag{29}$$

where $\Delta I > 0$, when $\cos2\nu_1 > 0$, i.e. at $-\pi/2 \leq 2\nu_1 \leq \pi/2$; and $\Delta I < 0$, when $\cos2\nu_1 < 0$, i.e. at $\pi/2 \leq 2\nu_1 \leq 3\pi/2$. From (10) it is obvious that when $\mathrm{tg}\phi\cos\Delta > 0$, then the angle $2\nu_1$ lies in the second or fourth quarters; and when $\mathrm{tg}\phi\cos\Delta < 0$, the angle $2\nu_1$ lies in the first or third quarters. From the estimates made for rotator of polarization plane and phase-shifting plate made of α-quartz it follows that $-\pi/2 - 10° < \phi\ \pi/2 + 10°$, $-\pi/2 - 10° < \Delta\ \pi/2 + 10°$, and angles ϕ, Δ lie in one quarter. Thus $\mathrm{tg}\phi\cos\Delta > 0$. And when $-\pi/2 < 2\nu_1 < 0$, then $\Delta I > 0$, and $I_2 = I_{max}$, $I_1 = I_{min}$. Expressing I_{out} while using (23) is possible to formulate:

$$I_{out} = a^4[(1-\rho) - \rho(1-\rho)\cos^2\phi + \\ + \rho(2-\rho)\cos^2\phi(1 + \mathrm{tg}\nu_1\mathrm{tg}2\nu_1)\cos^2 \nu u_1], \qquad (30)$$

then

$$\Delta I = a^4\rho(2-\rho)\cos^2\phi(1 + \mathrm{tg}^2 2\nu_1)\cos 2\nu_1. \qquad (31)$$

If we introduce designations

$$A = -\mathrm{tg}2\nu_1 = \frac{2ab\,\mathrm{tg}\phi\cos\Delta}{a^2+b^2} = \\ \frac{2\sqrt{1-\rho}\,\mathrm{tg}\phi\cos\Delta}{2-\rho} \qquad (32)$$

then (28) will look like:

$$I_{out} = \frac{a^4}{2}[2(1-\rho) - \rho(4-3\rho)\cos^2\phi - \\ - \rho(2-\rho)\frac{1-A^2}{\sqrt{1+A^2}}\cos^2\phi], \qquad (33)$$

$$\Delta I = a^4\rho(2-\rho)\sqrt{1+A^2}\cos^2\varphi \qquad (34)$$

and finally

$$P = \frac{2\rho(2-\rho)\sqrt{1+A^2}\cos^2\phi}{2(1-\rho) - \rho(4-3\rho)\cos^2\phi - \rho(2-\rho)\frac{1-A^2}{\sqrt{1+A^2}}\cos^2\phi}. \qquad (35)$$

In order to define polarization capability of double monochromator, it is necessary to know polarization properties of its single monochromators. If those are not taken into the account, error during spectrometric measurements could be as large as 70 %.

Polarizing ability of double monochromator according to (14) will be zero when $\phi = 90°$. The smallest spectral dependence of P from ϕ (at ϕ close to 90°) is noted at $\Delta = 90°$.

The monochromator effect on phase shift is negligibly small ($\Delta \approx 0$), thus, before intermediate aperture and after it, it is necessary to install a phase-shifting plate with $\Delta = 90°$ and rotator of polarization plane with $\Delta = 45°$. In general, $\Delta = 90° + n \cdot 180°$, $\phi = 45° + k \cdot 90°$, where n, $k = 0,1,2...$. However, proceeding from smallest dispersion condition for $\Delta i\phi$ values, the order of (n, k) should be chosen smaller, optimal case is when $n = k = 0$.

Rotators are made of crystalline α-quartz. Review of articles devoted to determining rotation dispersion of α-quartz and dependence of polarization plane rotation by α-quartz on λ is given in [10]. Thickness of rotator is estimated based on the formula:

$$d = \frac{\phi}{2\phi(\lambda)}, \qquad (36)$$

where $\phi(\lambda)$ is dispersion of rotation by α-quartz in direction of optical axis. The most precise approximation of $\phi(\lambda)$ is according to [10]:

$$\phi(\lambda) = \frac{127.02476}{\lambda^2 - (0.09790)^2} - \\ - \frac{119.77145}{\lambda^2 - (0.09575)^2} - 0.1879, \qquad (37)$$

where $[\lambda] = [\mu\mathrm{m}]$. If the polarization plane rotation angle by each rotator is equal to 45°, then $d = 45°/\phi(\alpha)$.

Values of rotation dispersion for α-quartz, thickness of rotator plate and thickness variability of phase-shifting plate ΔS for two marginal and one intermediate ozonometric wavelengths are given in Table 2.

Based on the data from Table 1, it is possible to find d for mean wavelength:

$$d = \frac{45\mathrm{deg}}{80.72\frac{\mathrm{deg}}{\mathrm{mm}}} = 0.557\ \mathrm{mm}. \qquad (38)$$

Phase-shifting components are designed for shifting phase front of the wave and for alteration of polarization condition. For transformation of linear polarization into circular and vice versa, a phase plate of "1/4th of wave" is used to delay the phase front. For phase shift $\Delta = 90°$, 1/4th-wave plates made of one-axis mica, selenite, gypsum, or quartz crystals with the surfaces cut in parallel to the crystal optical axis [11] are used. In UV range for phase-shifting plates α-quartz is the most suitable.

Due to double refraction in the plate, there are transmitted two beams with orthogonal polarization and with different speeds — regular and irregular beams. Between them, at the output from the plate, a phase shift occurs dependent on orientation of radiation polarization plane at the input relative to crystallographic axes of active crystal. At normal incidence, radiation is polarized at 45° to the fast axis, phase lag in the plate with thickness of d_{fp} equals:

$$\Delta = (n_e - n_o)d_{fp}\frac{2\pi}{\lambda}, \tag{39}$$

where n_e, n_o — refraction indices of extra ordinary and ordinary beams, respectively. Thickness of plate "one-fourth of wave" of the first order from crystaline quartz equals:

$$d_{fp} = \frac{\lambda_{cp}}{4(n_e - n_o)} = \tag{40}$$

$$= \frac{0.3125}{4 \cdot 0.010035} = 8.097 \text{ mkm.}$$

Value of double refraction beam for crystalline quartz ($\mu = n_e - n_o$), i.e. the difference between refraction indices for extra ordinary and ordinary beams depending on the wavelengths and specifically for 312.5 nm are presented in [8]. Thickness of the plate "one-quarter wave" is few micrometers, so modern technology does not allow yet manufacturing such thin crystal plates. That is why two plates are made with their thickness being close to 1 mm with mutually perpendicular optical axes lying in the plate plane. Their thickness variability equals 8.097 μm, then the total phase shift according to (39) and (40) equals:

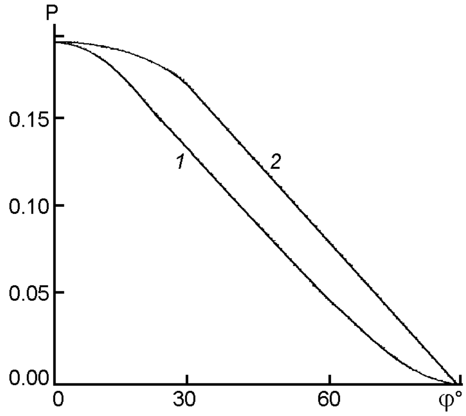

Fig. 2. Dependences of polarizing effect of double monochromator for different rotation angles of polarization plane on S_{int} with phase-shifting plate (*1*, $\Delta = 90°$) and without it (*2*, $\Delta = 0°$), if for each single monochromator $\rho = 0.1$.

$$\Delta = (n_e - n_0)(d_1 - d_2)\frac{2\pi}{\lambda}, \tag{41}$$

where d_1, d_2 — thickness of the crystal plates comprising phase-shifting plate.

For compensator designed for operation in several spectral ranges (segments), maximum distance from the plane of intermediate apertures l_{max} should not exceed the distance to divergence points (split-up) of "light" beams on the margins of spectral segments correspondent to different intermediate apertures. To provide such require-

Table 2

λ, nm	$\phi(\lambda)$	d, mm	ΔS, μm	$n_o - n_e$
255.5	146.86	0.3082	5.765	$1.108 \cdot 10^{-2}$
312.5	88.74	0.5081	7.697	$1.015 \cdot 10^{-2}$
339.8	72.74	0.6186	8.564	$0.992 \cdot 10^{-2}$

Table 3

l_{max}, mm	No.	ϕ_0, °											
		λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_9	λ_{10}	λ_{11}	λ_{12}
> 14	1	121.36	101.88	93.64	90.00	86.56	82.85	79.96	77.53	73.62	70.89	64.19	60.47
≤ 14	2	90.00	114.68	105.40	101.30	97.43	93.26	90.00	87.27	82.87	79.80	72.25	68.06
≤ 11	3	90.00	105.92	97.36	93.57	90.00	86.14	83.14	80.61	76.54	73.70	90.00	84.80
≤ 7	4	90.00	90.00	101.71	97.75	94.02	90.00	86.85	84.85	79.96	77.00	90.00	84.80
≤ 6	5	90.00	90.00	101.71	97.75	94.02	90.00	86.85	84.84	79.96	77.00	90.00	90.00
≤ 5	6	90.00	90.00	97.36	93.57	90.00	86.14	83.14	80.61	90.00	86.67	90.00	90.00

ment, several options of arrangement are possible. In Table 3 the rotation angles ϕ of polarization plane by two rotators for different wavelength numbers at spectral intervals for which the compensator plate was estimated are presented. The compensator own thickness is also included to l_{max} (~ 2.5 mm). If depolarizing compensator is manufactured for each ozonometric length separately, then there is no need to use phase-shifting plate.

Thus, a scheme with subtraction of dispersion allows to unite focal planes of the first and the second single monochromators of double monochromator, making it possible to use intermediate mask of apertures with their one-by- one opening to perform discrete spectrum scanning without linear relocation of the monochromator optic elements. Employment of spherical diffraction gratings as dispersing elements provides focusing of spectral lines on the apertures.

References

1. V.Vashchenko, Zh.Patlashenko, A.Loza, *Proc. SPIE*, **3237**, 31 (1996).
2. V.Vashchenko, A.Loza, E.Chernysh, Zh.Patlashenko, *Bull. Ukr. Antarctic Center*, **4**, 177 (2002).
3. A.R.Zaidel, G.V.Ostrovskaya, Yu.I.Ostrovsky, Spectroscopy Techniques and Practice, Nauka, Moscow (1972) [in Russian].
4. F.M.Gerasimov, E.A.Yakovlev, in: Modern Trends in Spectroscopy Techniques, Nauka, Novosibirsk (1982) p.76–82 [in Russian].
5. V.N.Vashchenko, A.V.Pedorenko, A.I. Loza, Authors‘ Cert. No.249877.
6. G.V.Rozenberg, M.S.Malkevich, V.S.Malkova et al., *Izv. AN SSSR, Ser. FAO*, **10**, 14 (1974).
7. V.I.Malyshev, Introduction to Experimental Spectroscopy, Moscow (1979) [in Russian].
8. A.V.Bruns, *Izv. Krym. Astrofiz. Observat.*, **69**, 139 (1984).
9. R.C.Jones, *J. Opt. Soc. Am.*, **31**, 488 (1941).
10. V.A.Kizel, V.I.Burkov, Gyrotropy of Crystals, Nauka, Moscow (1980) [in Russian].
11. Handbook of Designer of Optical-Mechanical Instruments, Mashinostroenie (1968) [in Russian].

Вибір методу обчислення аберації та результати оцінки аберації і характеристик компенсації ефекту поляризації подвійних УФ-монохроматорів для УФ-озонометрів, що встановлюються на супутниках

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Наведені результати обчислення оптико-механічних характеристик схеми подвійного дифракційного монохроматора з відніманням дисперсії, на базі сферичних дифракційних граток для дистанційного зондування озоносфери Землі з космічних платформ в спектральному діапазоні 255.5–339.8 nm з метою глобального картографування вертикальних профілів концентрації та загального вмісту озону. При цьому були враховані спеціальні вимоги до обладнання, що встановлюється на космічних орбітальних платформах. Подвійний дифракційний монохроматор, як і призмовий монохроматор, має власний поляризаційний вплив на випромінювання, що вимірюється. Нехтування монохроматора на спектрометричні вимірювання може привести до того, що помилка може досягнути 70 %. Експериментальні результати вказують, що залежність спектральної чутливості на поляризацію випромінювання, що вимірюється, визначається системою дисперсійних елементів і значенням вхідної апертури. Для вимірювання використовувалось джерело повністю деполяризованного випромінювання. Для зменшення ефекту поляризації УФ-спектрометра розроблені спеціальні деполяризатори та компенсатори ефекту поляризації. Проведено порівняння результатів вимірювання з використанням і без використання таких приладів для визначення їх робочої ефективності. Вимірювання було виконане для всіх довжин хвиль робочого спектрального діапазону спектрометра.