Experimental research on measuring image energy in the spectrum imaging system

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ABSTRACT
We reported the previous research of spectrum imaging with a double-grating imaging system in 2001. In this paper, we will investigate the energy of the image obtained using the same imaging method. A mercury-vapor lamp was used as the light source to measure the light energy of the image at different positions for four grating combinations. The experimental results were analyzed systematically. The factors affecting the brightness of the image were also discussed in this paper.

Keywords: convergent spectrum, converged images, spectrum imaging

1. INTRODUCTION
Grating is such an important optical element that it has been investigated extensively and intensively for long. Our reported results provided new insights into the properties of grating, that is the object spectrum diffracted by the first grating can be converged by the second grating to form images of the original object \[1\]. The method for imaging by grating spectrum differs from those reported in the literature \[2, 3, 4\]. In this paper, we focus on the in energy study for the image obtained by our spectrum imaging method.

The light from the object will form object spectrum after being diffracted by a grating \( G_1 \) with higher spatial frequency. After close observation, we found that images of the original object can be observed at different positions when the object spectra converged by a grating \( G_2 \) with lower spatial frequency. The converged images observed at these positions correspond to the first, second, ..., and nth order diffraction spectrum of grating \( G_2 \). We also found that the converged images obtained at the positions far from the object spectrum correspond to lower diffraction orders while the images at positions near the object spectrum correspond to higher diffraction orders. The energy of the observed converged image does not correlate with its distance from the object spectrum. Therefore, the energy of the converged image cannot be determined simply by the distance between the converged image and the object spectrum.

In this paper, based on the experimental measurements, we will investigate the energy of the converged image and try to find the relationship between the converged image and the diffracting order and the positions.

2. EXPERIMENTAL PROCEDURE
The optical path of the spectrum imaging and measuring by using two gratings can be described schematically as follow. In Fig. 1, S, S' (formed after S being diffracted by \( G_1 \)), L, D are mercury lamp (light source), virtual light source, lens,
and detector, respectively. G₁ and G₂ are two gratings with different spatial frequencies. In this optical path, G₁ is used to diffract the object waves to form the object spectra, while G₂ is used to converge the object spectra from G₁ to form reductive object waves so that images of the original object can be observed behind G₂ by naked eyes.

The converged image observed by naked eyes is a virtual image, i.e., its energy cannot be detected directly by a detector. In fact, the converged image is formed through converging the monochromatic light beams by the converging grating. Therefore, the energy of the converged image can be determined by measuring the energy of monochromatic light which contributes to the converged image. If the converged image is formed by using many separate monochromatic light sources as object spectra, at least three light sources are needed. However, monochromatic light sources are difficult to be used directly for the following reasons, 1) it can hardly be realized to put the monochromatic light sources at the exact positions so that the object spectrum from these light sources form images at the same position; 2) though the converged image can be observed clearly by naked eyes, the energy of the converged image is fairly low and the photocurrent detected by detector for some diffraction order could be as low as the magnitude of 10⁻⁸~10⁻⁹ A. However, an ordinary optoelectronic detector has no sensitivity like this. The monochromatic light sources used to form converged image must possess enough energy so as to be detected by the detector for all the diffraction orders, but it is also difficult to obtain monochromatic light sources which have high and same intensities. For this reason, we use mercury lamp with slit as the object. Our proposed optical path is shown in Fig. 1, the light rays from the mercury lamp form object spectra after being diffracted by grating G₁. Converged image can be formed if put the grating G₂ at a proper position inside the object spectrum. Thus, the energy of the converged image can be measured. Three wavelengths, 453.8 nm (purple), 546.1 nm (green), and 578.0 nm (yellow) were used as monochromatic light sources whose energy are the highest and nearly the same. In the experiment, their energy were measured behind G₂ for the corresponding diffraction order.

First of all, fix the position of G₁ and observe the converged image behind G₂ by naked eyes, then move G₂ so that the brightest image can be obtained. Put a 8 mm slit just in front of G₂ and 5 mm slit in front of G₁ and adjust the relative position so that only one of the three colors purple, green, and yellow can reach the slit in front of G₂ (the slit of G₂ permits only the light ray falling on it to pass). After measuring the energy of the three light beams passing through G₂ respectively, the energy of the different diffraction order can be determined. Move G₂ to another position of the converged imaging and repeat the above measurements.
In actual measurement, a photocell was used as the detector to measure the energy of the light beam corresponding the diffracting order of the converged image. The light beams from the mercury lamp were diffracted by \( G_1 \) and then converged by \( G_2 \) to form an image, so the photocurrent excited by some diffracting order is as low as the magnitude of \( 10^{-8} \sim 10^{-9} \) A order after the two times of diffracting process. Because the sensitivity of an ordinary photocell detector is not so high to be used to measure accurately the energy of the corresponding diffracting order, we improve the detecting part to satisfy the measurement needs. The purpose of the measurement is to compare the relative energy of the converged images with different diffracting order, not to measure the absolute intensity of the spectrum energy. Thus, the relative energy of the converged images of different diffracting orders can be compared even if the sensitivity of the photocell is not the same for the colors with different wavelength.

3. RESULTS

The purpose of this study is to investigate the correlations of the energy of converged image with the factors such as corresponding diffraction order, position of the converged image. In order to compare the energy effectively, the data are illustrated in such a way that every curve represents for the energy variation with the monochromatic light wavelength (three colors, purple, 453.8nm; green, 546.1nm; yellow, 578.0nm) for a diffraction order.

Figure 2 shows the spectrum energy for the grating combination of 1000L/mm---100L/mm, curve a corresponds to the second order image when the spacing between \( G_2 \) and \( G_1 \) is 40.5cm, curve b corresponds to the third order image when the spacing between \( G_2 \) and \( G_1 \) is 29.1cm. Figure 3 shows the spectrum power for the grating combination of 1000L/mm---300L/mm, curve a corresponds to the first order image when the spacing between \( G_2 \) and \( G_1 \) is 43.8cm, curve b corresponds to the second order image when the spacing between \( G_2 \) and \( G_1 \) is 9.0cm. Figure 4 shows the spectrum energy for the grating combination of 1000L/mm---136L/mm, curve a corresponds to the first order image when the spacing between \( G_2 \) and \( G_1 \) is 54.6cm, curve b corresponds to the second order image when the spacing between \( G_2 \) and \( G_1 \) is 22.5cm, curve c corresponds to the third order image when the spacing between \( G_2 \) and \( G_1 \) is 18.5cm. Figure 5 shows the spectrum power for the grating combination of 600L/mm---100L/mm, curve a corresponds...
to the second order image when the spacing between \( G_2 \) and \( G_1 \) is 36.5cm, curve b corresponds to the first order image when the spacing between \( G_2 \) and \( G_1 \) is 101.0cm, curve c corresponds to the third order image when the spacing between \( G_2 \) and \( G_1 \) is 17.3cm.

Figures 2~5 show the spectrum energy of the converged images when different grating pairs are used. Taking Fig. 2 for example, curve a shows the second diffraction order spectrum energy of three monochromatic light beams (purple, 435.8nm; green, 546.1nm; yellow, 578.0nm) when the distance between \( G_2 \) and \( G_1 \) is 40.5cm, curve b shows the second diffraction order spectrum energy of the same monochromatic light beams when the distance between \( G_2 \) and \( G_1 \) is 29.1cm, it can be seen that all the spectrum energys of curve a are larger than those of curve b over the regime of wavelength discussed. The intensity of the converged image formed by the three light beams of the former will surely higher than that of the image formed by the beams of the latter. Similar results can be obtained for Figs 3~5.

4. ANALYSIS AND DISCUSSION

Based on the above measurements, it can be concluded that for the grating combinations of 1000L/mm---100L/mm, 1000L/mm---156L/mm, 1000L/mm---300L/mm with the spatial frequency of \( G_1 \) fixed at 1000L/mm, the intensities of the converged image have the following characteristics: the energy of low diffraction order converged image is larger than that of the high order image and spacing between \( G_2 \) and \( G_1 \) corresponding to low diffraction order converged image is larger than the spacing corresponding to higher diffraction order converged image, that is to say the energy of the converged image is determined by the corresponding diffraction order. When the spatial frequency of \( G_1 \) is fixed at 600L/mm, the energy of the converged image for the grating combination of 600L/mm---100L/mm has a similar characteristic as the above cases when \( G_1 \) has a spatial frequency of 1000L/mm, i.e., the energy of the converged image corresponding to larger spacing between \( G_2 \) and \( G_1 \) (36.5cm) is higher than that of the image corresponding to smaller spacing (17.3cm).

The position of the above converged images corresponds to the case of small distance between \( G_2 \) and \( G_1 \) (e.g., smaller
than 1 meter). According to the measurements, the energy of the light falling on \( G_2 \) which is from \( G_1 \) will attenuate when the distance between \( G_2 \) and \( G_1 \) increases. In this case, the energy of low order converged images will no longer surpass over that of the higher order converged images. In Fig. 5, it can be seen that the first order converged image corresponds to the space of 101.0cm between \( G_2 \) and \( G_1 \) when grating combination of 600L/mm---100L/mm adopted and its energy is lower than the second order converged image when the spacing of \( G_2 \) and \( G_1 \) is 36.5cm, i.e., the energy of the converged image is not determined completely by the diffraction order and the position effects of the converged image should be considered.

From the obtained data, it can be noticed that the energy of zero order converged image is lower than that of the first order converged image for some grating combinations, but this will be reversed for other combinations. Therefore, the energy of converged image correlates to some extent with the diffraction efficiency of the gratings used.

### 5. CONCLUSIONS

Therefore, based on the above measurements we can conclude; 1) when the distance between \( G_2 \) and \( G_1 \) is relatively small (e.g., less than 1 meter), the energy of the converged image is determined by the corresponding diffracting order and the effect of the position of the converged image can be ignored; 2) when the distance between \( G_2 \) and \( G_1 \) is larger (e.g., more than 1 meter), the position of the converged image will affect its energy to some extent; 3) it is obvious that many factors will affect the energy of the converged image.

In this study, we focuses on the effects of diffracting order of the converged image on its energy. In order to know the energy distribution of the converged image comprehensively, it is necessary to take the effects of diffracting order, converging position, diffraction efficiency of the grating on the energy of the converged image into account. So further research on these is needed.

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