OPTICAL SCHEME OF SMALL-SIZE CURVED DETECTOR SPECTROFLUOROMETER

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ABSTRACT

We present two versions of a compact spectrograph optical scheme based on aberration-corrected concave holographic grating. It is shown that performance of a widely-known flat-field spectrograph scheme can be significantly improved by means of use of a curved detector and introduction of an additional condition of coma correction.The spectrograph provides spectral resolution up to 0.23 nm over an extended working range of 250-900 nm and can be used for fluorescence analysis of waste water.

Index Terms - Spectrofluorimeter, concave holographic grating, curved detector.

1. INTRODUCTION

Waste water storage, water storage, tailings storage, sludge storage, storage reservoir (sludge collectors), slurry dump, landfill, dumps, and other storage of industrial wastes are the main of hydraulic engineering structures operated by industrial enterprises. In order to prevent emergency situations of technogenic type by damage to components of the environment an environmental risk management should be implemented. Traditionally fluorescence methods of spectral analysis are used for monitoring of the hydraulic engineering structures. In the present paper we consider optical design options for a compact spectrofluorimeter intended for tasks like waste water control.

2. SPECTROGRAPH WITH CURVED DETECTOR

We propose optical scheme for small-size spectral devices having technical characteristics that are optimal for monitoring [1]. The spectral range of the spectrofluorometer is 250 ... 900 nm. We chose an optical scheme of a flat-field spectrograph as the basic scheme. Fig.1 shows a schematic of the flat-field spectrograph optical scheme.

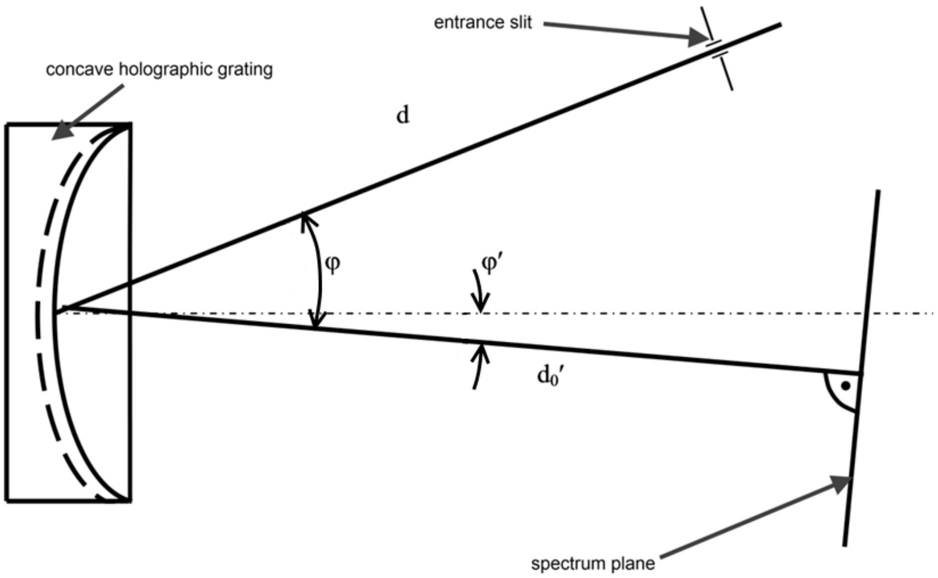

Figure 1. Flat-field spectrograph basic scheme

The spectrograph specifications are as follows: grating curvature radius of 100 mm, its' ruled surface diameter of 30 mm, spectrum length of 28 mm. The incidence angle φ = -2° allows to place the entrance slit and detector assemblies without introduction of additional mirrors. Two options are considered:

- optical scheme having approximately the same distances from the entrance slit to the grating apex and from the grating apex to the spectrum registration plane;
- optical scheme with correction of meridional coma for wavelengths 412.5 nm 737.5 nm.

For the first option using the flat-field spectrograph design technique [2] we obtained the following parameters: the distance from the entrance slit to the of the diffraction grating apex d = 100.9mm; the distance from grating apex to detector plane d'_0 =101mm; parameters of grating recording, i. e., distances from the recording sources to the grating apex d_1 and d_2 and angles of incidence of beams i_1 and i_2 from the recording sources onto the grating apex are as follows: d_1= 212.48мм, d_2 =156.18мм, i_1 = 52.1535° and i_2 = 37.4885° for the recording wavelength of 441.6 nm. The recording parameters were determined from the expressions for the hologram coefficients H_1, H_2, and H_3. The value of H_1 was found from the condition for minimizing the defocusing in the plane, the values of H_2 and H_3 corresponded to zero in the center of the spectral range of astigmatism and meridional coma, respectively. The need for a flat recording surface was dictated by the flat surface of multi-channel detectors. However, in recent years, curved detectors developed and successfully used [3, 4]. We have studied the aberration characteristics of the spectrograph with a cylindrical recording surface. The aberrations of the spectrograph on a cylindrical surface radius 55 mm are given in Table 1.

Table 1. Aberrations of the spectrograph (units are mm)

y	z	λ_{av}=575 nm y'=0 mm		λ_1=250 nm y'=-13.69 mm		λ_2=900 nm y'=14.23 mm	
		$\Delta y'$	$\Delta z'$	$\Delta y'$	$\Delta z'$	$\Delta y'$	$\Delta z'$
15	0	-0.005	0	0.025	0	-0.068	0
7	0	0	0	0.010	0	-0.019	0
-7	0	0	0	-0.004	0	-0.002	0
-15	0	0.003	0	-0.001	0	-0.028	0
0	7	-0.001	0	0	-0.076	-0.005	-0.332
0	15	-0.003	-0.001	0	-0.164	-0.024	-0.709

It can be seen from the table that the aberrations at the edges of the band significantly exceed the aberrations in the center of the field. The spectrograph instrument functions are presented on fig.2. The solid line corresponds to the width of the input slit 0.025 mm, the dashed line corresponds to the width of the input slit 0.01mm. The resolution limit was 0.01mm for the average wavelength, however, at the long-wavelength edge of the spectral range, a resolution drop is observed.

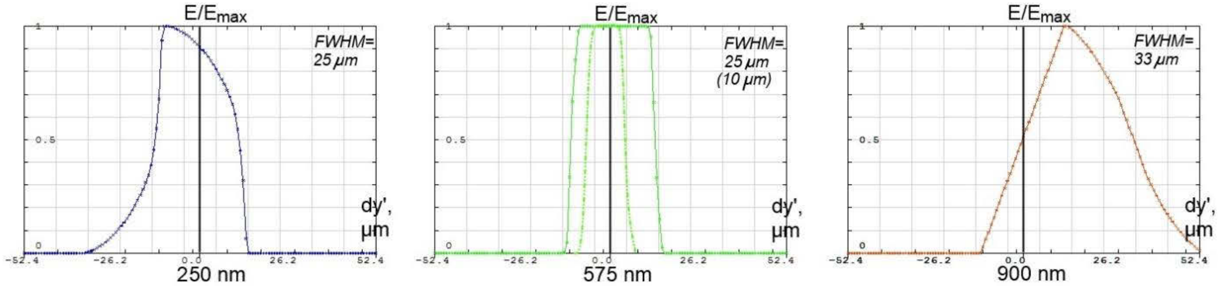

Figure 2 Instrument functions of the spectrograph

The spot diagrams are shown on fig. 3.

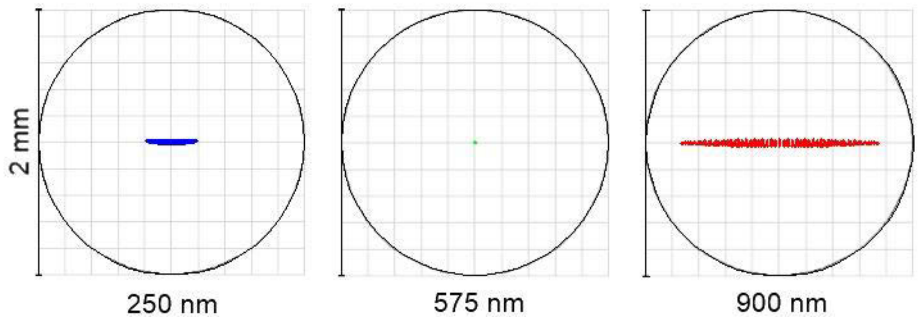

Figure 3. Spot diagrams of the spectrograph

3. SPECTROGRAPH WITH CORRECTED COMA

It is known that aberrations can be significantly improved by using a setup in which a meridional coma is corrected for wavelengths $\lambda_{av} \pm \frac{\lambda_1 - \lambda_2}{4}$. We redesigned the optical scheme using the same initial data and applying the coma correction condition. This spectrograph specifications are as follows: grating curvature radius of 100 mm, its' ruled surface diameter of 30 mm, spectrum length of 28 mm, the grooves frequency of the grating 370 1/mm, φ= - 2°, d = 91mm, d'_0 =112.9mm, cylindrical surface radius is 64mm. Parameters of grating recording are as follows:

d_1= 254.86мм, d_2 =217.31мм, i_1 = 33.2396°, i_2 = 22.9329° for the recording wavelength of 441.6 nm.

The spectrograph aberrations are given in Table 2.

Table 2. Aberrations of the spectrograph with corrected coma (units are mm).

y	*z*	250nm *y'*=-13.72 mm		412.5nm *y'*=-6.94 mm		575nm *y'*=0 mm		737.5nm *y'*=7.05 mm		900nm *y'*=14.16 mm	
		Δ*y'*	Δ*z'*	Δ*y'*	Δ*z'*	Δ*y'*	Δ*z'*	Δ*y'*	Δ*z'*	Δ*y'*	Δ*z'*
15	0	-0.009	0	-0.003	0	-0.002	0	-0.004	0	-0.010	0
7	0	-0.001	0	0	0	0	0	-0.001	0	-0.002	0
-7	0	-0.002	0	0	0	0.001	0	0.001	0	-0.002	0
-15	0	-0.004	0	0.003	0	0.007	0	0.005	0	-0.004	0
0	7	-0.001	-0.099	-0.001	-0.113	0	-0.077	0	0.011	-0.001	0.154
0	15	-0.006	-0.215	-0.003	-.247	-0.001	-0.171	0	0.017	0.003	0.321

The spectrograph instrument functions are presented on fig.4. Just as in Fig. 2, the solid line corresponds to the width of the entrance slit of 0.025 mm, the dashed line corresponds to the width of the entrance slit of 0.01mm. The spot diagrams are shown on fig. 5. When calculating the parameters of grating recording, the value of H_2 corresponding to the astigmatism correction at 737.5 nm was used, which provided more symmetrical values of astigmatism throughout the working spectral range.

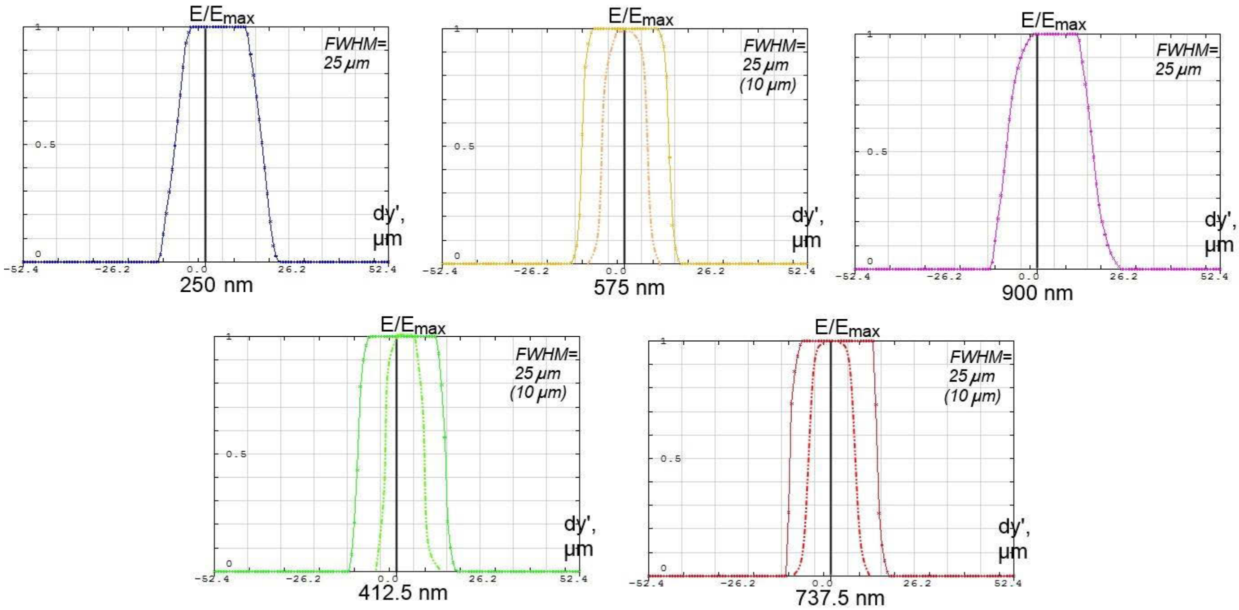

Figure 4 Instrument functions of the spectrograph

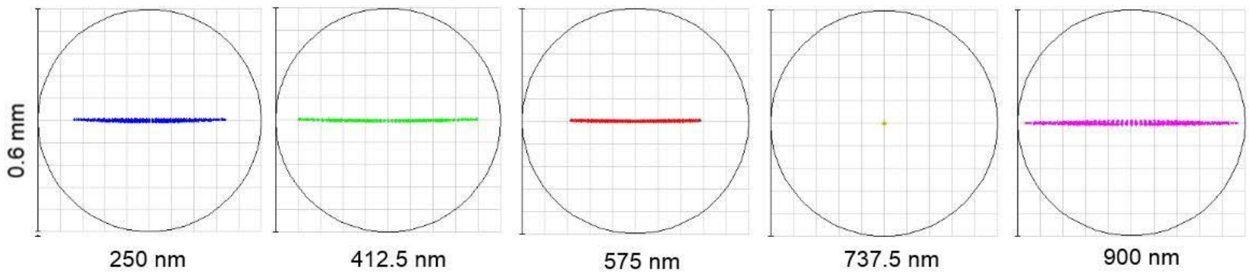

Figure 5. Spot diagrams of the spectrograph

It can be seen from the table 2 aberrations significantly decreased. Consequently, it is possible to create instruments with a high aperture. The spectrograph instrument functions for the relative aperture 1:2 (ruled surface diameter of 50 mm) is shown in Fig. 6.

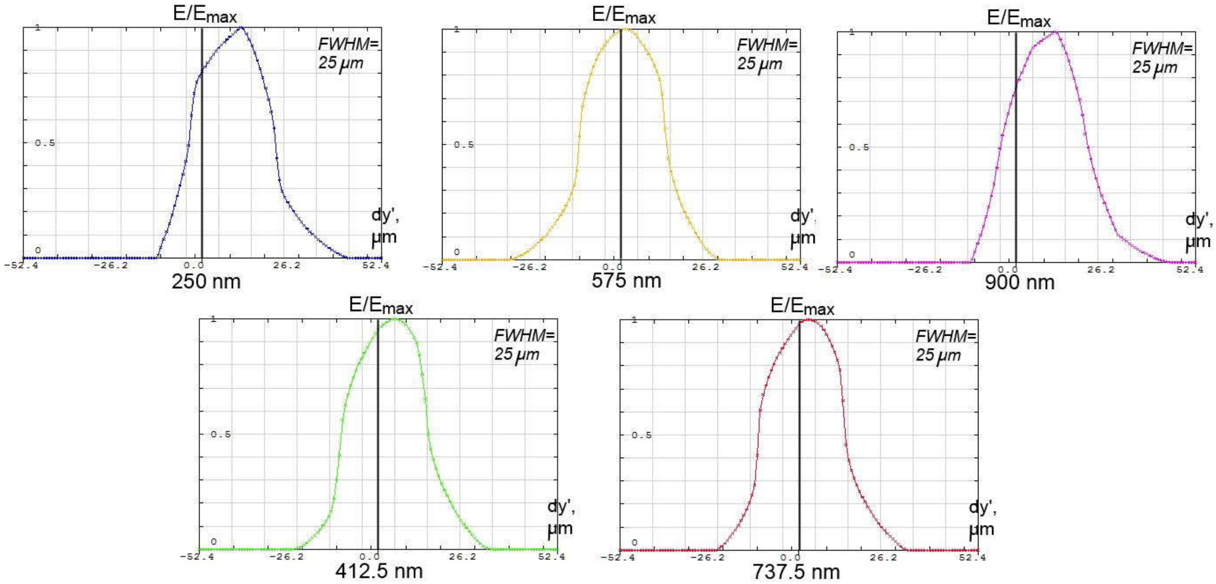

Figure 6 Instrument functions of a high-aperture spectrograph

4. CONCLUSION

The computation results clearly show that combination of a holographic diffraction grating and a curved detector allows to obtain a drastic improvement of spectral resolution with medium-to-high apertures. Thus it becomes possible to build a compact spectrograph with enhanced sensitivity in a broad spectral range from 250 to 900nm, which can be of high interest for fluorescence analysis of water samples.

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