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The Ebert vertical mounting spectrograph as high resolution scanning monochromator *

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The application of the Ebert vertical spectrograph as the high resolution scanning monochromator is discussed in detail. A simple method of the line tilt compensation is presented. The control electronics and mechanical control devices suitable for all Ebert vertical spectrographs are described.

1. Introduction

The Ebert optical system of spectrograph, described in 1889 and reviewed by FASTIE [1] in 1952, is used extensively because of its simplicity in design. In this system a large spherical mirror is used as collimator as well as camera lens. The light from the entrance slit is collimated by one half of the spherical concave mirror, it illuminates a plane reflection diffraction grating, diffracted light is then imaged in the focal plane of this mirror (where the photographic plate or exit slit is placed) by its second part. Such a system is named a horizontal one if the entrace slit, photographic plate (or exit slit), center of spherical concave mirror and diffraction grating are arranged in one horizontal plane. In this mounting the axis of the diffraction grating rotation is perpendicular to the horizontal plane. All the advantages and disadvantages of the horizontal Ebert mounting of spectrographs and monochromators were discussed in many papers [2]–[11].

JARRELL [12] described a modified Ebert mounting of the spectrograph, which can be named a vertical one. In this optical system (see Fig. 1) the entrance slit is below (or above) the diffraction grating. The photographic plate is above (or below) the grating. The small plane mirror is used to change the direction of the incoming light which makes the mechanical system simpler. In the vertical Ebert system the small plane mirror, the center of the spherical concave mirror, the center of the photographic plate and the axis of the diffraction grating rotation are arranged in a vertical plane. The large spherical concave mirror has two active reflection areas. The one area acts as collimator and forms a collimated light beam having a rectangular transverse section, the second part is wider and acts as camera lens. JARREL [12] noticed that when diffraction grating is rotated the spectral lines on the photographic plate tilt appreciably from the normal. An

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approximate expression describing this effect, valid for small elevation angles, has been published by GIL and SIMON [13].

In an earlier paper [14], the exact theory of this phenomenon and its comparison with experimental results obtained for the C. Zeiss–Jena PGS–2 spectrograph has been presented, and a simple method for compensation of the line tilt has been proposed.

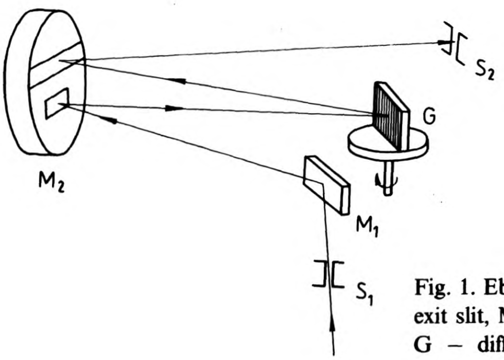

Fig. 1. Ebert vertical optical system, S_1 – entrance slit, S_2 – exit slit, M_1 – plane mirror, M_2 – spherical concave mirror, G – diffraction grating

In the present paper we present the application of the Ebert vertical mounting spectrograph as a high resolution scanning monochromator. This paper also contains a detailed discussion of a method of compensation of the line tilt.

2. General remarks

The Ebert vertical mounting spectrographs can be used as a high resolution scanning monochromators, if the line tilt is compensated. In a previous paper [14] we have shown that the angle of the line tilt away from the normal is given by the formula

$$\vartheta = \cos^{-1}\left[\frac{\chi}{[(1-\chi^2)\sin^2 2\alpha+\chi^2]^{1/2}}\right] \tag{1}$$

where

$$\chi = \cos\gamma\cos[\tan^{-1}(\sin\gamma\tan\alpha)], \tag{2}$$

γ – angle of diffraction grating setting, α – angle of elevation of light beam. As was noted in paper [14] this effect can be eliminated if the entrance or exit slit are tilted. Obviously, the angle of the tilt of a slit is equal to ϑ.

Figure 2 presents the plots of the mercury 435.8 nm line registered using a PGS–2 spectrograph with 1302 grooves/mm diffraction grating, for different settings of the entrance slit. The line was registered on the line recorder during the fast scanning of the spectra, so the hyperfine structure is not detected. The reduction of the signal in the peak and broadening of the line caused by the line

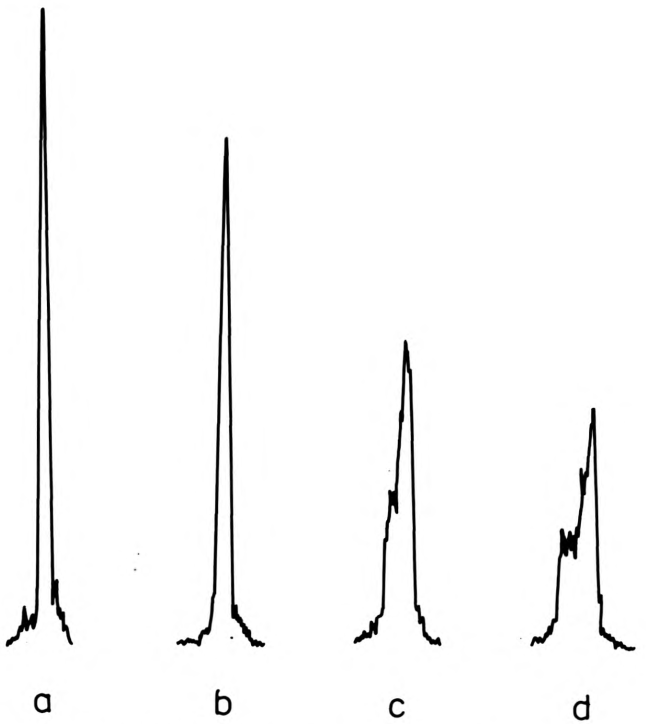

Fig. 2. The 435.8 nm mercury line registered for different settings of the entrance slit at fast scanning. **a** – the slit tilt is fixed accordingly to the relation plotted in Fig. 3, **b–d** – the slit is rotated from the former position for an angle 0.06°, 0.12°, 0.24°, respectively

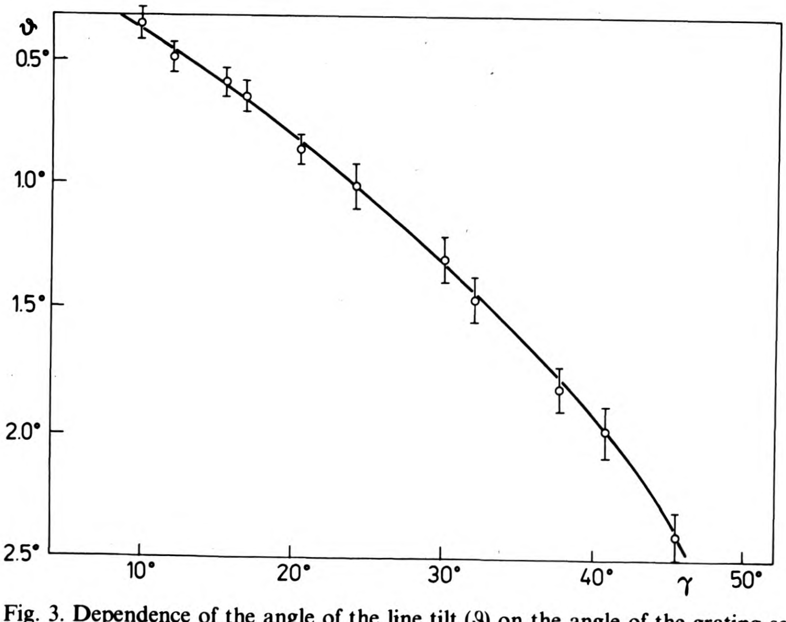

Fig. 3. Dependence of the angle of the line tilt (ϑ) on the angle of the grating setting (γ), for the PGS–2 spectrograph (elevation angle $\alpha = 1.15°$ calculated from Eq. (1))

tilt effect is significant. Figure 3 shows the dependence of the angle of the line tilt ϑ on the diffraction grating setting angle γ, calculated from Eq. (1) and measured values of angle ϑ. These results were obtained for the PGS–2 spectrograph in which the elevation angle $\alpha = 1.15°$. As can be seen from Figs. 2 and 3 the neglection of the line effect makes it impossible in practice to apply a spectrograph of this type as a high resolution scanning monochromator.

3. Compensation of the line tilt

These difficulties may be overcome and the Ebert vertical spectrograph may be used as high resolution scanning monochromator if there is a possibility of tilting the entrance (or exit) slit accordingly to the diffraction grating rotation. Setting the

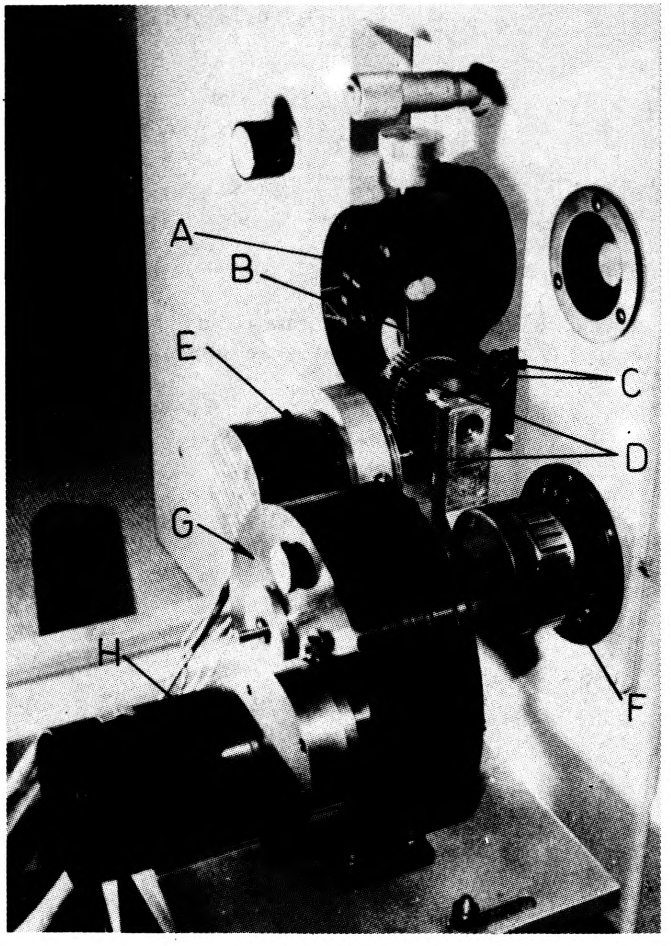

Fig. 4. Mechanical control devices applied in the spectrometer described in this paper. A – entrance slit, B – micrometer screw, C – 1:1 gear, D – 1:50 clearanceless worm-gear, E – slit tilt stepping motor, F – knob of grating rotation, G – grating setting gear-box, H – grating setting stepping motor

internal mechanical system in a commercial spectrograph is practically impossible because, as can be seen from Fig. 3, it should assure nonlinear correction. It is easy, however, to make an additional external correction system. In high resolution scanning monochromators scanning of the spectral region is usually achieved by electronically controlled rotation of the dispersion element. It is very convenient to use the stepping motor controlled by the special electronics. It enables steplike or continuous registration of the spectra. Our method of compensation consists in the synchronization of the diffraction grating rotation and slit tilt. It can be done mechanically (using a very complicated gear-box) or electrically. We chose the second way as a simpler one. The proposed system of correction was applied to the spectrometer (using the PGS–2 spectrograph as scanning monochromator) described in an earlier paper [15]. The propulsion of the diffraction grating is obtained from the EDS–11 stepping motor. One step of this motor corresponding to 5° turn is reduced by the special gear-box and cause the rotation of the diffraction grating equal to 1/15000°. The tilt of the slit has been achieved by the rotation of the slit using the next stepping motor and a control electronics (Fig. 4). The correction of the line tilt may be achieved by the rotation either of the entrance slit or the exit slit. The choice between these two slits depends on convenience of application and simplicity of the correction system. In the case of the PGS–2 spectrograph it is more convenient to rotate the entrance slit because this spectrograpgh is equipped with a screw which enables tilting of the entrance slit. In the present work, we used a special clearanceless worm-gear to rotate this screw. It permits a very precise correction because one step of the motor rotates the entrance slit for an angle equal to 0.0003°. As can be seen from Fig. 3 the relation between the angle of the line tilt and the angle of the diffraction grating setting is not linear. We can approximate the curve by the broken line and carry on the linear compensation on every intercept. From Fig. 3 we can determine the

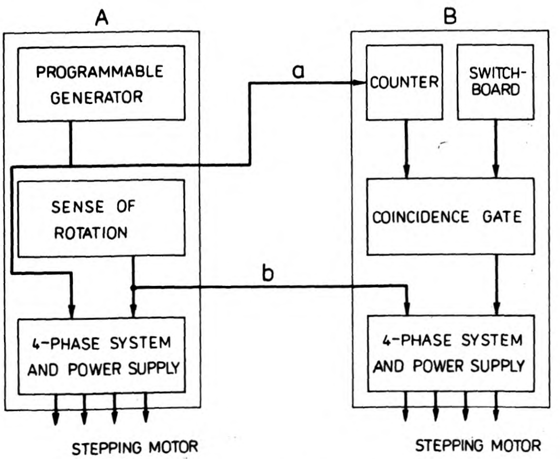

Fig. 5. Block scheme of the diffraction grating control electronics (unit A), the slit tilt controller (unit B) and the external links between them. Details in the text

required change of the slit tilt as a function of changes of the diffraction grating setting. The rate of the changes of the slit tilt increases with the growth of the angle of the diffraction grating setting. The gears are selected to obtain one step of the slit tilt correction for from 133 to 46 steps of the grating motor (accordingly

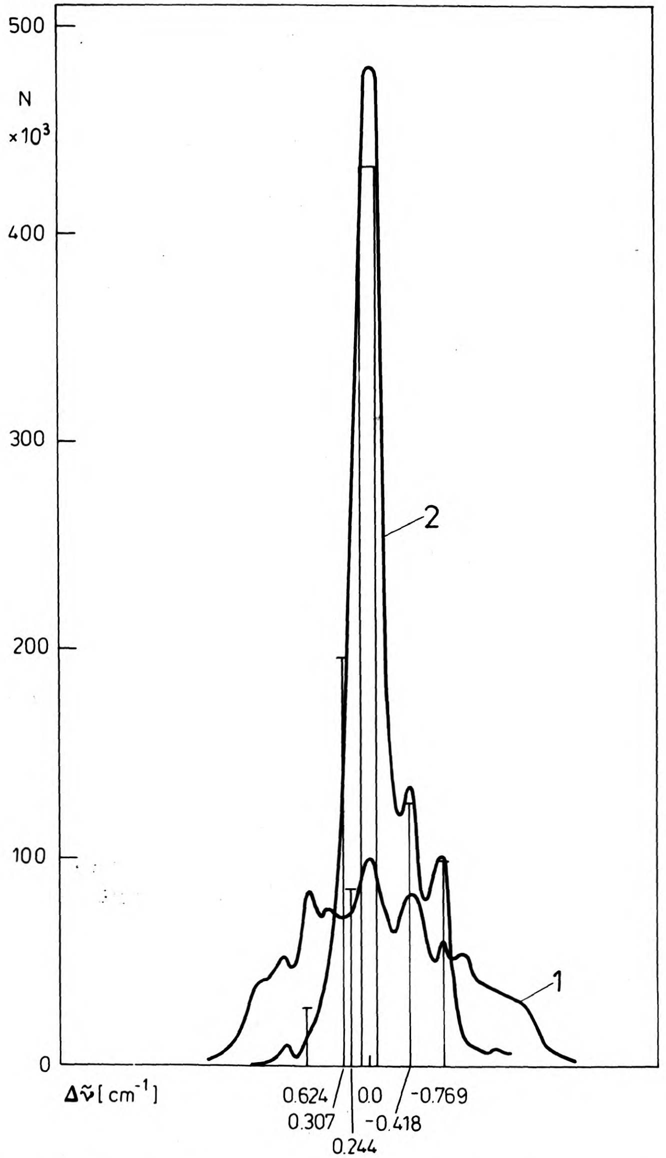

Fig. 6. Records of the 404.66 nm mercury line in the first diffraction order. N – measured number of counts. Vertical lines show positions and theoretical intensities of all line components. Rectangles show position and intensities of all even isotopes. Record 1 shows the line shape when the correction of the line tilt is neglected and both slits are fixed vertically. Record 2 shows the line registered with the use of the corrector. The entrance slit was rotated from the vertical position for an angle of 0.6°

to the spectral region). The correction takes place every 0.01° (for γ close to zero) to 0.003° (for $\gamma = 50°$) of the grating rotation, so it may be considered as very precise and practically continuous. The occurrence of the corrections (i.e., the number of steps of the grating motor between the following steps of the slit motor) is preset on the switchboard of the slit tilt controller. When the investigated

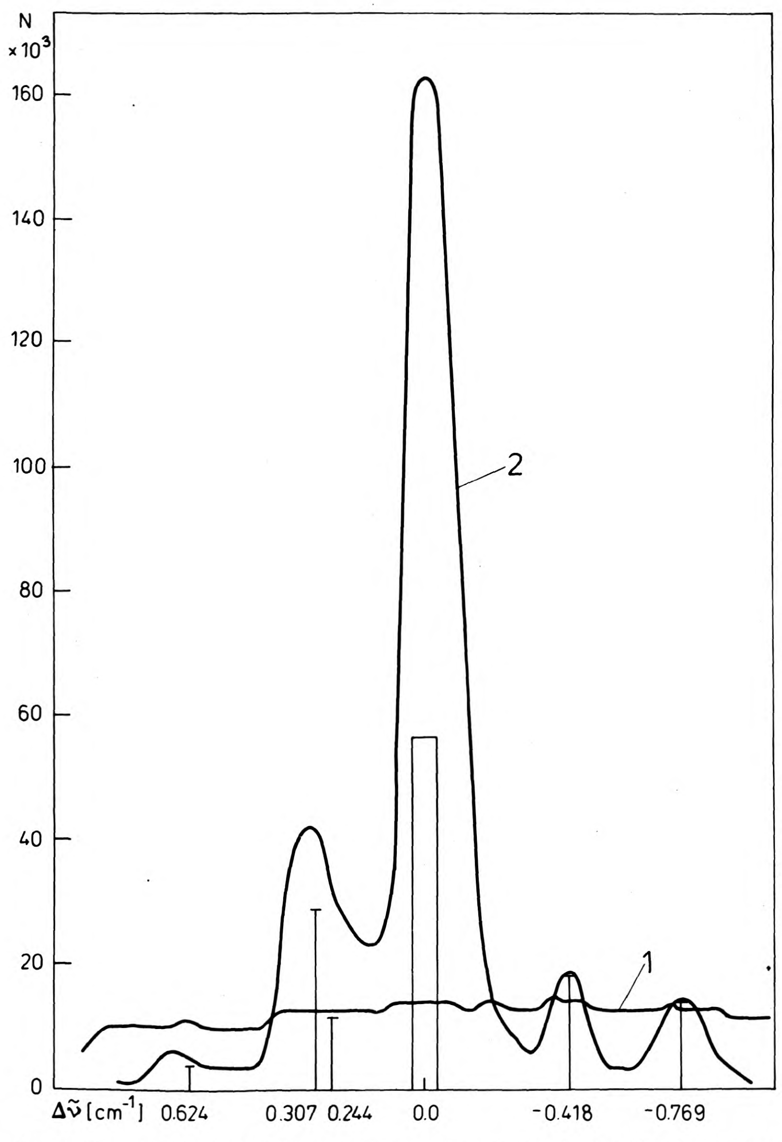

Fig. 7. Records of the 404.66 nm mercury line in the third diffraction order. Record 1 shows the line shape when the correction is neglected and both slits are fixed vertically. As can be seen the line and its structure is practically invisible. Record 2 shows the line registered with the use of a corrector. The entrance slit was rotated from the vertical position to an angle 3°

spectral range covers a few regions approximated by different intercepts of the broken line we change the preset value during passing of the terminal point of every intercept.

Cooperation of the diffraction grating control electronics (unit A) with the slit tilt controller (unit B) is shown in Fig. 5. Block A contains the programmable generator, which enables two modes of operation: continuous scanning of the spectra, or steplike with the stop of the motor after a present number of steps. Pulses from the programmable generator are detected by the 4-phase system. It changes the voltage states of the power supply which causes the movement of the grating motor in the preset direction (towards short or long waves). Unit B has two external links with the A one. Link "a" provides a signal from the programmable generator. Pulses are counted by the counter and its indication is compared with the value preset on the switchboard. Coincidence of indications causes one step of the slit stepping motor, clears the counter and initiates the following cycle of counting. Link "b" determines the sense of the slit tilting accordingly to the sense of the diffraction grating rotation. Unit B also contains a 4-phase system and power supply for the slit tilt stepping motor.

4. Performance test

To test the overall performance of this effect we have recorded a number of spectra. Figures 5 and 6 show the 404.66 nm mercury line recorded in the first and the third order of diffraction. Each figure shows the shape of the line with and without the correction of the line tilt effect. As can be seen from Figs. 5 and 6, compensation of the line tilt is necesssary if the Ebert vertical mounting spectrograph is to be used as high resolution scanning monochromator in wide spectral range. The simple method of compensation presented in this paper is good enough in order to assure high accuracy investigation of the spectra.

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Спектрограф Эберта, построенный в вертикальной установке как монохроматор высокой разрешающей силы

Точно описано применение спектрографа Эберта построенного в вертикальной установке как монохроматора высокой разрешающей силы. Представлен простой метод компенсации наклона спектральной линии. Описана электроническая и механическая контрольная система соответствующая всем спектрографам построенным в вертикальной установке Эберта.